Exploring User Experiences of Active Workstations: A Case Study of Under Desk Elliptical Trainers

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ABSTRACT
Prolonged inactivity in office workers is a well-known contributor to various diseases, such as obesity, diabetes, and cardiovascular dysfunction. In recent years, active workstations that incorporate physical activities such as walking and cycling into the workplace have gained significant popularity, owing to the accessibility of the workouts they offer. While their efficacy is well documented in medical and physiological literature, research regarding the user experience of such systems has rarely been performed, despite its importance for interactive systems design. As a case study, we focus on active workstations that incorporate under desk elliptical trainers, and conduct controlled experiments regarding work performance and a four week long field deployment to explore user experience with 13 participants. We investigate how such workouts influence work performance, when and why workers work out during working hours, and the general feelings of workers regarding usage. Our experimental results indicate that while work performance is not influenced, the cognitive load of tasks critically influences workout decisions. Active workstations were alternatively used as mood enhancers, footrests, and for fidgeting, and there exist unique social and technical aspects to be addressed, such as noise issues and space constraints. Our results provide significant implications for the design of active workstations and interactive workplaces in general.

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Active workstations; health intervention; office furniture; exercise equipment

INTRODUCTION
Today, physically inactive and sedentary lifestyles mean that people are exposed to the risk of contracting a range of non-communicable and chronic diseases, including diabetes and cardiovascular diseases [37, 58]. Ubiquitous computing and Human-Computer Interaction (HCI) technologies have been widely utilized to design persuasive health interventions for the promotion of physical activity. For example, the monitoring of physical activities using on-body sensors aids the design of a variety of health interventions, such as the visualization of levels of physical activities [15, 38], supporting the settings of various goal [16], and the facilitation of social support [14, 38].

Because prolonged inactive/sedentary periods constitute a significant proportion of working hours [40], the workplace represents the center of interest for health promotion. The World Health Organization (WHO) has prioritized the workplace as a major target for health interventions, and provided detailed guidelines for a healthy workplace [10]. Researchers have studied a variety of technological attempts to reduce sedentary time and to promote physical activity during working hours. One approach is to record a user's physical status using sensors (e.g., sedentary postures, sitting time, and levels of physical activities), and then to prompt the user to take a break and/or exercise [8, 55]. Another approach is to deliver awareness information regarding physical activities through desktop accessories or appliances (e.g., ambient displays [32, 48] or desk lamps [21]).

Special office furniture that enables physical activities at work has also gained popularity in recent years, giving rise to so-called "active workstations". Active workstations enable office workers to concurrently perform office tasks while engaging in various physical activities, such as standing at a height adjustable desk, walking on a treadmill, and pedaling a stationary bicycle or an elliptical trainer. There has been significant interest in such furniture for the promotion of health at work. For example, sales of the TreadDesk, which is from a major active workstation manufacturer, have grown by more than 50 times over the last six years, and large corporations including Google and Microsoft have purchased active stations in large quantities to benefit their employees' health [56]. Furthermore, researchers in medical and physiological fields have been actively investigating the effectiveness of various types of active workstations on health, and their influence on work performance [41].

However, this new domain of research concerning active workstations has so far been under-explored in terms of the user experience, despite the many research opportunities. For example, office workers who use active workstations can concurrently execute two different tasks, work and exercise, in ways that constitute a new type of multitasking in the workplace.

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Prior studies regarding the physiology of exercise have reported that the use of active workstations while performing office tasks may decrease task performance [41]. The leveraging of ubiquitous computing and HCI technologies can therefore help to create a balance between work interference and the health benefits of active workstations, such as by identifying opportune moments to encourage workouts using contextual work information (e.g., interactions with computing devices [31, 43], physical activity [20, 43], and ambient sound [31]). Furthermore, the distinctive characteristics of active workstations, including their dual role as both office furniture and exercise devices, opens up significant design opportunities for enriching conventional workplaces in new ways. For example, active workstations could be used as a novel interaction tool for office work [45], and as a new medium for cultivating social interactions and collaborative participation (e.g., collectively using active workstations during break times [36]). A conventional workplace can be redesigned as an activity-permissive workplace, where office workers are allowed to perform various physical activities with active workstations depending on the types of office tasks [46]. As a first step towards exploring these research opportunities, it is critical to understand active workstations and their users.

In this paper, we perform an exploratory study to investigate the user experience of active workstations, and to uncover productive design opportunities. As a case study, we chose an under desk elliptical trainer as a target active workstation, because it has a lower price and is smaller in size than other active workstations, such as treadmill desks and standing desks. We ask three primary research questions: (1) How does the use of an elliptical trainer influence the performance of office tasks? (2) When and why do office workers use elliptical trainers at work? (3) How do office workers feel about the use of an elliptical trainer at work? To answer these questions, we conducted both quantitative and qualitative studies involving 13 participants. We measured their performance on cognitive tests and computer tasks that are common among office workers in order to understand the extent and nature of work interference due to the use of the elliptical trainers. In addition, we modified existing elliptical trainers with tracking and goal setting features and deployed them for four weeks, during which we collected a usage log and administered weekly surveys regarding user experiences. Subsequently, we conducted a one-on-one exit interview to elicit rich commentary and reflection on user experiences.

Our results revealed that the use of the elliptical trainers did not have a significant impact on the performance of office tasks, once participants were accustomed to their use. Nonetheless, in connection to cognitive load, office workers tended to use the elliptical trainers only when performing simple tasks or taking breaks. We found that the active workstations were alternatively used as mood enhancers, footrests, and for fidgeting. Although the active workstations were positively perceived on account of their health benefits, they caused discomfort in relation to noise issues and limited leg room in the office environment. Our results provide significant design and research insights, such as regarding general active workstation design, balancing work and workouts for intervention mechanisms, feedback delivery, and interactive workplace design, which are beneficial to a broad range of stakeholders, including end users, researchers, and device designers.

RELATED WORK

Here, we summarize related studies regarding (1) workplace interactive technology for promoting well-being and work productivity, and (2) exercise physiology and health intervention studies on the effectiveness of active workstations.

Workplace Interactive Technology

Various interactive technology has been developed to promote social/emotional/physical well-being and productivity in the workplace. Researchers have explored individual and collective behaviors using sensors in the workplace, in order to understand various workplace metrics, for example, by collecting data such as physical proximity and social interactions [17]. Several interactive systems have been prototyped to promote social awareness in the workplace. For example, the collective mood was measured by having workers squeeze a colored ball from a box set and then displayed in an ambient display at a public place [24]. In addition, a social awareness system was designed to encourage workers to join existing breaks to increase group cohesion by leveraging situated sensing and displays [36]. Mathur et al. suggested the quantified-workplace system, which collects and visualizes various workplace data such as noise, color, air quality, self-reported mood, and self-reported activity, and they investigated the engagement patterns of office workers and their privacy concerns regarding workplace sensing [39].

The pandemic of physical inactivity has significantly spurred the recent advancement of technological interventions to promote health in the workplace. For example, prior studies tracked bodily postures using various sensors, including visual, on-body, or on-chair sensors, and provided feedback to encourage good posture and body stretches [8, 48]. To reduce prolonged sedentary time, several applications encouraged office workers to take breaks and rise from their chairs by reminding them of their sitting time through ambient displays [32] or explicit notifications [8, 55]. In addition, physical activities were promoted by delivering awareness of a worker's physical status (e.g., daily step counts) using ambient light displays [21] or by allowing his/her physical status to be shared with colleagues via Facebook [22]. Furthermore, Probst et al. proposed activity-promoting office designs, such as by allowing office workers to give interactive commands using chair-based bodily gestures [45], and to seamlessly change their work environments and working postures [46]. Despite the ever increasing popularity of active workstations, incorporation of exercise equipment in the work context has rarely been explored in the HCI field. To our knowledge, researchers have only used exercise equipment as input devices for designing novel exergames [30, 44], but no prior studies have considered office environments to address how and why people use active workstations while working, and to investigate the resulting user experiences.

Active Workstations and their Effectiveness

An active workstation aims to facilitate physical activities while the user works in an office. Well-known physical activities include standing at height adjustable desks [2, 29, 53], walking on a treadmill [5, 23, 33, 34, 53], cycling a stationary bike [13, 53], pedaling an elliptical trainer [11, 12], and sitting on a balance ball [52]. In existing exercise physiology literature, researchers have mostly focused on studying the effectiveness of such workstations in terms of health benefits and work performance. Overall, many studies have effectively documented the positive health benefits of active workstations, such as reduced sitting time [2, 5, 11, 34] and increased energy expenditure [5, 13], which are commonly observed in standing, walking and cycling workstations. In addition, the use of standing workstations helps to decrease musculoskeletal discomfort [29] and to increase high-density lipoprotein (HDL) cholesterol (known as good cholesterol) [2]. With walking workstations, other health-related outcomes include decreased hip/waist circumference and overall cholesterol level [34].

Furthermore, researchers have invested considerable effort to identify the impact of active workstation usage on work performance or productivity. Prior studies have mostly focused on analyzing how workouts affect fine-motor skills (e.g., keyboard typing and mouse pointing) and cognitive skills (e.g., selective attention and information processing) in lab settings. In general, researchers observed that walking and cycling have a negative effect on fine-motor skills including mouse pointing and/or keyboard typing performance [13, 23, 33, 53]. In addition, it was revealed that mouse pointing was more sensitive than typing [13, 53]. Such skills may be influenced by different workout intensities, although its impact is minimal in the light intensity zone [23, 53]. Furthermore, performance degradation in fine-motor skills was more pronounced with walking than cycling, possibly due to the higher level of bodily movements involved [13, 53]. In contrast, cognitive skills are not significantly influenced by the use of active workstations [13, 33], except for mathematical reasoning in walking conditions [33]. A few real-world deployment studies showed that the use of active workstations such as standing and treadmill desks has a positive effect on self-reported productivity [5, 29]. We note that readers can obtain further information regarding the health benefits and work performance changes of active workstations in a recent survey paper [41].

In this work, we examine under desk elliptical trainers in terms of work performance and user experience, motivated by the lack of prior evaluation in controlled and field trials. The kinematic and muscle activation patterns of desk elliptical trainers are quite different from those of cycling [27]. Furthermore, no prior studies have qualitatively evaluated how and why people use active workstations and investigated their use in general. All of these are critical for designing interactive health intervention systems for the workplace.

STUDY PROCEDURE

We conducted a comparative study on office task performance and a deployment study using the target active workstations for four weeks. In this section, we begin by elaborating on the process of recruiting subjects and describe our target active workstations. Then, we present the experimental design, including objective measurements, surveys, and interviews.

Subjects

To recruit eligible subjects for this study, we first set the following criteria for subjects: (1) engaging in sedentary and computer-related work for at least 6 hours per day, (2) having the intention to exercise more within a month, and (3) being physically capable of working out at a light intensity (i.e., metabolic equivalent of task (MET) < 3.0; walking at 4 $\mathrm{km\,h^{-1}}$ measures 2.9 MET). We note that the second criterion relates to the preparation stage of the transtheoretical model, which identifies a subject's readiness for health-related behavioral changes [47]. Because people in the preparation stage intend to perform some actions (i.e., to begin exercising more) within a month, we felt that such participants may be well motivated and actively use elliptical trainers at work. The third criterion is based on the previous finding that pedaling elliptical trainers represents a light intensity exercise [12].

(a) Stamina InMotion Elliptical

(b) Using an elliptical trainer at work

Figure 1: Our target active workstations

From the self-reporting of candidates regarding the criteria, we recruited 13 participants (namely, P1 to P13; 9 males) from our university, ranging from 24 to 33 years of age (*mean*: 26.5, *SD*: 2.7). These were all graduate students of our university who were working in office environments, and their average sedentary working time was 8.7 hours per day (*SD*: 1.6). To better understand the characteristics of their physical fitness, they were asked to report their height/weight for body mass index (BMI) calculation, mean workout time per week, and moderate-to-strenuous Leisure Score Index (LSI) via the Godin-Shephard Leisure-Time Physical Activity Questionnaire [25], which indicates the sufficiency of physical activity during leisure time. Two participants [P4, P9] were overweight, one [P2] was underweight, and the others were of normal weight. They exercised for three hours per week on average (*SD*: 2.3). The LSI indicated that two [P6, P7] and five [P1, P4, P8, P12, P13] participants engaged in sufficient and moderate leisure-time physical activity, respectively, while the others engaged in an insufficient level of physical activity in their leisure time. The participants were compensated with $130 at the end of the four week experiment.

Target Active Workstation

As a target active workstation, we employed Stamina InMotion Elliptical trainers (see Figure 1). The Stamina InMotion Elliptical measures 55 cm in length, 32 cm in width, and 55 cm in height, and its weight is 14 kg. This device provides an adjustable resistance level and displays usage information, such as the number of strides, total exercise time, and calories burned, through an electronic display.

Experimental Protocols

Our experimental protocols comprised the following: (1) Comparison of office task performance with and without using desk elliptical trainers, and (2) deploying desk elliptical trainers in participants' offices for four weeks. As shown in Figure 2, we began by conducting a performance measure on simulated office tasks in the cases of using and not using desk elliptical trainers. We then asked participants to use desk elliptical trainers in their offices for four weeks. During the deployment study, the participants responded to weekly surveys to track user experiences with the under desk elliptical trainers. After the four weeks, we assessed task performance again. In

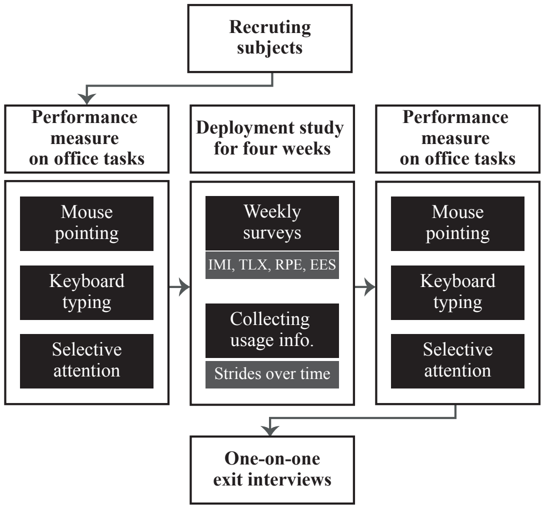


Figure 2: Overall experimental protocols

total, task performance measurements were conducted under four conditions ({using desk elliptical trainers, not-using desk elliptical trainers} × {before deployment, after four weeks of deployment}). We then conducted one-on-one exit interviews. These experimental protocols were approved by our institute's Institutional Review Board (IRB). Here, we present each experimental protocol in detail.

Comparative study on office task performance

In this experiment, we aimed to investigate the influences of desk elliptical trainers on the performance of office tasks. Many prior studies have been performed on the effects of active workstations on work performance, but there is no general consensus among these. Effects on work performance may vary depending on the type of active workstations, tasks, and the workout intensity. Therefore, we wanted to be sure of the effects of our target workstations, under desk elliptical trainers, before conducting our deployment study.

We assessed two different aspects to measure work performance, namely fine-motor skills and cognitive capabilities, which are widely employed to measure the work performance of office workers in laboratory settings [13, 53]. The fine-motor performance was evaluated through mouse pointing and keyboard typing tests, and cognitive capability was measured by a selective attention test (see Figure 3). Each participant performed these three tests while sitting in a chair with and without pedaling an elliptical trainer.

We first held a practice session for thirty minutes. During the session, participants were instructed to perform and practice each test. In addition, they adjusted the position of the chair and the elliptical trainer to be able to perform office tasks and pedal the elliptical trainer easily. Each participant then performed five blocks of each task, both with and without pedaling. The order of assessments was counterbalanced using a Latin-square design. To avoid fatigue effects, we inserted one minute breaks between blocks. Further, participants took 20 minute breaks after completing three blocks of all tests. In the tests, we used a desktop computer with an Intel i5-3470 3.20 GHz processor and 8 GB of RAM, and a Samsung SyncMaster T27B350T 27-inch monitor.

To measure mouse pointing performance, we adapted the single direction pointing task presented in [18] using the FittsStudy application [59]. In this program, a user alternatively uses a pointer to locate and click on two rectangles a certain distance apart. As in [18, 44], we combined three different widths of target rectangles and the distances between the two rectangles (for a total of six conditions) as follows:

- Width: {80 pixels (2.5 cm), 120 pixels (3.7 cm)}
- Distance: {200 pixels (6.1 cm), 300 pixels (9.1 cm), 400 pixels (12.4 cm)}

Each participant performed ten trials for each condition. During the test, we recorded the throughput (TP; in bits per second), which is the standard performance measurement for non-keyboard input devices [1], as defined by

$$TP = \log_2(D/W_e + 1)/MT \quad (1)$$

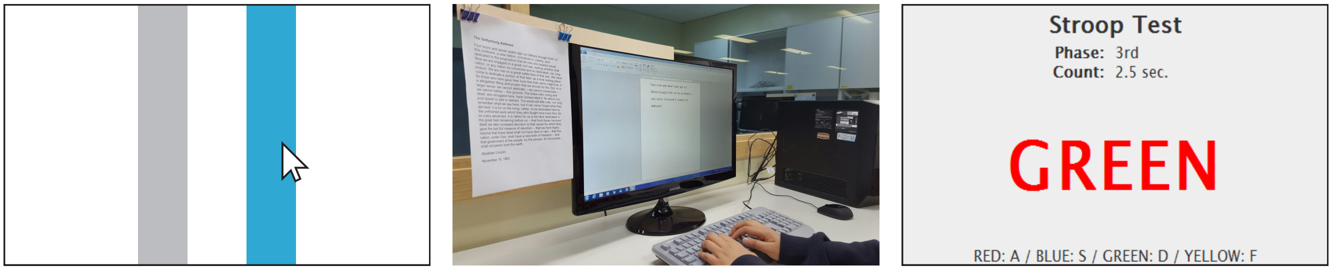
where D is the distance between two rectangles, MT is the time between consecutive clicks, and W_e is the effective width of the target rectangle, which is calculated by multiplying 4.133 by the standard deviation of the straight distances actually moved to the target rectangle.

For the keyboard typing performance measurement, participants were asked to type the Gettysburg address, a printed copy of which was mounted on the side of the monitor using a monitor copy holder, for one minute. To prevent technical support (e.g., spell checking and predictive text input) from influencing the typing performance, we used the Windows WordPad application. After each block, participants stored their transcriptions and created new text files for the next block. Measurements were taken in terms of net words per minute (NWPM), which is calculated by subtracting the number of error words from the words per minute (WPM) [51]. The WPM is defined as the number of typed entries per minute divided by five, where *five* is the average number of letters in a single English word.

To assess selective attention and information processing, we adapted the Stroop Color-Word Test, which has been widely employed to measure psychological capacities in neuropsychology [26]. This test is composed of three subtests, as follows:

- *Word*: A subject reads as many names of colors (e.g., red, blue, yellow) colored in black as possible for 45 seconds.
- *Color*: A subject identifies the colors of arbitrary symbols (e.g., XXXX) colored in varying colors as often as possible for 45 seconds.
- *Color-Word*: A subject identifies the color of colored words filled with an incongruent color (e.g., the word *red* colored in yellow) as often as possible for 45 seconds.

We implemented a computerized version of the Stroop test, in which participants attempt to identify each item by pressing a key corresponding to the color. The primary measurement was the difference score, I_D, which indicates the capacity of selective attention [26]. A lower difference score indicates less interference in identifying incongruent color names, and a higher selective attention. With the number of correctly identified items in the respective subtests denoted by W, C,



(a) Mouse pointing task (b) Keyboard typing task (c) Selective attention task

Figure 3: Visual description of simulated office tasks

and CW, the difference score is calculated as follows:

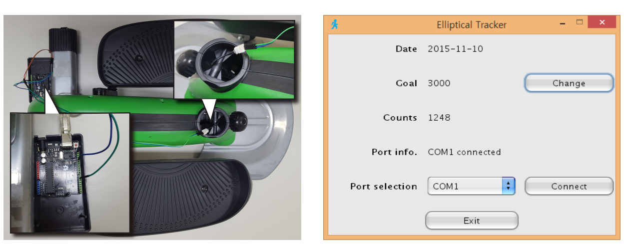
$$I_D = CW - P_{CW} \quad (2)$$

where

$$P_{CW} = (W \times C)/(W + C) \quad (3)$$

Deployment study

Following the office task comparative study, we conducted a deployment study. The goal of this study was to investigate the contexts in which elliptical trainers are actually used, and how office workers feel about using them. Considering that participants shared their offices with colleagues, we first treated the Stamina InMotion to minimize the noise caused by the friction between the rollers and base board on which the wheels roll. We greased the crank frame and wheels of the elliptical trainers, and taped rubber patches onto the base boards. We then modified the desk elliptical trainers to track usage information, as shown in Figure 4. In the Stamina InMotion Elliptical, there is a reed switch connected to an internal crank frame that sends a signal at every single stride. We connected this switch to an Arduino Uno, which transferred the signal to a desktop computer through a USB cable. We then placed the Arduino Uno into a plastic enclosure, and attached it to a rear stabilizer to protect against physical impact. To promote the use of elliptical trainers, each participant was asked to perform at least 3,000 strides as a daily goal, which typically take less than one hour. In addition, we implemented a simple application to store the usage information on the computer and show the total step counts per day and the participants' goals by following design guidelines of persuasive computing systems [42]. The resistance level was set to the lowest setting, and we asked participants not to modify the level to avoid any confounding effects of different workout intensities. For the four weeks of deployment, the participants were allowed to use elliptical trainers only on week days, twenty days in total.



(a) Modifying the Stamina InMotion Elliptical (b) The desktop application to track the usage information

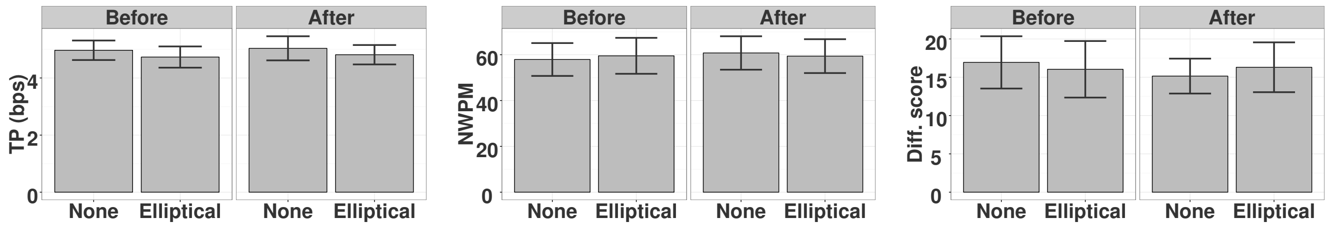
Figure 4: Modification of the desk elliptical trainers

In addition, each participant responded to weekly surveys to evaluate their experiences in relation to both work and exercise aspects. The weekly surveys included the Intrinsic Motivation Inventory (IMI) [50], NASA Task Load Index (NASA-TLX) [28], Rating of Perceived Exertion (RPE) [7], and Evaluation of Exercise Setting (EES) [57]. The IMI is a form of Likert-scale rating, which uses multiple dimensions to assess self-desire to perform a certain activity. It includes a total of 45 items across seven sub-scales, including interest/enjoyment, perceived competence, effort/importance, pressure/tension, perceived choice, value/usefulness, and relatedness. We selected five sub-scales (29 items), excluding perceived choice and relatedness, because these two sub-scales were not closely related to our study. Through the IMI, we aimed to measure how participants prefer to use desk elliptical trainers at work.

The NASA-TLX test assesses perceived workload in performing a specific task, based on six dimensions of load: physical demands, mental demands, temporal demands, performance, effort, and frustration. The rating procedure is composed of two steps: rating each source of load and weighting these by comparing two pairs (15 comparisons in total). The outcome variable is the overall workload score, which is a weighted average of all sources, and weighted ratings of each dimension. Using NASA-TLX, we aimed to assess how burdensome the use of elliptical trainers at work was for the participants.

The RPE is a widely employed scale for measuring the perception of exertion in medicine and sports [7]. This scale ranges from 6 (no exertion at all) to 20 (maximal exertion). The higher the value, the higher the perceived intensity of a physical activity. The EES measures a subject's preference for certain settings for physical exercise. This scale is composed of five Likert-scale items. Using these scales, we aimed to investigate participants' feelings regarding the office as a place of exercise.

In addition to these surveys, we conducted one-on-one exit interviews for approximately an hour per participant, to explore user experiences in depth. All interview sessions were recorded and transcribed for thematic analysis. Our interviews mainly focused on three questions: (1) What are the contextual factors influencing elliptical trainers at work? (2) What are the pros and cons of using elliptical trainers at work? (3) Are there any physical or emotional changes caused by using elliptical trainers at work for four weeks?



(a) Throughput comparison in the mouse pointing task (b) NWPM comparison in the keyboard typing task (c) Difference score comparison in the Stoop test

Figure 5: Office task performance with and without the elliptical trainer in the case before and after deployment

ANALYSIS & RESULTS

RQ1. Are There Any Impacts on Task Performance?

We analyzed the office task performance measurements from controlled experiments under four conditions, as stated in the previous section. For each given condition, we performed repeated-measures ANOVA with Helmert contrasts to remove the effects of learning on performance improvement, which occurs when a task is repeatedly tested, as suggested in [44]. After dealing with learning effects, we performed a paired t-test with the pair composed of with and without elliptical trainers, for before and after the four weeks of deployment. Our results showed that significant effects were only observed in the pointing task initially, but after a four-week deployment, no significant effects were found in any tasks.

Figure 5 presents the results of the office task performance measurements. The pointing task results in the pre-deployment case show that significant throughput differences were observed: $t(12) = 4.308$, $p = .001$, and Cohen's $d = 1.195$. The average throughput without and with the elliptical trainer was 4.97 ($SD = 0.57$) and 4.73 ($SD = 0.62$), respectively. The results in the post-deployment case showed that significant throughput differences were no longer observed: $t(12) = 1.772$, $p = .102$, and Cohen's $d = .492$. In the typing tasks, we did not find any significant differences in performance with or without the elliptical trainer in either experiment. Before deployment the results were $t(12) = 2.163$, $p = .051$, and Cohen's $d = .600$, and after deployment these were $t(12) = 2.073$, $p = .060$, and Cohen's $d = .575$. Likewise, the cognitive task results also did not show any significant performance differences in either experiment. Before deployment we found $t(12) = 1.133$, $p = .207$, and Cohen's $d = .370$, and after we found $t(12) = 1.280$, $p = .225$, and Cohen's $d = .355$.

We note that our cognitive task results are consistent with the results of prior studies on treadmill walking [33]. While prior studies have reported slight performance degradations in pointing and typing tasks [23, 33, 53], in our experiments with under desk elliptical trainers we did not observe any significant performance degradation other than for the throughput in the mouse pointing task. Even this performance decrease became insignificant after four weeks of elliptical trainer usage. This difference may result from the fact that elliptical trainers provide more stable bodily movements than stationary cycles, although the pedaling of elliptical trainers results in more muscle activation than cycling [27]. This may also be explained by the reduction of dual-task interference, because participants would become practiced in the use of elliptical trainers after four weeks of deployment [49]. Overall, we found that desk elliptical trainers result in minimal impact on fine-motor tasks and cognitive tasks in office workers.

RQ2. When and Why Do People Use Active Workstations?

We analyzed the data from the interviews and active workstation usage to answer RQ2. The interview analysis began with the segmentation of the original transcripts into sentence units and labeling of these. The labeled sentences that shared themes were then clustered into broader categories. These entire processes were conducted iteratively until there was a consensus between two coders. In [9], a detailed description of this analysis process is provided. Over four weeks of deployment, our participants performed an average of 2690.8 strides for an average 38.4 minutes on work days. Five participants failed to complete 3,000 strides per day, and the others took 43.0 minutes to meet their daily goals (see Table 1). Our results showed that work contexts, such as cognitive loads and urgency, are the most critical in deciding whether to simultaneously perform a workout. Participants engaged in the use of elliptical trainers for various reasons, such as staying in an awake, invigorating mood, resting feet (and fidgeting), and social comparison.

When do people use? Cognitive load matters

Our interview analysis revealed that the use of active workstations was mainly determined by the perceived cognitive load of primary tasks. A majority of our participants used the elliptical trainers while performing relatively simple and trivial tasks, such as writing short emails, skimming academic papers in a familiar domain, and arranging daily schedules; or while taking breaks, such as reading online news and watching sports videos. In contrast, they tended not to use the active workstations while performing complex and difficult tasks, such as reading difficult papers, or writing papers. One participant commented: *"I pedaled this machine while surfing the web or watching sports videos on YouTube during a rest [...] I may pedal when doing familiar tasks. For example, when reading an academic paper in a familiar domain, pedaling did not disturb me. However, it was difficult to comprehend a novel or an unfamiliar paper while using this machine."* [P11]. In addition, the presence of urgent tasks (e.g., facing deadlines) lowered workout engagement: *"I did not use the elliptical trainer when I had to cope with a task quickly. For example, if I had a meeting at 1PM and it was 11AM or 12AM, then I did not use it."* [P2].

Other factors include a user's physical condition and social environment. When participants were tired or sick, they lowered their exercise intensity (e.g., slow pedaling, lower number of strides) or even stopped using elliptical trainers. P1 commented: *"Typically, I met the goal number of strides within 20 to 30 minutes. When fatigued, I pedaled slowly, so I took 40 minutes to an hour to meet the daily goal."* Another important factor was the social environment in which exercise took place,

Measurements	Mean (95% CI)	SD	Range
Step counts	2690.9 (±146.4)	1151.1	14.0 – 8646.0
Pedal time (min.)	38.4 (±3.0)	23.9	0.1 – 157.7
Proportion of participants who met the daily goal (%)	59.6 (±5.5)	11.7	46.2 – 84.6
Pedal time taken to meet the daily goal (min.)	43.0 (±2.2)	13.6	20.1 – 77.2

Table 1: Overall statistics of daily elliptical usage

because all participants shared their offices with others. A majority of our participants (n=10) reported that they engaged in lighter workouts or even decided not to work out because of noise issues when there were other colleagues in their offices. For example, P3 said: *"When there were other colleagues in my office, I meant to use this elliptical trainer after they got off work, because the noise from this machine may distract them."* Two participants [P8, P13] worried about how other people looked at them when they engaged in working out in the office. In particular, P8 said: *"Since I use this machine in the office, I felt uncomfortable, because someone noticed the pedaling motion and noise."*

Overall, our participants quickly learned which tasks are appropriate for a concurrent workout. Nine participants reported that they initially attempted to use elliptical trainers while performing various tasks. However, they often stopped pedaling when focusing on a certain task, or their tasks were disturbed because of their attempts to pedal consistently. Therefore, after a week or so, they distinguished between the types of tasks appropriate for a concurrent workout. For example, P5 said: *"Initially, I tried to use this machine anytime, like when doing a course project, reading difficult materials, or taking a rest. However, I stopped using the machine when I had to concentrate on something, like comprehending academic papers. Also, I thought that my productivity may decrease if pedaling anytime, so I naturally used the machine only when I performed cognitively less burdening tasks after a week."* The use of elliptical trainers over a longer duration seems to result in the simultaneous performance of cognitively demanding tasks and workouts with elliptical trainers [49]. Nonetheless, concurrent workouts would be achieved up to a certain level of cognitively demanding tasks, because to some extent even simple physical activities (e.g., walking or pedaling) demand cognitive resources for motor control [60].

Why do people use? Beyond exercise reasons

Because the main purpose of active workstations is to promote physical activity at work, we expected participants to use them for exercise. As such, five participants [P3, P5, P10, P11, P13] commented that they treated active workstations as a form of exercise: *"When I wanted to work out my muscles, I pedaled fast until my legs were strained."* [P10] *"Usually, I pedaled this machine hard in short bursts [...] For the effect of exercise, it may be better to intensively use the machine."* Another major usage motive was to stay awake and to improve mood. Ten participants typically used active workstations after meals to stay awake. P8 commented: *"After eating a meal, I felt sleepy and could not concentrate on work, so I used the machine to stay awake."* As shown in Figure 6, the number of strides was typically large around lunch breaks and after dinner. More than half of the participants used active workstations when they were mentally exhausted owing to work, and took a break to relieve their stress and invigorate their mood, as P5 said: *"When having difficulty understanding papers and feeling annoyed, I pedaled the machine intensely while leaving the window open. That made me feel as if I was riding a bicycle outdoors and refreshed me."* When switching tasks, participants tended to take short breaks and engage in workouts, as P10 commented: *"After completing a portion of work, I wanted to relax myself. Then, I used this machine."* When colleagues participated together in the experiment, they sometimes discussed elliptical workouts (e.g., sharing how many strides they had completed so far), which helped them to encourage one another, as P4 remarked: *"I sometimes competed against other participants to decide who meets the daily goal first [...] For example, I had more than 1000 strides left to meet the daily goal, and someone had only 1000 strides left. Then I had a bout with him."*

Interestingly, a majority of our participants used the elliptical trainers as footrests, because they usually placed their feet on the pedals (due to limited leg room with the trainer). Our participants commented that they often pedaled unconsciously as a form of fidgeting in the midst of some tasks. P8 said: *"I placed my feet on the pedals almost all day. [...] Unlike fast pedaling for exercise, I unknowingly and habitually pedaled."* Furthermore, three participants [P2, P4, P5] said that they originally had fidgeting habits such as shaking their legs and tapping their feet. After installing the elliptical trainers, they pedaled the elliptical trainers instead of shaking their legs or tapping their feet. P4 said: *"I have a habit of shaking my legs, but placing my foot on the pedals changed this habit into pedaling."*

RQ3. What about User Experiences?

We explored user experiences of active workstations by analyzing interviews and surveys, including perceived motivations and task loads, perceived exertion and health behavior, and evaluations of exercise environments. Furthermore, we examined how these aspects changed over time. The number of survey items was 56 in total, from which 40 items were 5-Likert scale ratings (IMI: 29, NASA-TLX: 6, EES: 5), 15 items were pair-comparisons in NASA-TLX, and the remaining one was RPE. Participants took 426.9 s(±62.7) on average to complete the survey.

Overall, our participants were positively motivated to use the elliptical trainers for a light intensity workout. Over the four

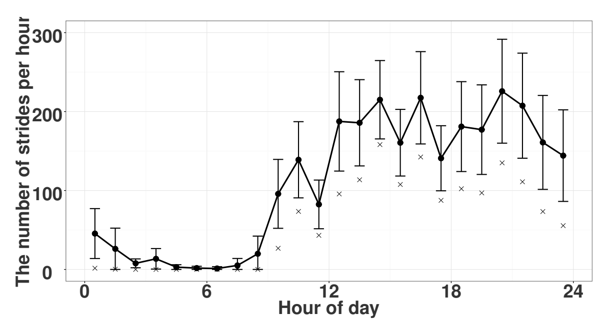
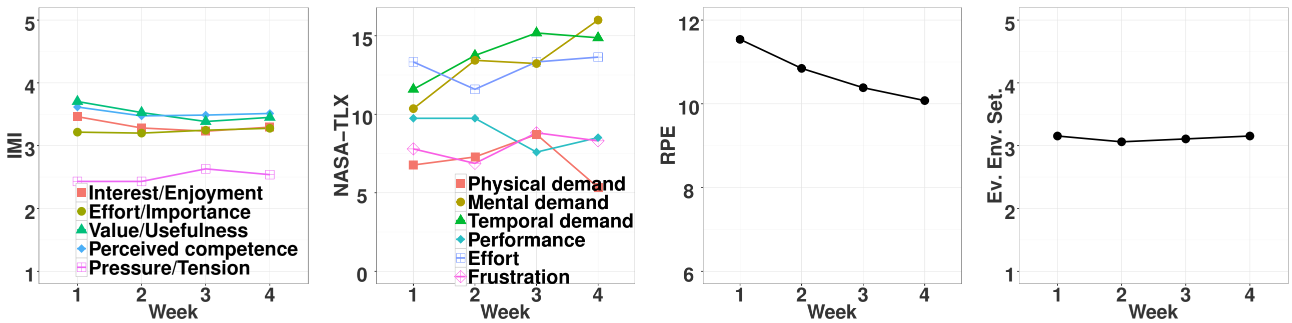


Figure 6: Diurnal elliptical usage data with 95% confidence intervals (error bars) and 5% truncated means (X marks)



(a) IMI results over four weeks (b) TLX results over four weeks (c) RPE results over four weeks (d) EES results over four weeks

Figure 7: Survey results over four weeks

weeks of use, the motivation slightly decreased. Furthermore, the perceived task load somewhat increased. In addition, active workstation usage positively influenced health behaviors. However, these benefits came at the cost of potential discomfort in the office environment in terms of noise concerns and limited leg room.

Perceived motivation and task load

We found that the IMI scores were reasonably positive across all sub-scales (see Figure 7a). The average values regarding value/usefulness, perceived competence, and interest/enjoyment sub-scales were initially rated as 3.70 (*SD* = 0.41), 3.62 (*SD* = 0.60), and 3.47 (*SD* = 0.71), respectively. However, the value/usefulness sub-scale significantly decreased over time, as shown by the results of the one-way repeated-measures ANOVA ($F_{3,36}$ = 3.367, *p* = .029). The average value/usefulness sub-scale decreased from 3.70 (*SD* = 0.41) to 3.45 (*SD* = 0.53) after four weeks. Other sub-scales, such as perceived competence and interest/enjoyment, tended to show similar trends. Interestingly, ten participants expressed their willingness of continued usage after the experiment, but a majority of participants suggested that noise and leg room issues should be addressed for sustainable usage.

The NASA-TLX results were obtained as follows. After the first week, the average overall TLX score was 59.59 (*SD* = 9.53), which indicates a moderate task load, as the maximum score is 100. However, we found that after four weeks this value significantly increased to 66.67 (*SD* = 10.89), which was confirmed by the result of our one-way repeated-measures ANOVA ($F_{3,36}$ = 4.49, *p* = .006). The weighted average ratings of the six sub-scales are presented in Figure 7b. The mental demands significantly increased over time ($F_{3,36}$ = 3.965, *p* = .015). After the first week, this was given as 10.36 (*SD* = 7.44), but after the fourth week, it increased to 16.00 (*SD* = 9.62).

Although the intrinsic motivation was reasonably positive, the motivation slightly decreased, and the perceived task load slightly increased over the four weeks. This may be partly because the perceived exertion significantly decreased ($F_{3,36}$ = 5.108, *p* = .005), as shown in Figure 7c. In our experiment, the resistance level was fixed to the lowest level in order to control confounding effects of changing exercise intensities. For this reason, the value/usefulness of the desk elliptical workout may have decreased. P4 commented: *"At an early time, I was interested in this machine and felt a sense of accomplishment when I met the daily goals. [...] As time went by, this machine became dull to me, and the exercise intensity was not enough."* The increased perceived task load can be interpreted that participants tended to feel more time pressure and mental demands to complete their daily goals, as the novelty effect decreased. Our participants confessed their difficulties in meeting the daily goals: *"The use of this machine seems like a mission to meet a daily goal, not exercise [...] I should spend time to achieve 3000 strides."* [P7] Some participants had difficulties with properly scheduling time for workouts, as P10 commented: *"As I became less sensitive to this machine, the priority of using the active workstation dropped, and I tended to focus on other tasks. Therefore, ironically, I did not have enough time to meet a daily goal, which increased the time burden."*

Perceived exertion and health behavior

Our participants perceived the pedaling of elliptical trainers to be a light intensity workout (RPE: 10.39 – 11.54). Two participants [P5, P10] commented that the elliptical workout helped them to enhance their physical strength: *"Although I used this machine only for four weeks, I felt lighter and supple. [...] It became less strenuous to go up the stairs."* [P5] In addition, three participants [P5, P11, P12] stated that the use of the elliptical trainers aroused interest and motivation in exercise and health: *"This machine motivated me to exercise. Frankly, I intend to continuously use it."* [P11] *"I became more and more interested in health. [...] During this experiment, I ordered green vegetable juice, refrained from having a lot of coffee, and drank more water because I felt thirsty after pedaling. [...] By using this machine, I started to practice healthy activity, so that seems like a trigger."* [P5]

There was a general consensus regarding the overall effect of the exercise. Namely, this type of exercise cannot provide a substitute for conventional exercises, mainly on account of its low intensity. P6 differentiated between workout types, saying, *"I think of exercise at work and conventional exercise differently. The exercise at work seems like refreshing myself, but conventional exercise is for fitness."* Our participants concurred that energy expenditure with the elliptical workout is much lower than with regular fitness exercises. P7 commented: *"Even if the use of the active workstation may burn calories a little bit, only doing this is not enough for fitness."*

Perceived exercise environments

As shown in Figure 7d, the evaluation of the exercise setting showed that our participants were moderately satisfied with the exercise environments in the workplace. The average EES value was obtained as 3.15 (SD = 0.61) in the first week. There were no significant changes in the EES value over time ($F_{3,36}$ = .392, p = .760).

Our participants reported both pros and cons of using the workplace as an exercise setting. Nine participants agreed that the major advantage of active workstations is availability, and a workout is not generally affected by weather conditions, preparation requirements, and time constraints: *"The best advantage of exercise at work is that I can exercise everyday regardless of bad weather conditions."* [P8] *"Outdoor exercise requires the preparation of clothes and equipment, and to go to a certain place for exercise, like a gym or pool. But I can exercise at work even though I wore flip flops and jeans."* [P9] However, four participants [P1, P2, P3, P12] stated that exercise at work is less refreshing than outdoor exercise. P13 felt that exercise at work constitutes an office task, because it is performed at work: *"When taking a walk outdoors, I can enjoy the breeze and fresh air, which helped to refresh my mind and body. But, the office is not a pleasant place for exercise."* P13 added: *"As I stayed in the office, I regarded exercise at work as a part of office activities."*

All participants shared their offices with colleagues. Under such environments, a majority of participants commented that noise is a serious issue. Before the deployment study, we tried to reduce the noise as previously described (e.g., greasing joints and taping rubber patches). Despite these efforts, as participants pedaled fast, significant noise was caused by a rotating flywheel, which is prevented from disassembling and thereby we could not engineer to reduce the noise. Our participants commented that they could easily recognize small noises particularly in a quite office environment.

Another major issue regarding setting relates to office furniture, such as desks and chairs. Although an under desk elliptical trainer is small in size, it still requires some space below the desk. This results in limited leg room, and thus users were required to adapt their postures accordingly. P8 commented that he slightly has to bend his back to use the machine, due to his height (185 cm): *"My knees hit the desk while I pedaled this machine if I pulled up my chair under the desk. But I did not have much room behind my chair, I had to move my hips back and bend my body forward to use the elliptical trainer."* Like P8, most male participants reported that they stayed at a certain distance from the desk because their knees often hit the desk while using the elliptical trainers. Four participants [P3, P5, P9, P11] owned chairs with casters, and pedaling resulted in chairs disturbingly moving back and forth.

DISCUSSION

Our results showed that under desk elliptical training in the workplace has minimal impacts on the performance of cognitive and fine-motor tasks once users are accustomed to the exercise. The results for cognitive tasks are consistent with the results of prior studies on treadmill walking [33], but we did not find any performance degradation when participants performed fine-motor tasks after the four weeks of deployment. We identified the perceived cognitive load of a primary task as the critical factor in determining whether a user will work out concurrently with that task. Overall, our participants tended to use elliptical trainers while performing simple and trivial tasks, or having breaks. Other important factors include the physical conditions of the workers and social settings. We found the major motivation for workouts included simply performing exercise, staying awake, invigorating mood, resting feet (and fidgeting), and competing with others. A user experience analysis showed that our participants were positively motivated by light intensity elliptical workouts. Furthermore, elliptical trainer use resulted in several health benefits, although overall motivation decreased slightly over time. In addition, active workstations can cause some discomfort on account of noise concerns and limited leg room in the office environment. From these findings, we discuss several practical design implications as well as the limitation of this work.

Practical Considerations for Active Workstation Design

Our participants reported that noise is considered to be problematic in shared offices, because noise may disturb colleagues. In the case of an elliptical trainer, noise is mostly generated when a flywheel rotates, and rollers attached at the bottom of the foot pedals glide through the surface. In addition, noise level is related to exercise intensity, such as pedaling speed and resistance level. To adapt active workstations for the office environment, parts of active workstations should be carefully engineered to minimize noise. In addition, there should be a systematic measurement of noise levels performed by varying the exercise intensity. An interactive system can monitor ambient noise levels, and possibly recommend suitable exercise intensities to lower work disturbance. Another issue is related to the ergonomics of office furniture. To facilitate physical activity at the workplace, users should be able to comfortably perform physical activity. Physical constraints of typical office furniture, such as desks and chairs, should be properly considered when incorporating exercise equipment (e.g., maintaining sufficient leg room to avoid hitting the underside of a desk).

Balance between Primary Tasks and Workouts

In the office environment, health intervention features, such as reminders and goal-setting, should be introduced with the consideration of the balance between primary tasks and workouts. In our study, we found that participants mostly preferred to exercise when performing less cognitively demanding tasks, or during breaks between tasks. Thus, when designing intervention methods to promote physical activities at the workplace, we should carefully consider the cognitive demands of the tasks at hand and task switching patterns. For example, it would be useful to deliver notifications when a user casually browses the internet. This type of work context awareness is essential for designing persuasive intervention methods for encouraging physical activity in the workplace. We can leverage existing workout history data and work context data (e.g., computer usage logs) to build machine learning models that can infer opportune moments for workouts, which will be a part of our future work.

Designing Alternative Feedback Delivery Mechanisms

There are several ways of delivering feedback by using various computing devices, such as desktop computers, wearable sensors, and ambient displays in the workplace [39]. In our experiments, visual feedback was used in our desktop application. Interestingly, our results showed that pedals can be modified to deliver tactile feedback, because most participants used a desk elliptical trainer as a footrest. Furthermore, we can implement mechanical nudging, where an exercise device automatically actuates a flywheel to make a slight pedal movement to bootstrap physical activity.

Exploring Design Opportunities for Fidgeting

Fidgeting is a bodily action that is often performed repeatedly and mindlessly (e.g., swinging legs). According to psychology literature, fidgeting has been shown to wane attention [19], but is also viewed as a positive act for sustaining attention [4]. We found that fidgeting with active workstations may help to sustain attention by increasing physiological changes and arousal [3], or by providing a mental break between task switching [4]. As in prior HCI studies on fidget widgets [35], active workstations could provide novel interaction design opportunities for fidgeting. Thus, investigating fidgeting patterns with active workstations and exploring how to leverage fidgeting to promote physical activity would be an interesting area for future work.

Redesigning the Workplace with Active Workstations

Our results showed that active workstations were often used as refreshers, and social awareness of physical activities helped to facilitate workouts in the office environment. Thus, active workstations provide new opportunities for redesigning the workplace. One promising direction is to design exergames for office environments as discussed in prior studies on workplace exergame design such as Limber [48]. In addition, office furniture can be used as an input device for exergaming. For example, a semaphoric chair [45] supports various seated gestures, such as rotating and tilting. To make exergames more engaging, we can allow users to receive virtual game rewards in proportion to the actual pedal counts that are accumulated over a day [6]. Furthermore, social facilitation can be leveraged by sharing activity statistics among office workers [42]. Office workers can be grouped based on their office names, and collaborative and competitive activities can be performed (e.g., inter-office pedal count competitions). Another design opportunity is to incorporate inconvenience interactions, in which an interactive mechanism coerces users to make intended actions [54]. For example, pedaling can be required to keep a computer monitor powered on. When considering coercive engagement, a proper balance should be maintained between primary tasks and workouts.

Limitations

This work is limited in its generality. To measure work performance, we considered elementary tasks, not more complex, real-world work scenarios [41]. Further studies on evaluations of work performance under more naturalistic environments are required to deeply understand work-related outcomes regarding the use of active workstations, as performed in prior studies [5, 29]. In addition, user experience research should be conducted using larger user groups and different active workstations. Furthermore, employing quantitative measurement tools, such as activity and computer usage trackers, and video/audio recording would provide additional insights into user behavior.

CONCLUSION

Active workstations that incorporate various physical activities have gained considerable popularity, owing to their effectiveness in fighting against sedentary behaviors. This rapidly growing field has received little attention from HCI and UbiComp researchers. While the efficacy of active workstations has been well documented in the medical and exercise physiology fields, there has been a lack of user experience research performed regarding active workstations. The results of our exploratory study on under desk elliptical trainers revealed that (1) the perceived cognitive loads of primary tasks have a critical impact on a worker deciding whether to exercise while working; (2) secondary usage purposes include mood enhancers, footstools, and fidgeting, and (3) despite positive usage motivations, incorporation of physical activities introduces noise and limited leg room issues in office environments. Our results provide significant implications for the design of active workstations and interactive technologies for the workplace.

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