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Erglove: a wearable ergonomic solution for wrist injury prevention

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Hotel house cleaners are at high risk for musculoskeletal disorders due to strenuous and repetitive tasks: in particular, wrist injury is prevalent due to many combined hours of wiping in inappropriate postures. Erglove is an instant and long-term wrist posture feedback system that allows cleaners to gain awareness of their posture and change their behaviour as they wipe. An exploratory user study was conducted to compare the effects of using the Erglove feedback system versus no feedback on the wiping behaviour of a group of college-age participants. The results indicated that the perceived system usefulness was higher in the group with real-time feedback. The study findings provide initial insights into how design can influence usage behaviour in the context of posture improvement. These insights likely extend beyond the specific application to wrist MSDs prevention for hotel housecleaners and are applicable to a wide variety of everyday tasks.

Keywords: Hotel Cleaners; Musculoskeletal Disorders; Ergonomics; Wearable Computing

1 Introduction

The hotel industry is one of the largest workforce sectors in the United States, with 163,000 employees predicted to be working in this field by 2024 (Bureau of Labor Statistics, 2015). The incidence rate of nonfatal occupational injuries for the hotel sector was 4.5 per 100 workers in 2017, in comparison to 3.1 per 100 workers in across all industries (Bureau of Labor Statistics, 2017). In a 3-year cohort study of hotel workers, the average rate of injury was 5.2 injuries per 100 person-years and housekeepers had the highest rate of injury amongst the jobs surveyed, with an injury rate of 7.9 per 100 person-years, as well as the highest rate of musculoskeletal disorders - 3.16, in comparison to 2.0 for the average of all jobs (Buchanan et al., 2010). Another study of 258 hotel housekeepers in San Francisco reported that 75% of housekeepers experienced work related pain, 73% had to visit a physician due to severe pain, and 53% had to take time off work to recover (Lee & Krause, 2002).

These statistics highlights the significant risk of work-related injury among housekeepers. These injuries are considered musculoskeletal disorders (MSDs), and occur when a worker's physical task is too strenuous or too repetitive. Housekeeping jobs involve many repetitive and strenuous tasks, including bed-making, vacuuming, item organizing, and wiping a variety of surfaces. These tasks often involve high force exertion, repetitive actions, standing for long periods, and lack of physical recovery time, leading to ergonomic risks and potential MSDs.

Repetitive cleaning using a sponge or a cloth is an example of such a task, which can lead to potential MSDs that are commonly performed by housekeepers. The European Agency for Safety and Health (Tim Tregenza, 2009) identified this task as moderate risk. The exertion for this task is exacerbated by the rise in chrome surfaces, large mirrors and floor to ceiling windows in hotels (Hedge, 2016). Several studies have demonstrated the negative impact the task of cleaning poses on workers. For instance, in a study comparing cleaners versus non-cleaners, researchers found that cleaners had poor electrophysiological function in their median nerve (which runs through the arm and wrist), indicating intrinsic nerve damage (Pierre-Jerome, Bekkelund, Mellgren, & Torbergsen, 1996). Median nerve damage can lead to serious disorders such as carpal tunnel syndrome (Upton & Mccomas, 1973). Moreover, in another study comparing workers performing vacuuming versus toilet cleaning tasks, cleaning toilets was identified as a task that required immediate intervention (Weigall, Simpson, Bell, & Kemp, 2005). These studies suggest that the task of wiping (i.e. cleaning using a sponge or cloth) poses great strain on the wrists, making this articulation a potential place for injury among workers in hotels.

Currently, to our knowledge, while there is no tool developed with explicit intention to support a user’s posture when wiping, there are a few product options that decrease the ergonomic burden of cleaning. For example, the SakSak wiping glove, which is covered in small bristles, allows the user to combine the action of wiping with scrubbing. However, this glove is designed for dishwashing and would not be useful for wiping large wide areas such as windows due to its small surface area. In this particular aspect, the Duop (Clean Design Company LLC, 2017) wiping tool seems a better wiping tool option: it features a wide, flat square for wiping large surfaces connected to a ball shaped grip, resulting in an bigger wiping surface area compared to SakSak. Still, the greater the area the greater the effort made by the workers. The Duop may improve efficiency but not necessarily ergonomic posture. Lastly, the market offers robotic window cleaner, which drives around the window surface removing dirt, eliminating all ergonomic burden from workers. However, this approach is not feasible for most hotels due to purchase and maintenance cost. Although the aforementioned tools improve the workers’ task of wiping, they are limited in raising workers’ postural awareness and stimulating them to change their postures. A good wiping tool could still cause physical burden if workers are not assisted to consciously operate them. The Delta 1 (Iterate Labs Inc, 2019) created by Iterate Labs is a wrist motion and position-tracking tool designed to assess risk of developing MSDs. This product shows promise, however it appears to focus on data tracking rather than providing feedback focussed on informing hotel workers on their specific ergonomic risks.

To mitigate this issue, this paper proposes Erglove: a wearable product that informs hotel housekeepers about the ergonomic risks resulted from improper wrist posture while wiping. Erglove also aims to encourage workers to change their behaviour, protecting against median nerve damage or other wrist MSDs. In the following sections, we will introduce our design process followed by a preliminary user study, and illustrate a functional prototype.

2 Conceptual Design Process

Our main design goal was to provide feedback for hotel cleaners so that they could improve their wrist posture. In practical terms, our design consists of a glove embedded with flex sensors, a micro-computer, and sewn-in LED lights. The flex sensors would collect movement input from the worker using the glove; the LED lights would inform the workers about their wrist posture.

To better inform our design, we conducted an expert interview at a hotel where we learned more about the concerns of housekeepers. We observed some of the staff as they cleaned a room and asked them a series of questions about their work schedules, tasks, training, as well as worker demographics and most common difficulties. Based on this interview, we found four major design concerns: flexibility, waterproofness, social acceptability, and privacy of feedback. Equipment flexibility is crucial for hotel cleaners since they have to perform many micro-tasks with the same tool. Good equipment should not hinder workers movement when carrying out these various tasks. Waterproofness is essential for the system to be applied in the real world. Cleaners need to use water and other liquid detergents during their work and the system will inevitably contact them. Lastly, we brought to the interview the idea of a product that reads a user's behaviour and provides feedback on the behaviour. We explained that such product would collect data; in concordance with our initial view, the workers shared concern with privacy. We considered these four major concerns in conceptualizing our design.

It is worth making one particular observation regarding the expert interview and our system's feedback function. Although most of approaches to designing for behaviour change suggest giving users real-time feedback as a means of increasing their awareness (e.g., Niedderer et al., 2014; Wende, 2013), our participants expressed contrasting opinions. The hotel cleaners we spoke were not enthusiastic about real-time feedback. To better understand the usefulness of real-time feedback, we conducted an exploratory user study that tested how cleaners would respond to real-time wrist feedback, which is described in the following section.

Figure 1. Photos of existing tools used by hotel cleaners

3 User Study

3.1 Participants
We conducted a preliminary study with a convenience sample of four college students. The study was anonymous and no demographic information was collected.

3.2 Study setup
The study focused on assessing the effectiveness of different types of feedback on participants' experience and perception of our design. One of our success criteria was an improvement in wrist posture between the first and second round of cleaning. We counted the number of wrist posture mistakes made while cleaning. The other criterion was a positive perception towards Erglove. This was measured through a post session survey. There were two conditions in our study: one group performed the task using our glove with real-time feedback, plus post task feedback; the second group performed the same task using our glove, but with post task feedback only. We instead used Wizard of Oz technique (Buxton, 2010). We observed participants during their task performance instead of using flex sensors. Also, we gave feedback using a remote-controlled light.

3.3 Procedure
Each session of our study consisted of four phases:

1. Introduction: Participants were read a verbal consent statement followed by a brief explanation of the study procedure. Participants were introduced to the tasks they needed to complete, the setup, and the cleaning tools they would use. Participants then had the opportunity to get acquainted with the cleaning tools.
2. Cleaning 1: In order to gauge participant motivation, participants were asked to set a goal for how well they wanted to clean on a Likert scale (very well, well, average, poorly, very poorly). Participants were then asked to clean the first window.
3. Cleaning 2: After completing the first cleaning, researchers told the participants how many mistakes they made. Participants were then asked to set a goal for how much they wanted to improve on a scale of 10% to 50%. Participants were then asked to clean the second window.
4. Survey: After cleaning the second window, participants were given a survey asking 3 positively worded questions and 3 negatively worded questions. They were asked to respond via a Likert scale of strongly agree, agree, neutral, disagree, strongly disagree.

Figure 2 illustrates our study set up. Participants were asked to wear arthritis compression gloves to simulate our product and were given a Swiffer and glass cleaner to clean food colour off of windows. LED lights were mounted in the corner of both windows and were activated for the experimental group. A facilitator of the study observed and counted the number of mistakes for both groups and manually triggered a LED light for the experimental group (i.e., participants with real-time and post task feedback). Mistakes were determined by wrist deflection of more than fifteen degrees in any direction. The facilitator judged this deflection visually. Real-time feedback was delivered in the form of a colour changing LED light. The LED light was lit green when a participant's wrist posture was correct, and the LED light was turned red whenever a participant's wrist deviated significantly from good posture. The control group was given no real-time feedback while cleaning. Both groups were told how many mistakes they made during each round of cleaning and both groups were asked to complete the same post-session survey.

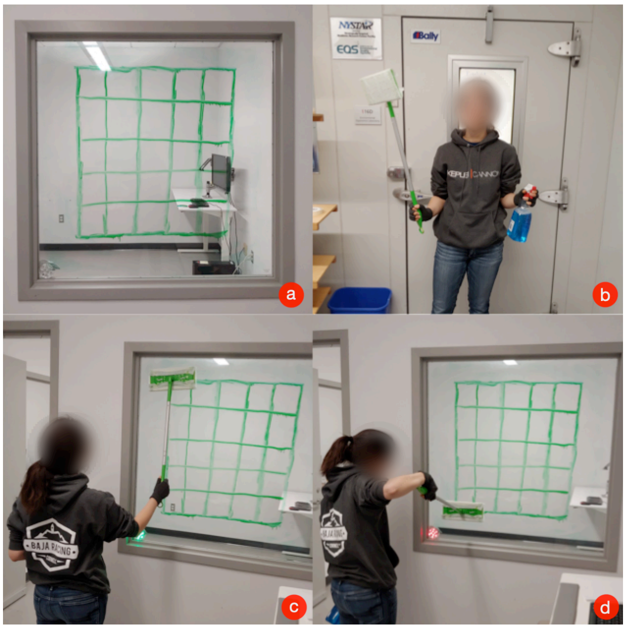

Figure 2. Study set-up. a) food coloured pattern on a window b) a researcher holding cleaning implement and cleaning spray c) green light when wrist posture is good d) red light when wrist posture is bad.

3.4 Results

Table 1 shows the questions and average responses from the post session survey. The survey results show a difference between the experimental group and the control group's perception of our design and feedback system. The experimental group was more positive about the feedback and the system as a whole compared to the control group. Not enough participants participated to allow for any statistical analysis to be done with the data beyond recognizing the aforementioned differences between the groups.

Table 1. Average user response to post session survey: scoring of 1-5 on a Likert Scale with 1 corresponding to strongly disagree and 5 to strongly agree.

Statement	Average User Score	
	Experimental	Control
I think this glove is comfortable	2.0	4.0
I do NOT want to wear this glove	4.0	2.5
I want to use this sweeper	3.0	2.0
I think the feedback is POINTLESS	1.5	4.0
The system is NOT going to change my behaviour.	2.0	3.0
I feel like the system will protect me from injury	3.5	2.0

Participants were generally interested in performing well and also sought to make a small to moderate improvement in the second round of cleaning. The average desire to clean ergonomically was 4.25 out of 5, with 5 corresponding to very well. On average, participants wished to make a 20% postural improvement. All participants saw improvement in their cleaning posture between rounds 1 and 2. The average improvement between rounds was 1.25 fewer mistakes and there was no significant difference between the experimental and control groups.

In addition to data, there were some interesting observations; multiple participants desired more instruction between cleanings on how they could improve. Since participants were not provided these instructions, they did not know how to clean more ergonomically and expressed confusion. Another observation was made regarding cleaning improvements and speed variation between the two rounds of cleaning. During the second round, all participants cleaned slower and made fewer mistakes. Participants in the experimental group appeared to be more aware of the LED light. This was interpreted as a consequence of participants making efforts towards correcting their wrist posture.

4 Discussion and Future Work

4.1 Discussion

The results of the study demonstrated that workers tended to well respond to real-time wrist feedback when cleaning a window. All participants (both experimental and control groups) saw improvement in their cleaning technique between the first and second rounds, while the experimental group with real-time feedback showed higher perceived system usefulness. In addition, as observed from our expert interviews, ergonomic instruction is critical in affecting behaviour change. Our user study further demonstrated the importance and impact of feedback and usage instruction. Based on participant feedback and observation, simple binary feedback was insufficient in fully informing users on how to make ergonomic improvements to their cleaning technique.

As explained before, the device used during the user study was not fully working; we used Wizard of Oz technique to emulate the design's proposed behaviour. This technique, however, proved valuable because it helped us clarify the contradiction between the initial user interview and the typical suggestion from the literature of design for behaviour change literature.

For future work, we plan to conduct a field study including actual hotel workers cleaning the mirrors or windows of a hotel room. For this, we are currently developing a fully functional interactive prototype that can serve the study as a stimulus (see Section 4.2). Different feedback methods could also be investigated, including instantaneous feedback vs. post session feedback, moving average feedback (how the cleaner is doing in comparison to their own average, their peers' average, etc.), higher or lower threshold level feedback, haptic feedback, only positive or neutral feedback, and only negative or neutral feedback. Furthermore, research should be conducted on the mental effects of receiving this type of feedback (e.g., mood, work satisfaction, stress, social effects). High job demand and low job control—two major characteristics of hotel house cleaning—can lead to psychological problems such as fatigue, anxiety, depression, exhaustion, sleep disruption, and physical illness (Karasek & Theorell, 1990; Sanne, Mykletun, Dahl, Moen, & Tell, 2005).

4.2 Improvement of Erglove prototype

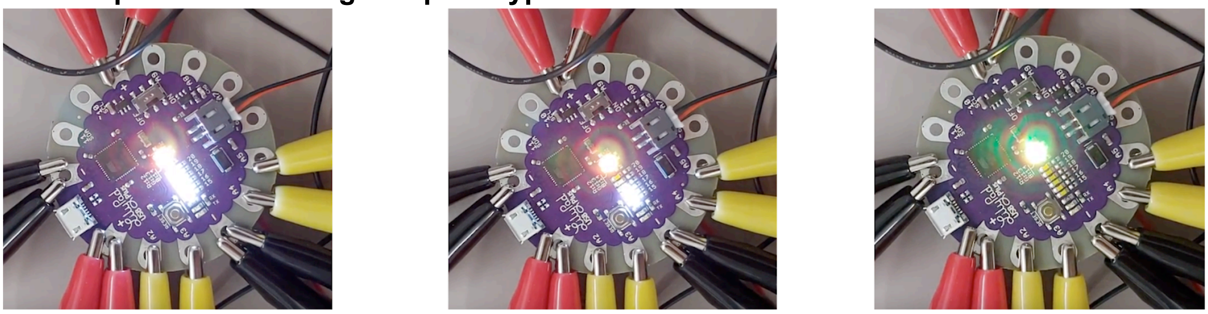

Figure 3. Photo of the real-time feedback bar-graph-like LED from fully flexed (left) to fully relaxed (right), and the long-term feedback colourful LED from red (left) to green (right).

Building on the insights gained from the user study, the concept of Erglove has been further improved and developed into a fully functional prototype. We selected Lilypad USB Plus for the prototype because it is sewable as well as waterproof. Visual feedback, via wrist mounted LED lights, was chosen for this system since most cleaners work alone in their own assigned room with no other people around. The system consists of four flex sensors which are attached to the inner side of an arthritis compression glove to measure four primary types of deflection (ulnar deviation, radial deviation, flexion, and extension), onboard LEDs as visual feedback, and alligator clips to connect all these parts.

Feedback is given according to real-time wrist deflection and the overall wrist risk potential. Real-time feedback is shown in the form of a bar-graph-like LED sequence indicating current flex (deflection) level (Figure 3). These real-time white bar graph lights would allow users to test different postures and figure out a better way to accomplish cleaning tasks. Long-term wrist risk potential is expressed through a coloured LED light, which turns from green to yellow and then red throughout the day if they repetitively clean using poor wrist posture (Figure 4).

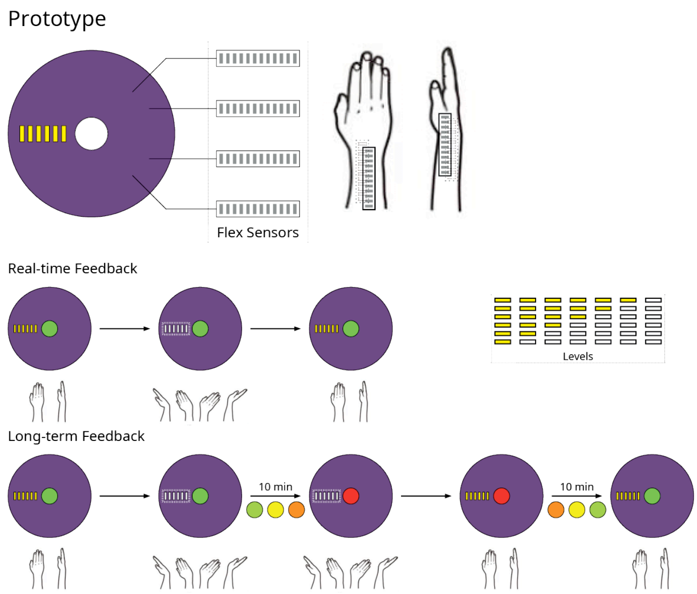

Figure 4. Illustration of Real-time and Long-term Feedbacks. Some resources used in the figure were adapted from (Loh & Muraki, 2014).

5 Conclusion

This paper revealed a new method for alerting hotel housecleaners to an ergonomic issue regarding their wrist postures, and developed a framework and a prototype for them to improve their form and technique, using immediate and long-term feedback. Results from our user study have demonstrated that the system design is functional. Erglove provides inspirations for products designed to change or influence behaviour, stressing the importance of real-time feedback.

The implications of this study likely extend beyond the specific application to wrist MSDs prevention for hotel housecleaners. Our user study was a behaviour intervention to a simple physical task. The results of our study may be applicable to a wide variety of everyday tasks.

Carefully implemented real time feedback could become a powerful tool in improving health across a variety of modalities. Our exploratory study tested one form of real time feedback and further iteration will lead to more effective and beneficial forms of feedback.

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