Exploring Smart Standing Desks to Foster a Healthier Workplace

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Sedentary behavior is endemic in modern workplaces, contributing to negative physical and mental health outcomes. Although adjustable standing desks are increasing in popularity, people still avoid standing. We developed an open-source plug-and-play system to remotely control standing desks and investigated three system modes with a three-week in-the-wild user study (N=15). *Interval* mode forces users to stand once per hour, causing frustration. *Adaptive* mode nudges users to stand every hour unless the user has stood already. *Smart* mode, which raises the desk during breaks, was the best rated, contributing to increased standing time with the most positive qualitative feedback. However, non-computer activities need to be accounted for in the future. Therefore, our results indicate that a smart standing desk that shifts modes at opportune times has the most potential to reduce sedentary behavior in the workplace. We contribute our open-source system and insights for future intelligent workplace well-being systems.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**.

Additional Key Words and Phrases: healthy, smart furniture, standing desk, work environment, smart environment

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1 INTRODUCTION

The modern office has been designed to optimize productivity and efficiency, resulting in minimal physical movement [30]. As a consequence, office workers are sedentary for the majority of the workday [16]. Chronic sedentary behavior constitutes a public health risk [9], increasing the risk of diabetes [63], chronic low back pain [4], cardiovascular disease [25], and mortality in general [53]. As such, there is a need to develop technologies that transform workspaces by integrating physical activity and interrupting extended sedentary behaviors.

Electric sit-stand desks allow users to easily transition their desks between sitting and standing heights. Studies indicate that adjustable desks can lead to reductions in sitting time, sedentary behavior, and discomfort [14, 47]. However, long-term investigations have demonstrated that few users utilize the standing mode and height-changing features [62]. Autonomous standing desks are one potential tool that could trigger users to stand more often. Prior work has shown mixed responses to autonomous desks that change at regular time intervals [38], with half the users preferring a manual desk due to distraction levels. Lee et al. [43] found that interrupting users

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with height changes during tasks causes frustration. All prior investigations with autonomous desks occurred in single-contact lab-based user studies. Therefore, how users prefer to interact with autonomous standing desks in repeated, day-to-day use remains to be investigated.

In this paper, we developed a control system for standing desks and evaluated it in an in-the-wild study. We designed and implemented an open-source plug-and-play controller for standing desks that records changes in height and enables desks to be controlled remotely and move autonomously. We evaluated standing time and user perceptions regarding interacting with intelligent standing desks by conducting a three-week in-the-wild user study with 15 users. We investigated three levels of intelligence for shifting the desk to standing height: **I** (Interval mode), which raises the desk once per hour; **A** (Adaptive mode), which only raises the desk if the user has not stood within the past hour; and **S** (Smart mode), which raises the desk any time the user is away from their computer. Specifically, we aimed to address the following research question:

RQ: *How should an autonomous standing desk behave to encourage users to increase standing time without causing frustration?*

Our results show that participants stand significantly more often and perform significantly more sit-stand transitions when their desk moves autonomously. Participants stood most often when their desks moved hourly in Interval mode, but qualitative feedback indicates that this mode is frustrating. Smart mode was the preferred system, as participants appreciated that the desk moved while they were away, but future systems should account for non-computer work to avoid interruption. Our results demonstrate that autonomous standing desks which adapt to user behavior have the highest potential to be adopted by users, thereby reducing sitting time without causing negative feelings. Overall, we contribute i) an open-source plug-and-play system to transform an electronic sit-stand desk into an intelligent standing desk, ii) quantitative and qualitative results from an in-the-wild evaluation of our system with varying levels of intelligence, and iii) specific design recommendations based on user feedback for future designers of health-focused smart furniture.

2 RELATED WORK

In this section, we first discuss workplace physical activity as motivation for our work. We then review HCI literature on automated office furniture and smart standing desks to provide context to our investigation. Finally, we outline past work on interruptibility for health interventions.

2.1 Physical Activity at Work

Despite the well-documented health benefits of increasing physical activity and decreasing sedentary behavior (e.g., [11, 36, 52]), most people are not active enough [18]. For instance, workers spend nearly three-quarters of their day sitting [16, 60] because most jobs inadvertently push workers toward sedentary behavior [17]. Continuous sedentary behavior leads to an increased risk of all-cause mortality [53], chronic low back pain [33], diabetes [63], and cardiovascular disease [25].

Some prior work has tried to increment physical activity in the workplace by introducing more breaks from productive activities [10, 42, 45]. However, past research has also found that active 'microbreaks' could benefit physical and mental health without adversely impacting productivity [54]. A recent review by Damen et al. [19] indicates that most current studies concentrate more on prompting breaks than increasing possibilities for physical activities in the office workplace.

Several studies have used ambient displays to quantify and visualize physical activity in the workplace. To this end, Fortmann et al. [26] created an ambient lamp named 'MoveLamp', which displays workers' physical activities by changing the light color. They found that MoveLamp encouraged office workers to take more steps each day. Similarly, Mateevitsi et al. [48] developed an ambient persuasive device called 'HealthBar' that encourages users to break up prolonged sitting periods by using a motion sensor and changing colors. On a similar note, Moradi and Wiberg [51] created a conceptual framework to describe movement patterns in the workplace, such as spatial possibility and social relations. They designed two prototypes, the Talking Tree and the NEAT-Lamp, using this framework. The Talking Tree is a tree-shaped ambient display that changes the color of its leaves to visualize movement in specific areas of an office. The NEAT-Lamp is an ambient display that automatically switches on if a person was sitting for 25 minutes. Once the user moves, the lamp automatically switches off. Other prior work has augmented an office chair with growing ivy to visualize sitting time [49], while another demonstrated that visualizing computer activity through desk-based ambient displays raises awareness, self-reflection, and social interactions for people to become physically active [7]. In our work, we take a more active role in nudging users towards standing rather than passively displaying sedentary time through ambient displays.

Prior work has aimed to incorporate physical activity into productive tasks by moving or exercising while working. Haliburton et al. [31] and Damen et al. [22] both investigated motivations and barriers for walking meetings. In line with this, there are several HCI investigations that developed technology to encourage or support walking meetings, such as artifacts for recording on the move [29]. One group used the persuasive approach to nudge users towards walking meetings through a mobile app [1–3], while another developed infrastructure-based technologies to facilitate periodic note-taking [21]. Similar to Damen et al. [21], we take an infrastructure approach to reducing sedentary behavior by augmenting standing desks.

Ren et al. [55] created a social exergame called 'Step-by-Step' to encourage office workers to have physical activity and social interaction with their colleagues. Damen et al. [20] designed three pieces of furniture called 'PositionPeak' to create a dynamic meeting room and encourage participants to avoid static poses. Their findings indicate that PositionPeak encourages participants to adopt different postures and creates more effective meetings, but it also causes inconvenience. Similarly, Damen et al. [23] created a wild office space to foster movement and combine physical activity with work. Some prior studies have used virtual and augmented reality to encourage workers to step away from their desks and interrupt sedentary time [56, 64]. Others have used tangible rewards. For example, Khot et al. [37] investigated a 3D printer that creates chocolates showing cheerful messages based on heart rate data. Tactile feedback using a push (something that catches the user's attention) mechanism has been shown to create a positive mindset towards exercise [12]. We use tactile push feedback by physically moving the desk to nudge users towards standing.

Our work takes inspiration from the many investigations into physical activity at work. We use a tangible, infrastructure-based approach to nudge standing desk users towards increased standing time and reduced sedentary behavior.

2.2 Automatic Office Furniture in HCI

Automatic office furniture has been employed as an intervention in the workplace to encourage behavioral change [17]. For example, Kronenberg and Kuflik [41] proposed a mechanical robotic arm that could automatically adjust the position of a computer screen based to optimize ergonomics. Similarly, Fujita et al. [27] designed an actuated office chair that changes the incline of the seat to manipulate the user's posture.

Automatic furniture has also been developed to help increase convenience. Sirkin et al. [58] created a robotic footstool that automatically approaches sitting users and tries to get them to rest their feet on it. Past work on transformable furniture has developed furniture that changes shape and function to fit different applications. Takashima et al. [59] proposed a transformable and interactive digital desk. The physical shape of the desk could be deformed into a circle, square, or rectangle. The desk also displays digital information on a screen whose shape adjusts with the table.

Zhu et al. [65] conducted a literature review showing that treadmill desks and other physical implementations in the workplace can lead to reductions in sedentary behavior and increased physical activity. Studies indicated that standing, under cycling, and treadmill desks are potentially helpful in decreasing workplace sedentary time while positively impacting stress and general mood [28, 46] without reducing productivity [34]. Moderate-intensity exercise performed on a cycling workstation during simulated office tasks has been shown to increase activity without increasing the error rate, but it does increase task execution time [40].

2.3 Smart Standing Desks

Adjustable desks reduce sitting time while creating a comfortable and dynamic working environment that can transform to adapt to different daily activities. Vandoorne-Feys et al. [61] designed a desk with three levels of adjustability: bench level, sitting desk level, and standing desk level. Past work has demonstrated that adjustable desks are effective at lowering discomfort [14].

There are a variety of commercial smart standing desks with different features in the market. The 'Autonomous SmartDesk'[1] is designed to adapt to a broad range of bodies. It has four programmable keypad settings to save up to 4 custom heights. The 'NextErgo'[2] guides users in setting up an ergonomic posture and provides desk exercise recommendations. It uses presence detection sensors to track standing time and features to track fitness goals. 'AiT Smart One'[3] is an app-controlled desk with three default settings: sitting, standing, and comfort mode. The app provides notifications for users to perform exercises, and the desk includes an air quality sensor that alerts the users when they need fresh air.

Despite the existence of "smart" standing desks on the market, there is a limited amount of fundamental research investigating how users want an autonomous standing desk to behave. Desk configurations are highly personal [6], and user preferences vary for different kinds of adjustable desks. Lee et al. [43] found that users prefer it when their desk moves between tasks. Kim et al. [38] found that half of their participants were receptive to using an autonomous sit-stand desk, while the remaining preferred to have some manual control. Another recent work by Kim et al. [39] found that participants generally prefer manual or semiautonomous desks to fully autonomous ones. Both Lee et al. [43] and Kim et al. [38] investigated desk motion in controlled lab studies where participants only used the desks for a short time, while Kim et al. [39] conducted a vignette study where users watched videos. As such, our study aims to extend this fundamental research by investigating how users prefer to interact with an autonomous standing desk on a day-to-day basis in real work environments. Our investigation is an implementation of research through design [66], where we aim to gain insights into user preferences and interaction patterns through interaction with a working prototype.

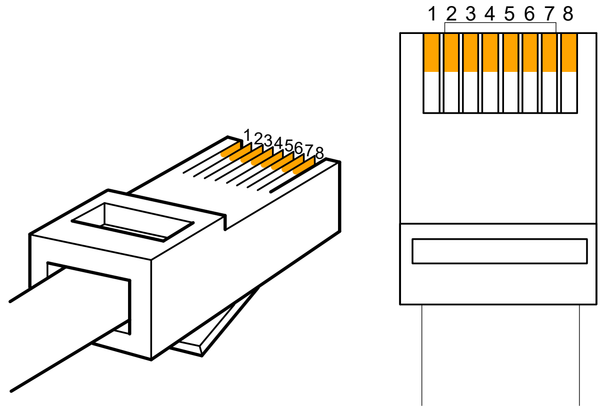
2.4 When to Interrupt the User

With the recent increase in mobile health technologies, health scientists are increasingly interested in understanding when users can be interrupted with just-in-time adaptive interventions (JITAIs) based on contextual information [44]. However, despite extensive work on interruptibility, our understanding of the receptivity of mobile just-in-time JIT health intervention is limited. Choi et al. [15] built a mobile (JIT) intervention system called "BeActive" to prevent sedentary behaviors. They found that availability for JIT intervention is multifaceted and context-dependent.

The ability to automatically recognize when the user is engaged in a work activity or taking a break is fundamental for JITAIs. Prior work (e.g., [24, 44, 50]) has leveraged machine learning to increase receptivity and identify opportune moments to interrupt users for health interventions. Past work has also used wearables to measure cognitive load and identify when workers are interruptible [57], while others have used mobile notification responses [13]. Interruption is crucial to our work, as Lee et al. [43] found that users are most

[1] https://www.autonomous.ai/en-FI/standing-desks/smartdesk-2-home
[2] https://www.nextergo.ai/
[3] https://www.indiegogo.com/projects/ait-smart-one-the-gamechanger-smart-desk/

(a) An example of the seven-button keypad found on multiple brands of standing desks. There is a three-digit seven-segment display and seven buttons.



(b) The pin number labels for an 8P8C connector. An angled view is included to ensure that the connector is in the proper orientation.

Fig. 1. Keypad and 8P8C components from the standing desk model used in the study.

receptive to a standing desk moving autonomously in between tasks. In our study, we attempt to identify times when the user is away from their desk to avoid interruptions altogether.

3 THE STANDING DESK CONTROLLER

This section outlines the design and implementation of our standing desk controller. The controller consists of a custom circuit board with housing and cabling and a back-end architecture. We aimed to develop a plug-and-play solution that would not require users to disassemble or permanently modify their existing desks in any way.

Through an exploration of available electronic sit-stand desks and observations at several offices, we identified two prominent controller designs. One is a simplistic controller that consists of either two buttons or a paddle that can be moved in two directions. This arrangement controls the direction of the desk motion — up or down — directly. The second design pattern enables the user to save specific desk heights as presets. One common implementation of this design, shown in Figure 1a, consists of seven buttons — up, down, four numbers for preset heights, and a button to change the presets — and a three-digit seven-segment display. The seven-button keypad can be found on multiple brands of standing desks (e.g., Fully, Kerkmann, Eureka). The keypad is connected to the motor control system via an Ethernet cable with an 8P8C (8 positions, 8 contacts) connector, which processes the keypad signals and subsequently controls the desk motors.

3.1 Reverse-Engineering the Desk Signals

We measured the signals sent through this cable for each button using an Agilent 54621D Mixed Signal Oscilloscope. The keypad is connected to the control board via an Ethernet cable with an 8P8C connector, which means there are 8 individual wires, numbered as shown in Figure 1b. The purpose of each wire is described in Table 4 in the appendix. Each button on the keypad triggers a consistent digital signal pattern on one or more of the wires. The full set of combinations is listed in Table 5 in the appendix.

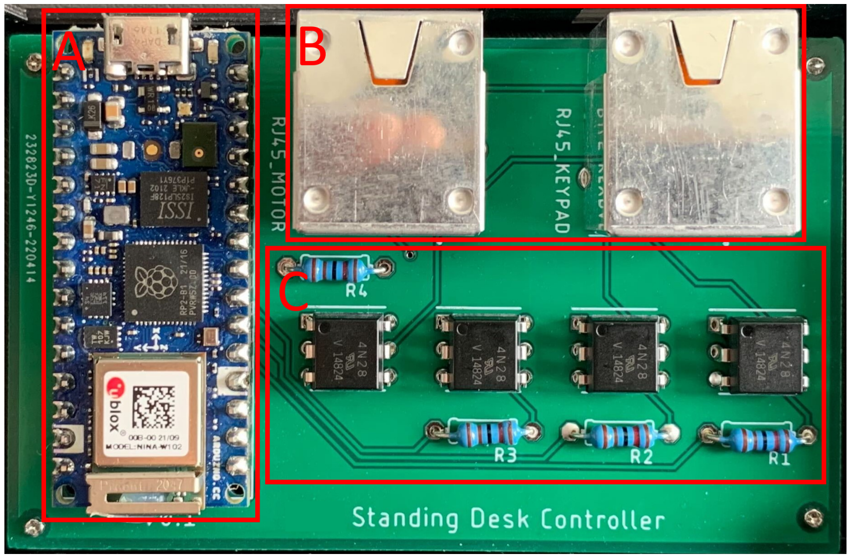


Fig. 2. The custom standing desk controller board. A) Arduino Nano RP2040 Connect, B) 8P8C Connectors, and C) Optocoupler circuits.

3.2 Control Board

We designed a circuit board (Figure 2) based on an Arduino Nano RP2040 Connect. The board records desk height, controls the height of the desk, and allows keypad commands to pass through to the motor control system.

The height signal wire (D4) is connected to the serial pin (RX)[4] on the microcontroller and also to the keypad. Using this arrangement, we can read out the height of the desk (in cm) while the display on the keypad still functions normally. The wires connected to the keypad buttons (D0-D3) are all pulled up to 5V by default. When a button is pressed, the associated wires are pulled down to 0V. We use GPIO pins on the microcontroller to control an optocoupler[5] connected to each wire associated with a keypad button. When one of the GPIO pins is set to high, the optocoupler connects the wire to ground and pulls the signal down, simulating a button press. The wire is also directly connected to the keypad, so the buttons still function normally.

3.3 Custom Firmware

We wrote firmware for the Arduino Nano RP2040 Connect using Micropython. The module "uRequests" is the only required package other than core Micropython functions. The controller records every change in desk height and sends it to the server over WiFi via a POST request using the REST API. We use a buffer to minimize the number of requests each board makes to the server. The board also periodically polls the server via a GET request to see if there are any commands. If a command exists (e.g., press the Preset 1 button), the board will simulate the appropriate button. We implemented a Watchdog to reset the microcontroller if the program gets hung up. The reset threshold on the Watchdog is set to 120 seconds.

[4] Arduino Nano RP2040 Connect Pinout: https://docs.arduino.cc/hardware/nano-rp2040-connect
[5] We used 4x Vishay 4N28 Optocouplers

Table 1. A description of each table in the database.

Table	Purpose
Users	Stores information about each user, such as a unique ID, which preset keys they use for standing and sitting heights, the study condition, and their start date.
Desks	Contains entries for each controller board attached to a specific desk.
Deskjoins	Associates a user with a desk.
Heights	Stores all desk height information sent to the server from each controller.
Commands	Contains commands for each desk to execute.
StartupLogger	Logs each time a board reboots so we can identify problem boards or potential issues.
AccessLogger	Logs each time a board communicates with the server so we can identify inactive boards.

3.4 Back-end

We built a web app using Flask on a remote server. We use Gunicorn to start the app and Nginx as a public-facing reverse proxy with TLS encryption. We use a MySQL database to store information. The tables in the database are summarized in Table 1.

3.5 Open Source

All source files (PCB design, 3D models, embedded firmware, and software) are available online for replication: https://github.com/mimuc/standing-desk-controller.

4 STUDY DESIGN

We conducted a three-week between-subjects in-the-wild study to investigate user interactions with automated standing desks. We chose this research through design [66] approach to understand the user experience of interacting with an autonomous standing desk through real interactions. We deployed the desks in the wild for three weeks to mitigate novelty effects and extract ecologically situated responses from our participants. Participants were randomly assigned to one of three experimental conditions. All participants completed an initial control week where they used their desks in Manual mode, followed by two weeks in their assigned autonomous condition.

4.1 Procedure

An overview of the study procedure is depicted in Figure 3. After introducing the study and obtaining informed consent, we installed a controller on each participant's desk. We asked all participants to create a preset (i.e., buttons 1-4) for their preferred sitting height and preferred standing height if they did not already have them set. The participants then complete a pre-study questionnaire that records demographics and qualitative information about how they typically use their standing desks.

All participants complete a baseline week followed by two weeks in an autonomous mode. During these two weeks, each controller moved a participant's desk according to their experimental condition. After two weeks of autonomous control, each participant completes a post-study questionnaire and an exit interview. We instructed the participants to use their desks normally during the manual week. For the active weeks, we told the participants to stand as long as they were comfortable and to lower their desks as often as they preferred. The behavior of the desks during the baseline week and each autonomous condition are as follows:

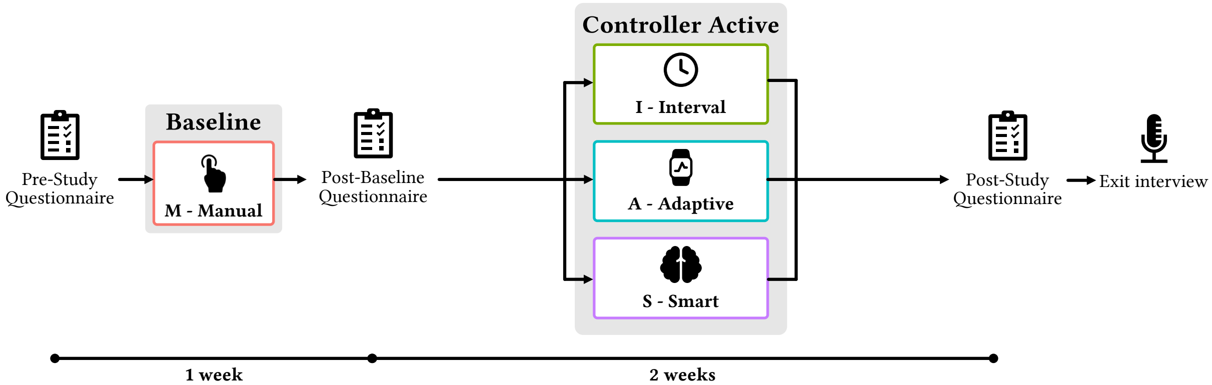


Fig. 3. Study Procedure: Each participant completes a pre-study questionnaire followed by a one-week baseline where the desk is controlled manually (**M)**. Each participant then completes a post-baseline questionnaire and is randomly assigned to either the **I**, **A**, or **S** condition for two weeks. Following the two-week autonomous period, the participants complete a post-study questionnaire and an exit interview.

M - Manual Mode: For the first week, the participants are instructed to use their desks normally while the controller records height information. This initial week is a baseline, so the controller passively records height data and does not move the desk. All participants used this mode for the initial week.

I - Interval Mode: The controller moves the desk to standing position once per hour at minute 50. This occurs regardless of how the participant manually used their desk. Participants are also able to control the desk normally using the keypad.

A - Adaptive Mode: The controller moves the desk to standing position once per hour at minute 50 if and only if the desk has not been in standing mode yet in the past hour. This mode is based on the standing reminders used by Apple Watches, which follow a similar principle. Participants are also able to control the desk normally using the keypad.

S - Smart Mode: Participants in this condition were given a custom activity monitor to install on their computers. The activity monitor records instances when any keyboard or mouse activity occurs. If the user does not interact with their computer for longer than 3 minutes[6], the monitor sends a message to the server. Thus, in this condition, the controller moves the desk to standing position only when the user stops using their computer for longer than 3 minutes. Participants are also able to control the desk normally using the keypad.

In all the active conditions, participants can cancel an autonomous desk movement by pressing any button on their controller. Additionally, the desks have a built-in safety feature that halts the desk any time a collision is detected. A desk transition (e.g., from sitting to standing height) lasts approximately eight seconds. It is also important to note that in all active conditions, the system only autonomously moves the desk *up*. The desk only moves down if a participant manually lowers it using the buttons.

4.2 Measures and Analysis

We collected desk height data over time, responses to questionnaires, and exit interviews. Each of these data sources requires a separate method of analysis. We have included the questionnaires and interview protocol in the supplementary material.

[6]We conducted a short pilot study to identify three minutes as a suitable time interval to use as a starting point.

All participants completed an initial week in Manual mode before moving on to one of three conditions. As such, we performed nested comparisons where appropriate. The nested procedures investigate the effects of Automation and Condition. Automation compares the results from the Manual phase against the results from all three automated conditions combined. The Condition effect investigates the between-subjects automated conditions (Interval, Adaptive, and Smart).

We analyzed desk height for each user over the course of the study. In particular, we calculated the portion of time spent standing, the number of sit-stand transitions, and the time between an automated desk raise and the next lowering. The desk height was recorded continuously. We did not ask participants to record their time spent at the desk. We performed nested ANOVA procedures to analyze the results with Bonferroni-corrected post-hoc pairwise t-tests where appropriate.

We analyzed the standard scales (AttrakDiff [32] and System Usability Scale (SUS) [8]) within the questionnaires according to their original documentation. We additionally collected Likert-scale responses to four positive perceptions (motivation to stand, motivation to be active, goal accomplishment, and likelihood to use the system in the future) and four negative perceptions (frustration, stress, interruption, and feeling forced to stand). We used nested ANOVA procedures to analyze the perception responses. Where applicable, post-hoc pairwise t-tests were performed with Bonferroni corrections. We also asked users to estimate how many hours per day they spent standing, which we analyzed using a nested ANOVA.

Finally, we collected qualitative feedback on our system through open-ended questions in the questionnaires as well as exit interviews. All interviews were recorded with consent and transcribed verbatim. The open-ended responses and interviews were imported into Atlas.ti analysis software. We coded the material in line with recommendations from Blandford et al. [5]. As an initial step, three researchers used open coding on a representative sample of 15% of the material. The researchers then agreed on a coding tree through a discussion. Finally, one of the researchers coded the remaining material.

4.3 Participants

We recruited 15 participants, aged 26-33, $M = 29.2$, $SD = 2.11$ (5 female, 10 male). We used a university mailing list and snowball sampling to recruit participants who already owned and used a standing desk at work, which was a prerequisite for the study. Three participants have used their desks for over one year, six participants between six months and one year, five between one and six months, and one less than one month. As motivation for using a standing desk, eleven participants mentioned health, five mentioned alertness and focus, and three mentioned using their desk because it is provided by their employer. Two participants purchased their own desks (Fully[7]), while the remaining thirteen had their desks (Kerkmann[8]) provided by their employers. We compensated participants $40 for the three-week study. The study was approved by the ethics committee within the Institute for Informatics at LMU Munich. We will refer to participants using their condition (I, A, or S) and study ID (e.g., A5).

5 RESULTS

We collected both quantitative and qualitative results from various sources to investigate the user experience of interacting with an autonomous standing desk. In the following, we first present desk height values measured by our system. We then show user experience and usability metrics, followed by user perceptions. Finally, we highlight themes identified in the exit interviews.

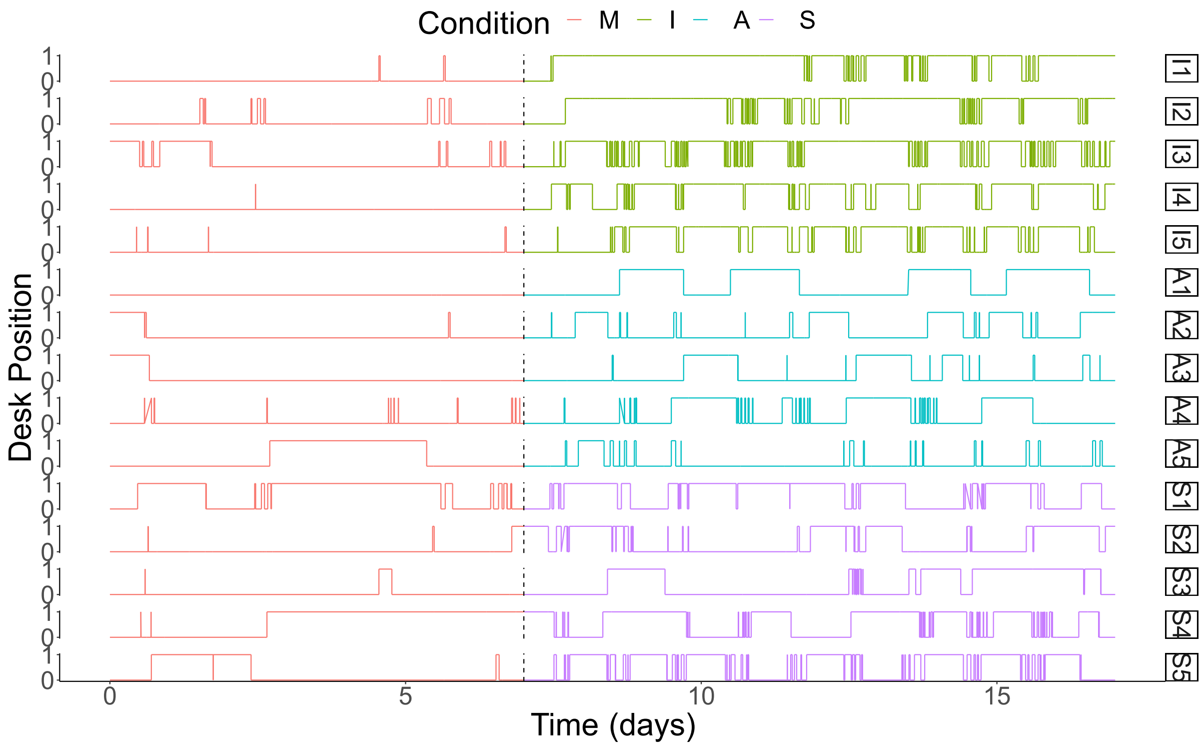


Fig. 4. Desk height over time for each user, color-coded by condition. Standing is 1 and sitting is 0.

5.1 Desk Height

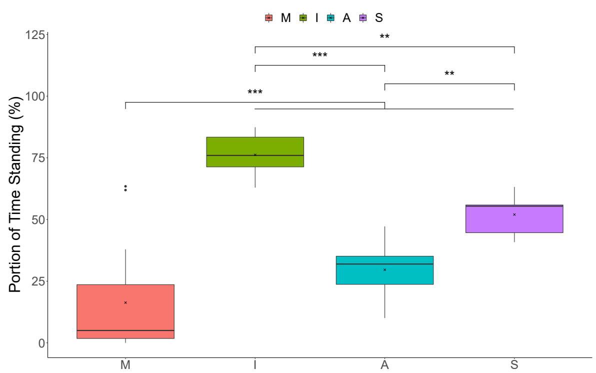
Figure 4 depicts the desk height over time for each user, colored by condition. The results reveal a notable increase in standing activity in all three conditions relative to the Manual phase. Some participants, such as participant I1, appear to have kept their desks in standing mode most of the time (the desk only autonomously moves up, not down), while others, like A5, appear to have forced their desks to remain at sitting height most of the time.

Figure 5a shows the portion of time spent standing in each condition. A nested ANOVA revealed a significant effect of Automation ($F(1, 25) = 30.7$, $p < 0.001$), indicating a significant increase in the standing portion in the automated conditions compared to the Manual phase. There is also a significant effect of Condition ($F(2, 25) = 8.56$, $p < 0.01$). Post-hoc Bonferroni-corrected pairwise t-tests revealed that participants in the Interval condition stood for a significantly larger portion of time relative to both Adaptive ($p < 0.001$) and Smart ($p < 0.05$). Participants in the Smart condition also stood a significantly larger portion than those in Adaptive ($p < 0.05$).

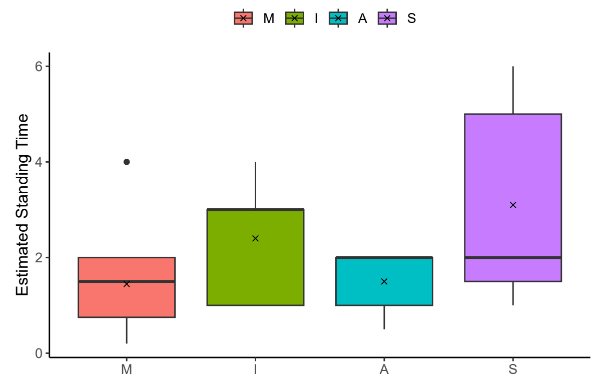
We also asked participants to estimate the time they spent standing. As shown in Figure 5b, there were no significant differences.

For the number of sit-stand transitions, a nested ANOVA revealed significant effects for both Automation ($F(1, 25) = 58.9$, $p < 0.001$) and Condition ($F(2, 25) = 7.99$, $p < 0.01$). In Figure 6a, we can see that the

[7] https://www.fully.com/
[8] https://kerkmann-bueromoebel.de/



(a) Portion of time spent standing. Participants stood significantly more in the automated conditions compared to Manual. There are significant differences between all three automated systems.



(b) Participant estimations of the number of hours spent standing per day. There are no significant differences between study conditions or between manual and active study phases.

Fig. 5. Plots of the portion of time spent standing and participants' estimates of the time spent standing.

participants performed significantly more sit-stand transitions in the automated conditions compared to Manual. Post-hoc Bonferroni-adjusted pairwise t-tests revealed no significant differences between the conditions ($p > 0.05$ for all).

We calculated how long participants' desks remained in standing mode after an automated desk raise, shown in Figure 6b. The 'time to down' after a command was sent to the controller is an indication of whether or not the participants accept the automated desk raise. A very low time may indicate that the participant manually canceled the automated desk raise, while a long time indicates that the participant used the desk in standing mode. There are no significant differences between the conditions.

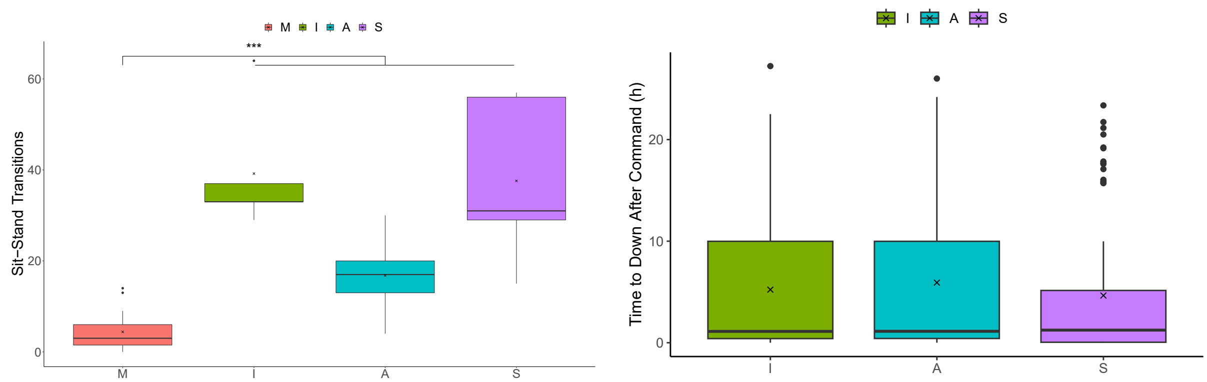
5.2 User Experience and Usability

We used the AttrakDiff questionnaire to gain insight into the perceived user experience for each condition. The results, see Figure 7, show that all conditions were rated close to neutral in each category. A nested ANOVA revealed a significant effect of Automation ($F(1, 25) = 12.3$, $p < 0.01$) for the Pragmatic Quality sub-scale, indicating that Manual was rated higher than the automated conditions. All other results were non-significant.

We administered the SUS to assess system usability for the Manual desk and the three automated systems. All four systems were rated as usable ($M_M = 80$, $M_I = 85.5$, $M_A = 71$, $M_S = 71$) with no significant differences.

5.3 User Perceptions

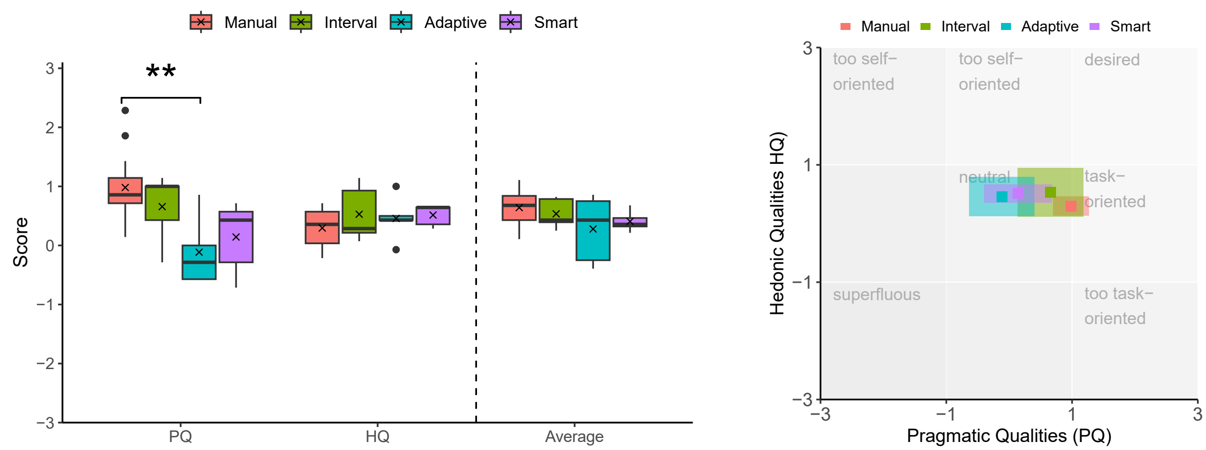
We evaluated our participants' positive and negative perceptions for each condition, shown in Figure 8. For the positive perceptions, see Figure 8a, we found a significant effect of Automation ($F(1, 25) = 4.982$, $p < 0.05$) for the likelihood of using the system in the future. All other results were non-significant. For the negative perceptions, see Figure 8b, we found a significant effect of Automation for Frustration ($F(1, 25) = 29.0$, $p < 0.001$), Interruption ($F(1, 25) = 29.7$, $p < 0.001$), and Forcing ($F(1, 25) = 90.3$, $p < 0.001$). There were no significant differences between the automated conditions.



(a) Number of sit-stand transitions for each condition. There were significantly more transitions in the automated conditions compared to MANUAL

(b) Time to down after a command for each condition. There are no significant differences between the conditions.

Fig. 6. The number of sit-stand transitions and the time spent standing after an automated desk raise for each condition.



(a) AttrakDiff results of the four dimensions: Pragmatic Quality (PQ), Hedonic Quality (HQ), as well as the average. There is a significant effect of AUTOMATION for PQ.

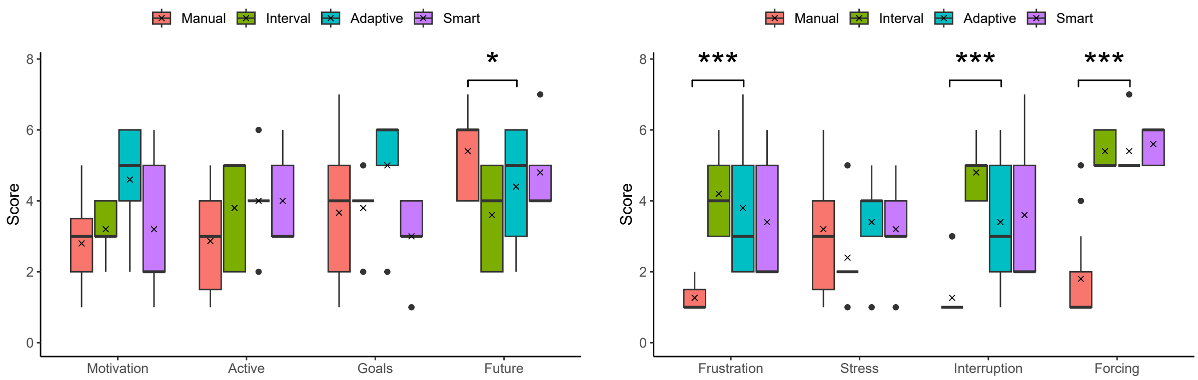
(b) The mean AttrakDiff results of Pragmatic Quality (PQ) and Hedonic Quality (HQ).

Fig. 7. Diagrams from the AttrakDiff questionnaire showing the Pragmatic Quality (PQ), Hedonic Quality (HQ).

5.4 Exit Interviews

In the following, we present the results of the exit interviews clustered by themes identified in the coding process.

5.4.1 Triggers to Sit and Stand. We asked participants for cues that triggered them to use their desks in either sitting or standing positions. The results, summarized in Table 2, reveal that pain and discomfort are the most common motivators for participants to shift to standing, while specific tasks, such as writing, are the most



(a) Positive perceptions. There is a significant effect of Automation for the likelihood of using the system in the future.

(b) Negative perceptions. There is a significant effect of Automation for Frustration, Interruption, and Forcing.

Fig. 8. Plots of participants' positive and negative perceptions for each condition.

common triggers for sitting. The results also show that certain triggers, such as pain, tiredness, and time of day, can be triggers for either standing or sitting.

5.4.2 Interacting with the desk. Participants in the Smart condition appreciated that the desk moved while they were away from their office on a break, and therefore tended to accept the new position:

> *"What I really liked is if I came back from a coffee and the desk was up, because usually I would have put the desk up myself then anyways, and I just didn't have to think about it."* (S1)

Participants in other conditions also coincidentally experienced moments when their desk would move while they were away. They reported that it was easier to keep standing in such situations rather than transition from sitting to standing:

> *"Since I was already standing when coming in or walking in, it was way easier to just keep standing and work from there. But actually standing up when it's going up, usually I was in the middle of something and it's just way easier to not do it."* (I5)

For some participants in the Smart condition, desk movement was rarely observed:

> *"It didn't really feel during that week that the desk was moving on its own, so to say. It was basically like, when I went in, it was just in a different state. It wasn't like – There wasn't this transition."* (S3)

Table 2. Participants identified cues that triggered them to move their desks to standing or sitting mode, ordered by how often they were mentioned.

Triggers to Stand	**Triggers to Sit**
Pain & Discomfort	Tasks (e.g., writing)
Tasks (e.g., meetings)	Tiredness
Timing (e.g., after a break)	Pain
Social	Focus
Tiredness	Timing (e.g., mornings)

However, some participants in the SMART condition still experienced interruptions. The interruptions mostly occurred during in-person meetings or non-computer work, where the participant was present at their desk but not interacting with their computer:

> *"When I talked to colleagues, it interrupted sometimes because it moved up, and then I stopped it, usually."* (S5)

For participants in INTERVAL and ADAPTIVE conditions, interruptions were frequent. Participants noted that the interruptions were particularly annoying for writing tasks: *"I was just writing, doing something and it was just moving up and I was like, 'Oh no'"* (A3) and during meetings: *"It was a bit annoying sometimes, especially in meetings"* (I5). Participants also reported negative experiences with the desk interrupting periods of concentration:

> *"It was a bit annoying if I was concentrating on something, and then it would start moving up, and I felt like it did it just to spite me."* (I4)

In situations where the desk moved during important tasks, participants often canceled the movement: *"I was in a meeting, it went up and then I just canceled it out and stayed in the meeting"* (A1).

Participants developed a new interaction technique to quickly cancel autonomous desk raises. The desks have built-in collision detection that automatically moves the desk back to its original position when a collision occurs. Based on this, three participants discovered that they could hit the desk when it tried to rise to quickly revert back to a sitting position:

> *"Hitting it just made it instantly go back and it's very fast. I can do that with one hand while I'm still typing with the other hand. That's very fast and easy to do. It's nice. I think it's automatic, but it's a nice action. [...] That was the easiest interaction that I figured out."* (I5)

Participants in the INTERVAL condition were annoyed that their desk moved even when they had just spent a long time standing:

> *"it annoyed me when it went up, especially if I stood the hour before, and then it still went up. I would be standing the whole hour, would put it down, and be really satisfied. 'Oh, now I stood for 45 minutes, so good for my back.' Then I'm sitting and it goes up again."* (I1)

Participants in the SMART condition also did not appreciate if their desk moved up after a long period of standing:

> *"I feel if I just stood for ages and then I left the room for three minutes, and then it went up again [...], that was also not too great"* (S1).

5.4.3 Desk Personality. Participants were asked to describe the personality of their desks. The results, shown in Table 3, show that all conditions had a mixture of positive and negative personality descriptors. Participants in all conditions believed that the desk had good intentions but also found it annoying.

5.4.4 Design the Perfect Desk. We asked participants to describe the ideal control system for their desk. In general, the results are in line with interaction patterns identified in Section 5.4.2.

Nearly all participants noted that they want their desk to **learn and adapt to their behavior over time**: *"I could just be using the desk for four weeks like I usually do, and then it would learn specific moments when I like to stand"* (I1). Participants also want their desks to learn when to leave them alone: *"Maybe you could also have a smart system that learns, when I put it down a couple of times in a row, that maybe today is not a standing day for me"* (A3). Participants revealed conflicting schedules for when they prefer to stand, which further reinforces the need to learn individual behaviors. For example, S1 prefers to stand in the mornings *"it should always, for me, at least, be up in the morning"* (S1), while I4 prefers afternoons: *"I also didn't feel like standing up in the morning. Don't know why. Maybe I was just tired. More like in the afternoon because then I already sat for a long time and then I decide to stand again"* (I4).

Table 3. Participants described the personality of their desks.

Interval	**Adaptive**	**Smart**
Wants the best for you	Supportive	Wants the best for you
Tries to help	Encouraging	Encouraging
Bold	Tries to do good	Laid back
Naive loyal friend	Misunderstood	Surprising
Forcing	Stubborn	Childlike
Doesn't listen	Annoying	Rigid
Demanding	Perceived as annoying	Prescriptive
Egocentric		Attention-seeking
Annoying		Never relaxes

Across conditions, participants noted that their **desks should move while they are away** from their offices, taking advantage of existing breaks to avoid interruption:

> *"In my ideal case, the system doesn't change when I'm working on it, so it uses these breaks, and there will be the breaks – I mean, I need to go to the kitchen to get water, I need to go to the toilet, right? This gives the opportunity [...] because I'm already having a mental break anyway, to rise the desk up."* (S3)

Participants expressed a desire for their desks to be aware of their tasks. Nearly all participants mentioned that they want their desks to **avoid interrupting important tasks**. This includes avoiding interrupting specific tasks, such as meetings: *"Things I totally do not want is during a meeting"* (A3), but also includes avoiding interrupting periods of concentration: *"I'm very concentrated for a long time and then I don't want to be disturbed"* (I4).

Task awareness was also mentioned positively, where the desk could **proactively move depending on the task**. For example, the desk could shift to standing before a meeting to improve alertness: *"in 15 minutes you have a super boring meeting [...] would you like to stand five minutes before so that you can a bit more awake?"* (S2).

Multiple participants noted that **calendar integration** would be helpful to avoid interrupting certain tasks: *"integration with a calendar where it, for example, would not prompt while I have in-person meetings"* (A5).

Although participants overwhelmingly mentioned preferences for automated desk behaviors, they still expressed a **desire to maintain some level of agency**. Participants asked for a switch to *"toggle between automatic mode and manual mode"* (A3). Participants also noted that they want to maintain the ability to *"interrupt it"* (I1).

Several participants noted that they would prefer to have a **notification or warning before the desk moves** because the movement can be startling. S4 clarified that a warning is useful when they are in the same space as the desk, but it can freely move while they are away from the office:

> *"it feels like it's not only me anymore, but it's a shared space of my desk and me. When we are both in the same space, there has to be an agreement. When I'm not there, it's fine that the desk does whatever it wants."* (S4)

Finally, only one participant (S1) stated that they want a graphical interface for manual control. All other participants prefer the current **physical buttons for manual control**. The participants also expressed a preference for simple sit or stand buttons, citing a lack of need for fine-grain control: *"It's completely sufficient to have the sitting and the standing option in a way. I don't need to have fine control"* (S3).

6 DISCUSSION

We conducted this investigation to explore the research question: *How can we design a smart standing desk to encourage users to increase standing time without causing frustration?* In the following, we will interpret the results of our three-week in-the-wild user study and provide concrete design recommendations for future designers of standing desk control systems.

6.1 Interpreting the Results

Regardless of condition, participants stood a significantly larger portion of time when their desks moved autonomously compared to baseline. Interestingly, there was no significant difference in the number of hours that participants *perceived* that they stood per day, implying that participants were standing more without realizing it.

Participants in the Interval condition stood the most, but the exit interview revealed that Interval and Adaptive participants often experienced interruptions during important tasks. Participants in all conditions expressed a strong preference for their desks to move while they were away. Although participants in the Smart condition were never interrupted during computer tasks, the interviews revealed that further contextual information is required for the system to avoid interrupting non-computer tasks, such as in-person meetings.

Interruptions caused users to have more negative perceptions of all autonomous conditions compared to manual control, so eliminating interruptions is crucial for user acceptance. Past work on interruptibility suggests that we could use wearables [57] or machine learning [24] to understand when workers are interruptible. However, our findings suggest that users prefer completely avoiding interruptions by moving the desk while they are away. Although we avoided using external sensors to increase reproducibility, they may be necessary to accurately quantify whether the user is away from the desk. Overall, the autonomous standing desk controller resulted in more standing time, but further development is required to create a system that truly avoids frustrating users.

6.2 Design Recommendations

This investigation sought to answer the research question (**RQ**): *How should an autonomous standing desk behave to encourage users to increase standing time without causing frustration?* Based on our results, we found that participants enjoy using an autonomous standing desk as long as it does not cause interruptions. To expand on this, we have created the following design recommendations based on the interaction patterns that participants experienced throughout the study, as well as the preferences they expressed when asked to design the ideal desk controller. The aim of these recommendations is to assist future designers in creating a desk control system that helps users achieve their standing goals without causing frustration.

6.2.1 Avoiding interruptions is paramount. In line with [43], we found that participants want their desks to move in a way that does not interrupt important tasks. Our strategy, moving the desk when computer activity ceased for three minutes, was reasonably successful in achieving our goal of moving the desk when participants were away from their offices. The participants showed a strong preference for the desk moving while they were away, however, tracking computer activity is not enough. The current system does not account for non-computer activities such as in-person meetings, physical note-taking, or other physical tasks that occur at a desk. To add awareness of non-computer tasks, a future system could use an external sensor to detect user presence or integrate with users' calendars. Both of these techniques could be implemented together for increased accuracy.

6.2.2 Adapt to behavior over time. Nearly all participants expressed a desire for the desk to learn their preferences. In particular, participants had individual preferences for tasks where they preferred to stand (e.g., meetings) as well as for specific times of day (e.g., after lunch). To operationalize this, a reinforcement learning scheme could be developed that accepts feedback from users (e.g., canceling an autonomous desk raise) in combination with contextual information (e.g., calendar appointments) to adapt to each user's behavior and preferences over time. Past work has shown that reinforcement learning can identify when to deliver physical activity interventions [44], which could be adapted to the standing desk context.

6.2.3 Maintain some level of user control. Although the participants appreciated the autonomous desk if it moved while they were away, many participants still expressed a desire to maintain a level of agency. This finding is aligned with Kim et al. [38], who found that half their participants wanted to have manual control. Prior work has also found that participants generally prefer manual or semiautonomous desks, while more familiar users are more likely to adopt autonomous desks [39]. This result is echoed in our findings because all of our participants are experienced standing desk users. Nearly all of our participants were satisfied with the existing physical buttons on the desk and did not want a digital display. The physical buttons enable users to quickly cancel an autonomous motion, and some even hit the desk to make use of the collision detection feature. These results indicate that manual control should be tangible and quick to activate.

6.3 Limitations & Future Work

One limitation of our work is that our controller is not universal. It only works with the seven-button style keypad and thus does not work with two-button keypads or paddle-style controllers, both of which are common. We do not claim to contribute a universal controller but rather an exploration of how users interact with automated standing desks.

Currently, the controller sends a GET request to the server every 30 seconds to check for new commands using the REST API. We used this implementation because the socket library for Micropython is non-functional. The boards eventually freeze if requests are sent more frequently. We expect this may be a hardware limitation of the Arduino Nano RP2040 Connect. In future iterations, we recommend developing a functional socket library for Micropython so that a WebSocket architecture can be used instead of a request architecture. If this does not solve the issue, a more powerful microcontroller should be used. It is important to solve this in future iterations to develop a responsive graphical user interface (GUI). In future work, it may be interesting to implement a GUI with a dashboard showing a user their statistics over time, enabling gamification elements to be investigated.

Additionally, there are some limitations to our study design. On the one hand, developing new habits has been found to take at least six weeks [35], so our study was not long enough for participants to develop new habits associated with their desks. However, the participants engaged in the study for long enough to mitigate novelty effects while remaining practical to execute. It is also possible that participants stood more often than they normally would because they were aware that they were being recorded for the study. We instructed the participants to use their desks in a way that felt natural. However, this increase would impact both the control and active conditions and therefore may balance out in the analysis. Our sample size was also relatively small to calculate quantitative results. However, as our study was exploratory, the user experience and qualitative insights are more valuable for this work. Our participants skewed relatively young, which may be due to the fact that we recruited primarily through a university mailing list.

Finally, as we did not use external sensors, we had limited awareness of when users were present at their desks. All of the measurements for standing and sitting time should be viewed through this lens. We assume that any abnormalities, such as work days with many away-from-desk tasks, would be randomly distributed across the conditions. However, as we did not control for this aspect, it is a limitation on the insights that can be gained from the quantitative data. We chose not to add external sensors to the system for ease of reproducibility. However, as we have discussed, it may be interesting for future work to investigate a desk control system with more detailed insight into user activity.

7 CONCLUSION

In this paper, we designed and evaluated an open-source plug-and-play standing desk controller to understand how users prefer to interact with an autonomous desk. We conducted a three-week in-the-wild between-subjects study with 15 people showing that autonomous desks significantly increase standing time but cause frustration when users are interrupted. Based on quantitative and qualitative feedback, we make concrete design recommendations for developers of future systems. Our research provides a practical basis for increasing standing time at work through an adaptive standing desk system. We hope to encourage future work on this topic by open-sourcing our project materials. If employed on a wide scale, automated standing desks could contribute to a reduction in sedentary time in offices and thereby improve health-related outcomes over time.

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A TECHNICAL DETAILS

Table 4. Description of each wire within the 8P8C cable connecting the keypad to the control box. Note that the wire colors may differ on different cables, so the wire positions are a more reliable guide.

Wire Number	Purpose	Wire Name
1	Key press signal	D3
2	Desk height signal	D4
3	Ground	GND
4	Not used	D5
5	Power	PWR
6	Key press signal	D2
7	Key press signal	D0
8	Key press signal	D1

Table 5. Description of which wires are activated when each button on the keypad is pressed.

Keypad button	Wire number(s)	Wire name(s)
Up	7	D0
Down	8	D1
Preset 1	7 & 8	D0 & D1
Preset 2	6	D2
Preset 3	6 & 8	D1 & D2
Preset 4	6 & 7	D0 & D2
M	1	D3