공학석사 학위논문

Development and Evaluation of a Novel Ergonomic Ambient Display for Rectifying Poor Sitting Postural Behaviors

-좌식 작업자의 근골격계 질환 유발 자세 저감을 위한 인간공학적 피드백 디스플레이의 개발 및 평가-

2017년 2월

서울대학교 대학원

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Abstract

Development and Evaluation of a Novel Ergonomic Ambient Display for Rectifying Poor Sitting Postural Behaviors

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Complete and accurate self-awareness of personal habitual behaviors can be a challenging task for modern day people. It is especially true when it comes to old habits, such as those of sitting postures. Awkward sitting postures, which are known to be a risk factor of work-related musculoskeletal disorders, are by and large habitual. Due to their habitual nature, seated workers find it difficult to detect the occurrences of awkward sitting postures and correct them in a timely fashion. A system which enhances a seated worker's awareness of working posture with little disturbance to computer task would greatly help reduce physical stresses associated with seated work tasks.

Several studies have developed systems that monitor a worker's sitting behavior in real time and provide feedback

to users when necessary; yet, few empirical studies were conducted to compare different display types and there is no consensus on which type of feedback display is the most suitable for daily use. As an effort towards developing an effective system for enabling awareness of sitting posture in an unobtrusive manner, this study developed a novel ergonomic ambient display based on the multiple resource model. The display used ambient light in the peripheral visual area to convey feedback information to computer users.

An empirical study was conducted to evaluate the ambient display in comparison with a typical pop-up display. The evaluation criteria were the effectiveness in rectifying poor sitting posture, the level of interference in the primary computer task, the detectability of feedback alarm during primary task, and user acceptance. A posture feedback system based on a sensor-chair was developed and the same feedback algorithm was implemented in each display. Both displays were found to cause changes in the occurrence of poor sitting position. The percentage of time of poor postures was similar in the ambient display and the pop-up display conditions. Also, the ambient display interfered computer task less than the pop-up display with lower mental workload. The results of subjective ratings showed that the ambient display was more visible during the computer tasks and was expected to contribute to posture correction more than the pop-up display.

The results of this study seems to support the fourth

dimension of the multiple resource model. Further studies for a long−term study of the ambient display and the development of adaptive ambient display are suggested. The findings from this study will be of great help to the engineers and designers, who are interested in using ambient display to develop an effective digital device to evoke changes in human behavior.

Keywords : **ambient display, feedback, sitting, smart chair, posture**
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Chapter 1. Introduction

1.1 Motivation

Many office workers using computers seem to perform their job tasks adopting awkward sitting postures instead of the ones recommended in the ergonomics literature. It occurs even when they are provided with an ergonomic workstation in the work place (Castellucci, H. I. et al. 2016; Epstein, R. et al. 2012). These behaviors of sitting in poor position seem habitual – once acquired, they are repeated and become a regular manner of behavior with little notice (Gerstacker, D. 2014). Such postural habit is problematic as working in awkward, stressful postures for prolonged duration are known as a risk factor for work-related musculoskeletal disorders (Harrison, D. D. et al 1999; Harcombe, H. et al. 2009; Taieb-Maimon, M. et al. 2012).

In order to address the problems of poor sitting postures, different intervention methods have been proposed. Several studies on the effects of education and training, and promoting self-monitoring have been investigated (Brisson, C., Montreuil, S., & Punnett, L. 1999; Gravina, N et atl. 2008; Robertson, M. et al 2009). While previous intervention methods have contributed to reducing poor sitting postures, they seem limited in that they did not consider the nature of habits.

Breaking a habit necessitates the prevention or reduction of the occurrences of habitual behavior over long durations before a new habit of not sitting in poor posture is formed (Jager, W. 2003). This requires constant monitoring on one's working posture and adjusting it when needed. Maintaining attention on one's own posture can be a difficult task to do when engaged in primary work task. Divided attention into more than one task lowers one's ability to be aware of the impulse and to inhibit the occurrence of habitual behavior, overcoming one's intention of the inhibition (Gardner, B. 2015). Hence, a system, which supports seated workers to be aware of their working postures, would greatly help reduce physical stresses associated with seated work tasks and may promote the formation of good sitting habits.

A real-time posture feedback system is a surrogate cognitive system of self-monitoring on seated working posture and notifies postural state information when needed. This technology helps online 'reflection-in-action' of users (Hermsen, S., Frost, J., Renes, R. J., and Kerkhof, P. 2016). Delegating monitoring task to the system allows users to concentrate on their work and reduces the potential risk of failures to notice and correct habitual poor sitting. Also, the feedback display may be associated with posture correction behavior and be a cue to form a new habit of unrisky positioning (Lally, P., Gardner, B. 2013).

A body of research on the real-time posture feedback system has focused on developing a posture recognition system with great accuracy (see Chapter.2 for detailed information). Meanwhile, little attention has been given to how feedback display should be designed for computer users, who have little cognitive resources left to detect the feedback.

Meanwhile, several researchers proposed that providing ambient information by changing the surrounding environment in a subtle way is unobtrusive and costs little attention to catch the information (J. Ham 2009; 2010; Müller, Heiko, et al. 2013). The ambient information which reflects user's behaviors has been successful at changing the behavior in various categories such as daily activity, energy savings, and computer usage time (Lin, James J., et al., 2006; Jafarinaimi, Nassim, et al., 2007; Nakajima, Tatsuo, et al.,2008; Ham, J., Midden, C., and Beute, F.,2009; Fortmann, Jutta, et al., 2013; Müller, Heiko, et al., 2013). There were similar attempts for postural correction, but empirical validation of them was absent (Daian, Ioana, et al 2007; Obermair, Christoph, et al.,2008). Moreover, the current ambient displays were not designed based on ergonomics basis.

Therefore, a new design for an ambient display needs to be explored based on ergonomics knowledge, guaranteeing the performances of both the rectification of risky postural behaviors and primary computer task.

1.2 Research Objectives

Research objectives of this study are established as follows. First, this study aims to develop a novel ergonomic ambient display for computer workers providing feedback on the current postural state to rectify their habitual poor postural behavior. Second, this study empirically validates the effectiveness of the display in comparison with the typical pop-up display (see Chapter 3 for detailed information of the typical pop-up display).

1.3 Overview of Dissertation

The rest of this article is structured in following manners; Chapter 2: Related Studies, Chapter 3: Design and Implementation of an Ergonomic Ambient Display, Chapter 4: Empirical Evaluation of an Ergonomic Ambient Display, Chapter 5: Discussion.

Before presenting detailed contents of a novel ergonomic ambient display, Chapter 2 investigates prior studies in related fields. In Chapter 3, the design and implementation of an ergonomic ambient display, PostureCloud, is described. In Chapter 4, empirical evaluation of the ambient display is presented. Finally, in Chapter 5 the summary of this study and future study is given.

Chapter 2. Related Studies

In this chapter, previous studies related to the development of an ergonomic posture feedback system are reviewed. This chapter begins with the multiple resource model and summarizes existing real-time feedback systems for sitting postures. Finally, it explains underlying visual information processing mechanism based on scientific findings.

2.1 The Multiple Resource Model

The multiple resource theory suggested by Navon and Gopher(1979) assumes performing a task involves using dividable sets of resources. According to the multiple resource theory, because each set of the resources has its capacity, multiple tasks requiring the same set of resource compete each other for the same resource. However, when each task uses the different set of resources, interference among the tasks do not occur.

Based on this idea, Wickens(1984) proposed the multiple resource model to explain the variation in the performance of time sharing multi-tasks. Figure 1 summarizes the multiple resource model. The model is composed of four dimensions, which are the stages of processing, the codes of processing, the modalities, and the visual channel.

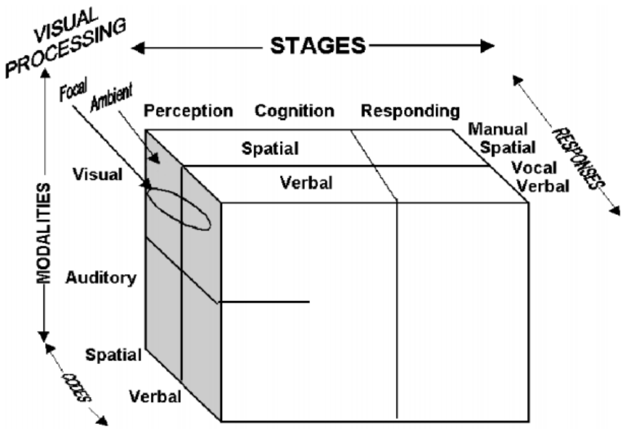


Figure 1. The 4-D multiple resource model (Wickens 1984)

According to the model, cognitive resource of each task is assigned to either of two levels of each dimension. In the stages of processing dimension, there are perception to cognition and responding stage. The codes of processing include spatial and verbal codes and they do not share the same resources when going through each stage of processing dimension. The modalities dimension indicates that visual and auditory perception consume different resources. Lastly, the fourth dimension, visual channel dimension is composed of focal and ambient vision, subdividing visual modality. Focal vision in this model indicates mainly foveal vision, which has high visual acuity and color perception. Ambient vision, on the other hand, refers to the peripheral vision which preserves orientation and movement perception. In the multiple resource model, ambient vision is regarded as the channel which needs almost no cognitive resource at all (Wickens 1984).

The multiple resource model explains that the more tasks are in the different levels of these dimensions, the less is competed for the resources to perform each task. For example, two visual tasks are more interfered with each other than the same tasks with different modalities such as one for visual and the other for auditory modality (Treisman and Davies 1973).

The strength of this model is continuously supported by the evidence from neurophysiological studies and has helped design decisions in many fields (Wickens, C. D. 2008). The model is especially useful in redesigning multitasking, where the cognitive load is overloaded by multitasking (Wickens, C. D. 2008). Designing secondary task is recommended to utilize remaining 'residual capacity' that is not used in the primary task.

Vibrotactile and peripheral visual display were thought to be the residual channel to convey additional information in information-rich environment, such as cockpit (Sarter, N. B. 2007). Vibrotactile display was found to be a useful display in vehicle, aviation, medical fields (Van Erp, J. B., and Van

Veen, H. A. H. C. 2001; Van Erp, J. B., Van Veen, H. A., Jansen, C., and Dobbins, T. 2005; Schoonmaker, R. E., and Cao, C. G. 2006). It was often combined with other displays as multimodal display and turned out to reduce reaction time of a task (Van Erp, J. B., and Van Veen, H. A. 2004). Peripheral visual display was also suggested as available alternative (Endsley and M. R., 1988; Nikolic, M. I., and Sarter, N. B. 2001). It was proposed to be useful in noticing the changes in the status of the highly automated system(Endsley and M. R., 1988). In 2001, Nikolic, M. I., and Sarter, N. B. installed the peripheral light display in peripheral vision and provided information on the mode transition by changing colors of the light. The use of peripheral light display had shorter mode transition time compared to the typical display and the display which changed the size of typical display to alarm mode transition.

2.2 Real-time Posture Feedback Displays for Sitting Position

Numerous studies have investigated several types of real–time posture feedback systems for sitting position. The studies developed sensing systems to recognize seated posture and displayed recognized results to users. Initial studies paid major attention to making reliable posture sensing system. As a result, there was a progress in the development of sensing systems such as wearables, camera–based computer vision, and sensor–attached chair (Kim, M. H., & Yoo, W. G. 2011; Park, S. Y., and Yoo, W. G. 2012; Gaffney, B. M., Maluf, K. S., and Davidson, B. S. 2016; Demmans, C., Subramanian, S., and Titus, J. 2007; Dunne, L. et. al 2007.; Breen, P. P., Nisar, A., and OLaighin, G. 2009; Haller, M et al. 2011; Lee, H. 2013; Sigurdsson & Austin 2008; Taieb–Maimon, Meirav, et al 2012; Zheng, Y., and Morrell, J. B. 2010). Enhanced sensing ability of the posture feedback system enabled researchers to study appropriate feedback display design by studying user's the interaction with it. While computer task is a primarily visual task, feedback displays adopted various modality types.

Among existing posture feedback display, visual modality was the most frequently used type. Graphical display was the most widely used to provide feedback information to users (Demmans, C., Subramanian, S., and Titus, J. 2007; Dunne, L. et. al 2007.; Breen, P. P., Nisar, A., and OLaighin, G. 2009; Haller, M et al. 2011; Lee, H. 2013). Some studies showed the photos of current sitting posture on a computer screen to help users to self-monitor one's posture (Sigurdsson & Austin 2008; Taieb-Maimon, Meirav, et al 2012). Other studies of EMG-based biofeedback visualized muscle activation level in an abstract form and showed the results on a computer screen (Kim, M. H., & Yoo, W. G. 2011; Park, S. Y., and Yoo, W. G. 2012; Gaffney, B. M., Maluf, K. S., and Davidson, B. S. 2016). Outside the screen, physical objects made movements to inform users of the occurrence of poor postures (Haller et al. 2011; Hong et al. 2015). In the perspective of visual channel dimension of multiple resource theory, the number of displays utilizing the foveal vision outnumbered the number of displays utilizing the ambient vision.

The second most frequently used display was vibrotactile display. Typical vibrotactile display was implemented by the tactors attached to a chair. Studies on the vibrotactile display found its significant effect on guiding sitting postures. Earlier studies found that the vibrotactile display promoted better posture guidance when combined with visual and auditory displays. (Van et al., 2004; Reed et al., 2007). Followed study by Zheng, Y., and Morrell, J. B. (2010) showed that single vibrotactile display could make participants maintain the reference posture when the feedback was secretly off.

Auditory feedback as unimodal display was rare to find. Yang, Y. S. et al. (2010) examined the effects of auditory feedback on sitting behaviors of wheelchair users. The result showed that there was a significant increase in pressure-relieving behaviors.

Ample evidence exists that the vision may be a better modality for posture feedback compared to vibrotactile modality in terms of its effectiveness on sitting behavior and the interference in primary task. In 2011, Haller et al. compared three different feedback displays – graphical, physical, and vibrotactile displays – on a sensor- based chair system, which computed the center of pressure (CoP) in classifying inadequate posture. When the inadequate posture occurred, feedback alarm was given to the participants and they were forced to have relaxing training sessions. The three displays showed similar effects on promoting target behavior, but vibrotactile display had the largest effect. On the other hand, vibrotactile display bothered computer task compared to the other visual displays; the physical display was the least interrupting display.

Further research of Zheng, Y., and Morrell, J. B. (2013) developed other designs of visual and vibrotactile displays. The displays were too implemented on a sensor-attached chair system. The visual display showed graphical icon on the screen and vibrotactile display used multiple tactors placed on the chair. The study showed that there was no significant difference in the effects on guiding sitting position. However, visual display was susceptible to inattentional blindness. Vibrotactile display was found to produce more cognitive loads and interrupted primary task more than the visual display did.

2.3 Visual Information Process of Human Visual System

2.3.1 Parallel processing of visual information

Human visual system is a representative parallel processing system. Psychophysical studies agree that there are separate independent channels for visual information such as color, movement, and depth (Livingstone, M. S., and Hubel, D. H. 1987).

Parallel pathways of the visual system enable the parallel processing of the different visual information (Nassi, J. J., and Callaway, E. M. 2009). Once visual information contained in the light is gathered by photoreceptors, the information is processed in the retina and transferred to central nervous system (Gazzaniga, M. S. 2004). In the retina, ganglion cells integrate the information from wired photoreceptors and each ganglion cell conveys its own information (Gazzaniga, M. S. 2004; Nassi, J. J., and Callaway, E. M. 2009). These ganglion cells are regarded to ‘underlie a unique channel of visual information’, which is the result of the first parallel process (Nassi, J. J., and Callaway, E. M. 2009) (See Figure 2).

Figure 2. The parallel process in the retina. Three different types of ganglion cells (red, yellow, blue circles) process different visual information (Nassi, J. J., and Callaway, E. M. 2009).

The second parallel processing occurs when each ganglion is projected in parallel from the retina to the lateral geniculate nucleus (LGN) of the thalamus (Nassi, J. J., and Callaway, E. M. 2009). Different types of ganglion cells projects to the assigned layers of the LGN. Then, visual information is transferred through synapse between the LGN and V1 in visual cortex. Information is converged and mixed to extract complex information such as orientation, direction and color selection (Nassi, J. J., and Callaway, E. M. 2009).

The third parallel processing takes place in dorsal and ventral streams in the extrastriate cortex (See Figure 3). Dorsal stream, or 'where pathway', starts from V1 and passes through MT and nearby area. Ventral stream, or ‘what pathway’ , also starts from V1 but goes to V4. Evidence shows that dorsal and ventral streams process relatively independent information (Nassi, J. J., and Callaway, E. M. 2009). The former is related to the function of location, locomotion, pursuit or tracking, target selection for arm and eye movements, object manipulation and visuospatial attention. The latter is responsible for color, contour selectivity, patterns, shapes, invariant representations of two-dimensional and three dimensional shapes and objects.

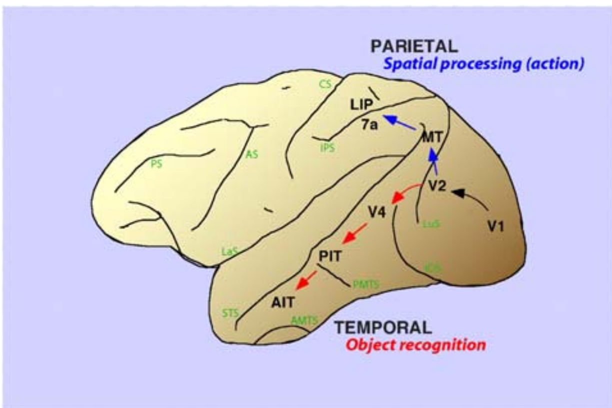


Figure 3. Where and what pathways in extrastriate cortex (Lehky, S. R., and Sereno, A. B. 2007)

2.3.2 Characteristics of central and peripheral vision

There is the difference in the visual perception of central and peripheral vision, and it is due to the asymmetric distribution of different types of photoreceptors in the retina. Central vision generally refers to the vision that is primarily engaged with cones in the center of the retina. Peripheral vision indicates the vision supported by rods, located in outside the center of the retina (See Figure 2).

Cones, which contributes to color perception, are concentrated around fovea (Gazzaniga, M. S. 2004). As the eccentricity becomes larger, its concentration level rapidly drops and so does color perception (Gazzaniga, M. S. 2004; Wickens, C. D. et al. 2015). A number of studies examined color vision in peripheral regions. Mullen, K. T., Sakurai, M., and Chu, W. (2005) found the decline in cone sensitivity across the visual periphery and became behaviorally absent by 25 to 30 degrees in the nasal field. In 2009, Hansen, T., Pracejus, L., and Gegenfurtner, K. R. proposed a broader range of color perceivable area to be 50 degrees. The study also found that the sensitivity of red-green perception is more susceptible to broader eccentricities to peripheral vision than the sensitivity of luminance is.

On the other hand, rods, which works for motion and luminance perception, show the increase in its population as it becomes distant from the parafoveal area (Gazzaniga, M. S. 2004). Due to this characteristic, motion perception remains relatively sensitive in larger eccentricity (Wickens, C. D., Hollands, J. G., Banbury, S., and Parasuraman, R. 2015). However, motion perception differs in monocular or binocular vision depending on the characteristics of stimuli (Lu, Z. L., and Sperling, G. 2001).

Chapter 3. Design and Implementation of a Novel Ergonomic Ambient Display

In Chapter 2., literature view on the related studies revealed that visual feedback display was validated to be effective and unobtrusive display for posture feedback display. However, existing displays were generally designed to use central vision. According to the multiple resource model, the two or more visual tasks sharing central(foveal) vision interrupt each other. Hence, it is hard to say all design alternatives for the optimal visual display for posture feedback for computer users are explored.

Inspired by the fourth dimension of the visual channel in the multiple resource model and the parallel processing of visual system, visual feedback using ambient vision (peripheral vision) was designed based on ergonomics and scientific knowledge.

In this chapter, the design of a novel ergonomic ambient display for a real-time posture feedback system is illustrated. To begin with, the overview of a sensor-chair based posture feedback system is described. Then, the design of a novel ambient display, named PostueCloud, are illustrated with underlying ergonomics and scientific knowledge.

3.1 Overview of Sensor-chair Based Posture Feedback System

A sensor−chair based posture feedback system was developed for this study. Figure 4 illustrates the system configuration map of the system. The system was composed of sensing sub−system, which was the sensor−based chair with posture classification algorithm, and the feedback display. This section will focus on describing sensing sub−system of the posture feedback system.

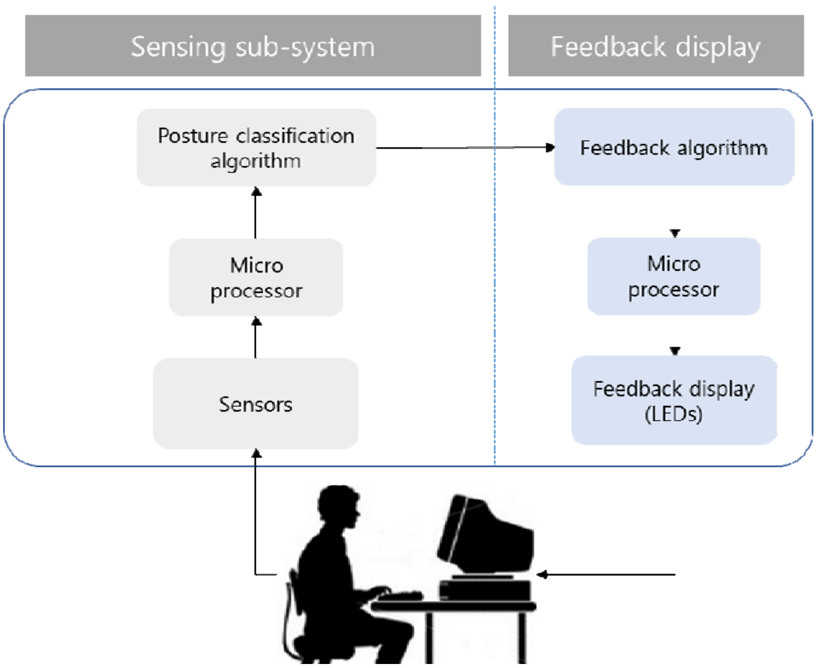


Figure 4. The system configuration map of the sensor−chair based feedback system

The sensing sub-system receives sensor data of sitting posture via distant and pressure sensors installed on a chair and classifies whether the current posture is poor or not. The chair is equipped with six force sensitive resistors (FSRs) and six infrared reflective sensors (see Figure 5). FSRs (3.8 cm × 3.8 cm square) are attached to the seat pan of the chair and measures pressure distribution of seated user. Infrared reflective sensors (Sharp, GP2Y0A41SK0F) are embedded in the seat back. The arrangement and location of the sensors on the chair were determined to accommodate 99% of Korean adult population based on Size Korea, a database of South Korean anthropometric data. The data sent by the twelve sensors are aggregated by Arduino and sent to PC. The primary control unit of the system is a PC running MATLBA, where posture classification algorithm classifies incoming data to poor posture or non-poor posture.

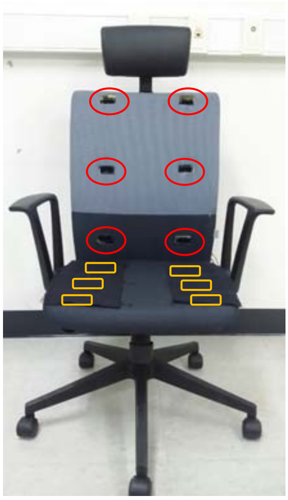


Figure 5. The sensor−based chair. Red circles are the infrared reflective sensors and yellow rectangles are the force sensitive resistors.

Posture classification algorithm was built based on the database collected by the same chair. The poor postures in the database were those ergonomics guidelines mentioned to be risky postures for musculoskeletal system. The guidelines were , ISO 9241−5 and OSHA[①], and NIOSH study by Schnorr, T. M. et al.(1991). Detailed description of the postures followed ISO 9241−5. Crossing legs were added to the list because some scientific literature raised the question of its safety (Lee, J 2011). The poor postures that the algorithm classifies were the partial list of postures in the database. The partial list included the forward inclination,

① https://www.osha.gov/SLTC/etools/computerworkstations/

lateral bending, trunk rotations, lumbar convex, slump posture, and the asymmetric gluteal pressure induced by crossing legs (See Figure 6). Postures that do not meet the criteria of poor postures are classified to be non-poor posture. The algorithm was verified to be 90.4% accuracy. The sensing subsystem was set to recognize a posture every second.

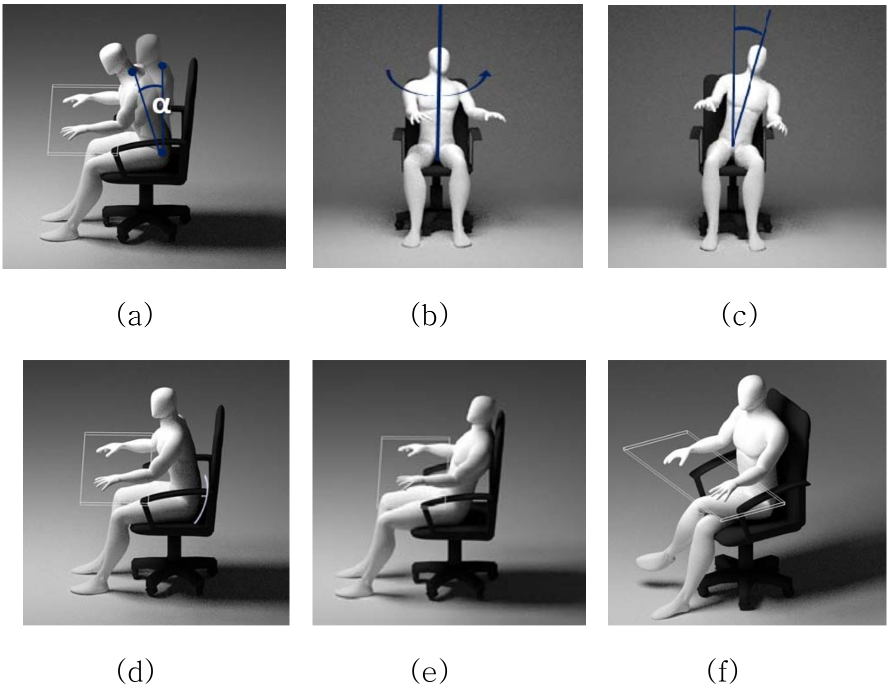


Figure 6. Poor postures classified by the posture classification algorithm: (a) forward inclination ($\alpha > 20^\circ$), (b) trunk rotation (leftward and rightward), (c) lateral flexion (leftward and rightward) (d) lumbar convex due to absence of lumbar support, (e) slump posture, (f) crossing legs (leftward and rightward)

3.2 Design of a Novel Ergonomic Ambient Display

3.2.1 Design Problems

A feedback display of a posture feedback system helps users rectify poor positions by alarming the occurrence of poor postures. The feedback displays designed for seated computer workers would provide feedback on sitting postures to the users who are actively engaged in computer tasks. In this context, the main interest of its design would be delivering feedback information with little disturbance to primary computer tasks.

The design of the feedback display has two main design problems. One is that the display should minimally interfere in the primary computer tasks. The interference in the computer tasks of this study is defined to be the degradation of the computer task performance and mental workload to perform the computer task while using the display. Another problem is that the users should find it easy to detect the feedback from the display while paying attention to the work.

3.2.2. Design Solution

As the design solution for the design problems, the display utilizing ambient vision was selected. According to the multiple resource model, ambient vision does not share the same resources with foveal vision. The model would predict the display presented in ambient vision would result in little competition with the computer work for cognitive resources because the computer work is primarily visual task and depends on foveal vison.

In this study, the ambient display utilizing ambient vision was developed based on the ergonomics and scientific knowledge. The display employed ambient light and aimed to design the light in efficient and effective way, suitable for ambient vision. The feedback alarm of the poor postures was displayed using two alternately flashing lights. The feedback displays for the non-poor postures did not flash but changed the colors of lights proportionally to the accumulated time of the non-poor postures.

Three postural states were mapped in this design. The states were poor posture, non-poor posture, and the maintenance of non-poor sitting posture. The maintenance of non-poor sitting posture state was adopted to encourage users to maintain non-poor posture states after the feedback alarm of poor postures was off (Spiegler, M.D. 2015).

Three hues were used to represent each posture state. Hue is effective means to represent categorical information of objects or discrete states (Wickens, C. D. et al. 2015).

For certain categorical information, some hues gained well-defined semantics; red for warning, amber for caution, white for advisory information (Pew, R. W. 1984). Therefore, red, white, and white with warmer temperature were selected as hues for the poor and the non-poor posture, and the maintenance of non-poor sitting posture, respectively.

Although red is assigned to deliver warning message when the poor posture occurs, peripheral vision may need extra help to notice the feedback alarm due to its degraded color perception (Virsu, V., and Rovamo, J. 1979). In order to complement such weakness, alternately flashing lights were used to create motion perception. Motion is often used to present something important which users would later glance or fixate at (Wickens, C. D. et al. 2015).

Creating motion perception is possible by changing locations of simple point lights (Saygin, A. P. et al. 2004). Two or more stimuli being alternately on and off produce the first-order motion perception, which is available in monocular vision (Lu, Z. L., and Sperling, G. 2001). The use of flashing lights to produce the first-order motion perception seemed justifiable because rods in the peripheral vision are sensitive to both luminance and motion, as mentioned in Chapter 2. Furthermore, it met the human factors design principles of redundancy gain (Wickens, C. D.

et al. 2015). As the result, as the feedback alarm display for poor posture the two red lights alternately flashing next to each other were determined. Flashing was not employed to provide the feedback for non-poor postures because it was not urgent information to be noticed.

The final design of ambient display was the shape of the cloud and the Moon (See Figure 7). Two led lights (DFR0106) were installed in the Moon and cloud-shaped objects. The lights were connected to the posture sensing sub-system and were controlled by MATLAB. When a user sat in a poor sitting position, the cloud and the Moon alternately flashed in red lights. The flashing rate was set to 2 flashings per second based on a pilot study. When the user changed posture from the poor posture state to the non-poor one, PostureCloud emitted white light. As the non-poor posture state maintained, color temperature of white light gradually became warmer temperature.

The feedback algorithm was developed for the ambient display based on the design (Appendix A). The algorithm counted the consecutive occurrence of non-poor postures. Three levels of positive feedback for the non-poor postures were set to increase the color temperature of the ambient light. As the non-poor posture state continued, the color of the display turned to warmer temperature. Once poor-posture occurred, the count for the non-poor postures was set back to zero. The threshold for the poor posture was set to two seconds to eliminate false alarms when the user was in the middle of changing posture. Duration longer than two seconds was regarded as indicating a posture rather than a transition of posture.

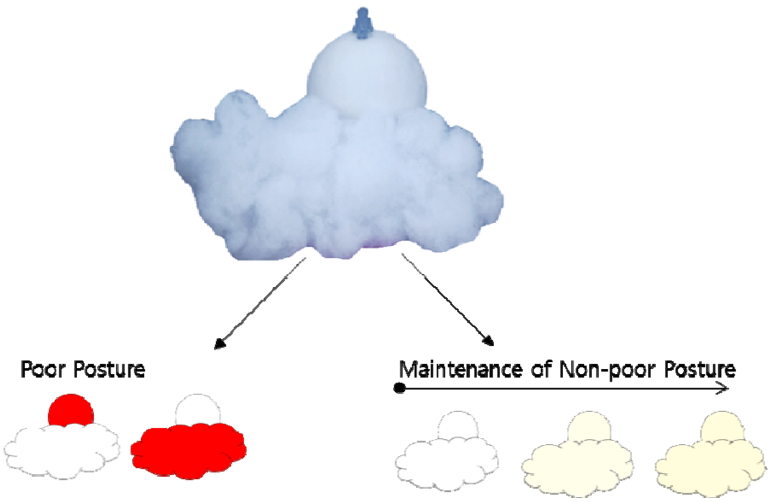


Figure 7. Interface design of the ambient display

Chapter 4. Empirical Evaluation

This chapter explains an empirical study was conducted to demonstrate the effectiveness and usability of the ambient display compared to a typical pop-up display (Dunne, L., Walsh, P., Smyth, B., & Caulfield, B. 2007; Haller, M et al. 2011; Zheng, Y., and Morrell, J. B. 2013). First, the detailed explanation on the experiment for this study is presented. Then, experiment results are shown.

4.1 Experiment

4.1.1 Participants

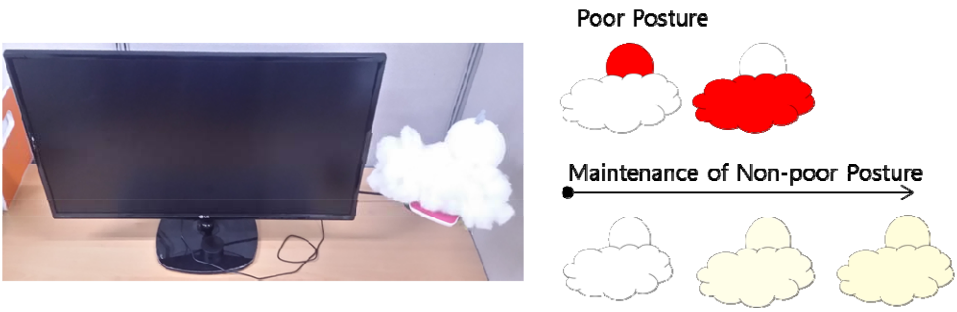
Twenty participants were recruited for the experiment (10 males and 10 females; mean age 25.3 and range of 20 to 31 years). All the participants had normal color vision and had no difficulty in performing computer tasks.

All participants gave their informed consent for inclusion in the study before participation. Subject recruitment procedures and experimental protocols employed in this study were approved by the Seoul National University Institutional Review Board (SNUIRB, IRB Approval No. 1701/003-15)

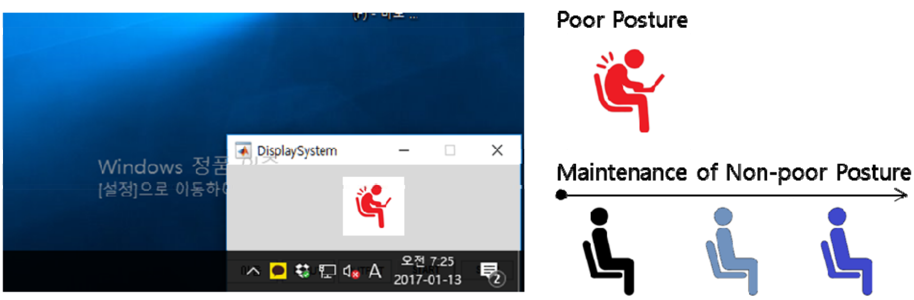
4.1.2 Independent Variables

The independent variables of this study were the display type and the computer task type. The display type was in the three levels of the no-display, the ambient display, the pop-up display conditions. Figures 8 and 9 show the design and the location of the two displays. The pop-up display was designed to represent typical pop-up alarm design of previous studies. Its size was set to that of a typical Windows notification. The size of graphics inside the notification window was the same as that of the icons in the taskbar of Windows 10. The graphics inside the notification window changed as the posture states changed. When the participant was in the poor position, a red icon of poor sitting position appeared. If not, an icon of upright posture was on the screen.

In the no-display condition, participants did not use any feedback display during the computers task. In the pop-up display condition, they received feedback on the current posture from the pop-up display on the computer screen. In the ambient display condition, they received feedback on the current posture from the ambient display placed next to the computer screen.



(a)



(b)

Figure 8. Interface of the ambient display and the pop−up display: (a) the ambient display (b) the pop−up display

The computer type had two levels of the simple and complex tasks. In the simple task, the participants transcribed three-digit numbers, shown on the left side of the computer screen, on the right side of the screen by typing (i.e. 111 to 111). In the complex task, they subtracted a one-digit number from a three-digit number ten times consecutively. The subtraction problems were shown on the left side of the screen. The subtracted numbers were typed on the right side of the screen. The subtracted numbers had to be typed in Korean, not in the form of Arabian numbers (i.e. Korean(Arabian numbers); 구십오(95), 구십(90), 팔십오(85)).

4.1.3 Dependent Variables

During the experiment, the occurrence rate of poor postures, performance of computer tasks, and subjective ratings of mental workload, user acceptance, and perceived detectability of feedback alarm were collected.

In this study, the occurrence rate of poor postures was defined to be the percentage of time of poor postures, which was determined using Eq. (1). $N_{poor\ posture}$ was the number of frames of poor postures and Nt_{otal} indicated a total number of frames.

$$\text{The occurrence of poor postures (\%)} = \frac{N_{poor\ posture}}{N_{total}} * 100 \quad (1)$$

The performance of the computer tasks was analyzed in two aspects, the speed and error rate. In the simple task, the speed was defined as the total number of typed three digit numbers in ten minutes. In the complex task, the speed indicated the number of typed answers in ten minutes.

The mental workload of the computer task while using each feedback display was measured by the NASA−TLX questionnaire (Appendix B). Each subscale was measured in the 7−point Likert scale.

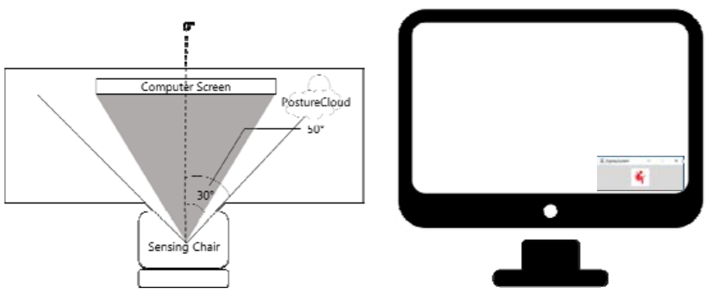
User acceptance toward each feedback display was measured by UTAUT (Unified Theory of Acceptance and Use of Technology) questionnaire (Venkatesh, V., & Zhang, X. 2010) (Appendix C). Among the eight constructs of UTAUT questionnaire, six constructs were selected for this study. The selected constructs were performance expectancy on posture correction, effort expectancy, attitude toward using technology, social influence, anxiety, and behavioral intention. A 7−point Likert scale was used to subjective ratings for the subscales of each construct. Note that user acceptance was considered because acceptance was the important factor to warrant the constant use of a device long enough to change a habit (Hermsen, S., Frost, J., Renes, R. J., and Kerkhof, P. 2016).

The detectability of feedback alarm during computer work was rated by a subjective rating in 7-point Likert scale (Appendix D). Additionally, there was a short interview on each display.

4.1.4 Experiment Setup

For the experiment, an LG LED monitor screen (634 X 381 X71 mm) was used for computer task and pop-up display. On the office desk, the screen was about 550 mm distant from users. The computer screen was in near peripheral vison, where color perception is relatively intact (Mullen, K. T., Sakurai, M., and Chu, W. 2005).

The ambient display was placed on the right side next to the screen, within 50 degrees of horizontal eccentricity. The height was set to user' s eye level. The pop-up display appeared on the bottom right on the screen.



(a) (b)

Figure 9. Location of the ambient display and the pop-up display: (a) the ambient display (b) the pop-up Display (rectangle)

4.1.5 Experiment Procedure

All participants were instructed to perform the computer tasks for 20 minutes in the three display conditions. Total experiment time was about 60 minutes. Overall experiment procedure was summarized in Figure 10.

First, all participants had a training session and became acquainted with the two displays. When participants let the researcher know they practiced enough to use the displays, experiment phase started.

In experiment phase, all participants were first in the no-display conditionprior to the other two display conditions. The two displays were presented in a randomized order. Subjective ratings on the mental workload and user acceptance were conducted after each display condition. When the participants were exposed to all display conditions, they reported the perceived detectability of feedback alarm of the two displays and participated in a short post-experiment interview.

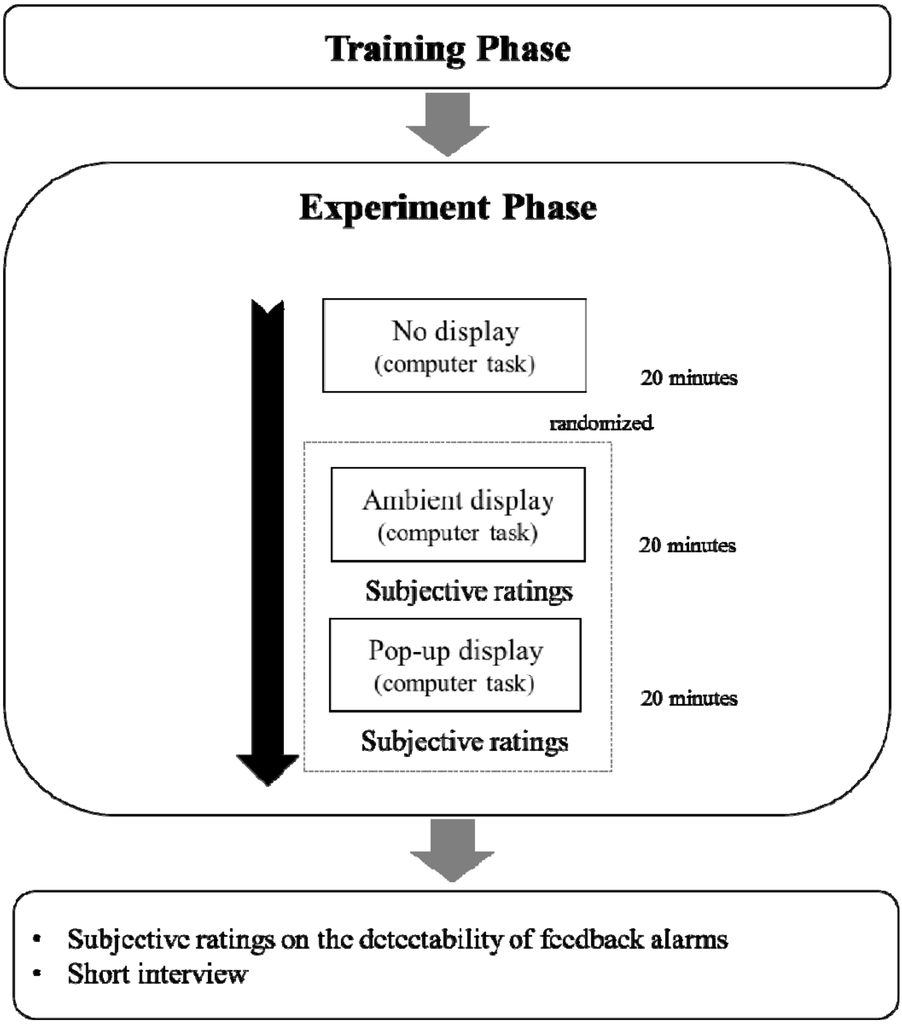


Figure 10. Experiment procedure

4.1.6 Hypotheses and analysis

Hypotheses of this study were established as follows;

- H1: The percentage of time of the poor postures is lower in the ambient display condition than the pop-up display condition.
- H2: The speed of a computer task is faster in the ambient display condition than in the pop-up display condition.
- H3: The error rate of a computer task is lower in the ambient display condition than in the pop-up display condition.
- H4: The NASA-TLX score is lower in the ambient display condition than in the pop-up display condition.
- H5: The score of each construct of UTAUT questionnaire is higher in the ambient display condition than the pop-up display condition.
- H6: The subjective rating on the detectability of feedback alarm of the ambient display is higher than that of the pop-up display.

In order to test the hypotheses, two-way RM ANOVA of the effects of display condition and computer task type on the percentage of time of poor postures was conducted. Paired-samples t-tests were used to compare the effects of display conditions in each computer task type. One−way RM ANOVAs of the effects of display condition on the performance of computer tasks, NASA−TLX score, UTAUT score, and the detectability of feedback alarm during computer task were done. Post−hoc tests using the Bonferroni corrections were used for each one−way RM ANOVA. Finally, qualitative analysis on short interview was done.

4.2 Results

4.2.1 The Percentage of Time of Poor Postures

Two−way Repeated Measure ANOVA was conducted for the main effects of display condition and computer task type on the percentage of time of poor postures. The assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhous−Geissler estimates of sphericity.

Table 1. Means and standard deviations on the percentage of time of poor postures

Display condition	Computer task	n	The percentage of time of poor posture (%) M	SD
No	Simple	20	45.26	44.10
No	Complex	20	55.77	40.00
Ambient	Simple	20	5.21	5.70
Ambient	Complex	20	3.20	7.45
Pop-up	Simple	20	10.83	13.10
Pop-up	Complex	20	4.45	9.71

No = no-display condition, Ambient = ambient display condition, Pop-up = pop-up display condition

Table 2. Two-way RM ANOVA of the percentage of time of poor postures

Effect	The percentage of time of poor posture (%)		
	F	p	η^2_p
Display condition (D)	26.341	<.001	.581
Computer task type (C)	.104	.750	.005
D*C	4.402	<.05	.188

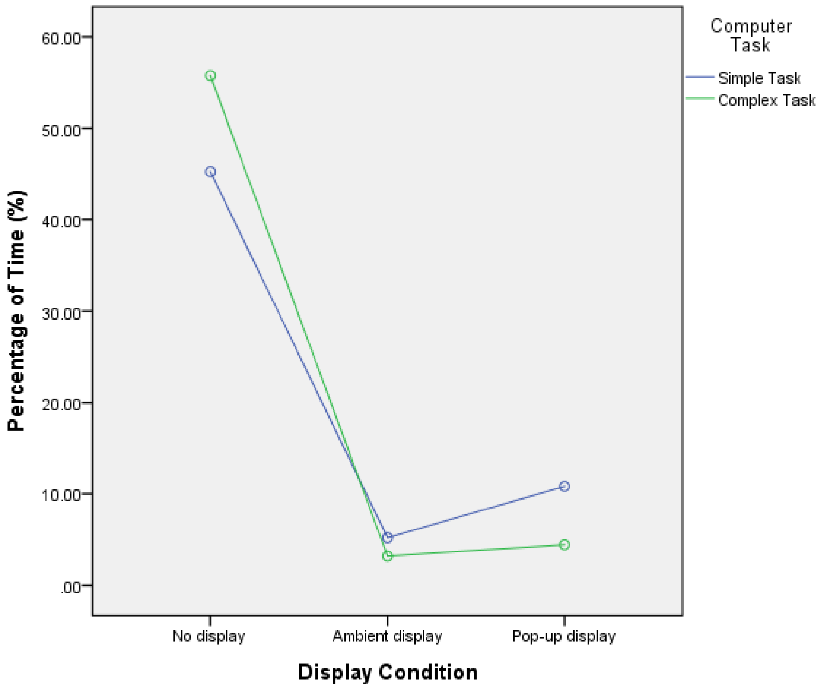


Figure 11. Mean percentage of time of poor postures

As shown in Figure 11, the percentage of time of poor postures was over 40% in the no−display condition, but it reduced to less than 10% in both display condition. Table 2 shows the two−way RM ANOVA results for the percentage of time of poor posture. There was the main effect of display condition on the percentage of time among display conditions (Wilks' Lambda=0.370, $F(1,19)=24.53$, $p<0.001$). Also, there was interaction between display condition and computer task type. In the no−display condition, poor postures occurred more often in the complex task. However, in the ambient and pop−up display condition, poor postures occurred more often in the simple task than in the complex task.

Paired-samples t-tests revealed that there was no significant difference of the percentage of time of poor postures between computer task types in the same display condition.

In the simple task, the results of paired-samples t-tests showed that there was significant difference in the percentage of time of poor postures between the no-display condition (M=45.26, SD=44.10) and the ambient display condition (M=5.21, SD=5.70) as well as the no-display condition (M=45.26, SD=44.10) and the pop-up display condition (M=10.83, SD=13.10); $t(19)=4.105$, $p<0.01$; $t(19)=3.385$, $p<0.05$, respectively. Also, in the simple task condition, there was partially significant difference in the percentage of time of poor postures between the ambient condition (M=5.20, SD=5.70) and pop-up display conditions (M=10.83, SD=13.10); $t(19)= -1.8948$, $p=0.07$.

Meanwhile, in the complex task, the results of paired-samples t-tests showed that there was significant difference in the percentage of time of poor postures between the no-display condition (M=55.77, SD=40.00) and the ambient display condition (M=3.20, SD=7.45) as well as the no-display condition (M=55.77, SD=40.00) and the pop-up display condition (M=5.45, SD=9.71); t(19)= 6.058, p<0.001; t(19)=6.049, p<0.001, respectively. However, no significant difference of the percentage of time of poor postures between the ambient display condition and the pop-up display condition was found.

4.2.2 The Performance on Computer Tasks

One-way Repeated Measure ANOVA was conducted for the main effects of display condition on the performance of each computer task type. The assumption of sphericity had been violated for error rate in simple task, and for speed in the complex task. The degrees of freedom were corrected using Greenhous-Geisser estimates of sphericity in both task types.

Table 3. Means and standard deviation on the speed and the error rates of computer tasks

Display condition	n	Speed		Error rate (%)	
		M	SD	M	SD
Simple task					
No	20	240.94	50.00	.60	1.23
Ambient	20	243.35	64.36	2.27	5.60
Pop−up	20	235.53	65.22	5.52	14.64
Complex task					
No	20	152.18	38.95	2.14	2.29
Ambient	20	184.59	52.75	1.15	1.47
Pop−up	20	178.71	37.87	2.15	2.55

No = no−display condition, Ambient = ambient display condition, Pop−up = pop−up display condition

Table 4. One−way RM ANOVA of the speed and the error rate of the simple task

Effect	Speed			Error rate		
	F	p	η^2_p	F	p	η^2_p
Display condition	.541	.587	.033	1.232	.292	.071

Table 5. One−way RM ANOVA for the speed and the error rate of the complex task

Effect	Speed			Error rate		
	F	p	η^2_p	F	p	η^2_p
Display condition	17.825	$<.01$	.527	2.167	.141	.119

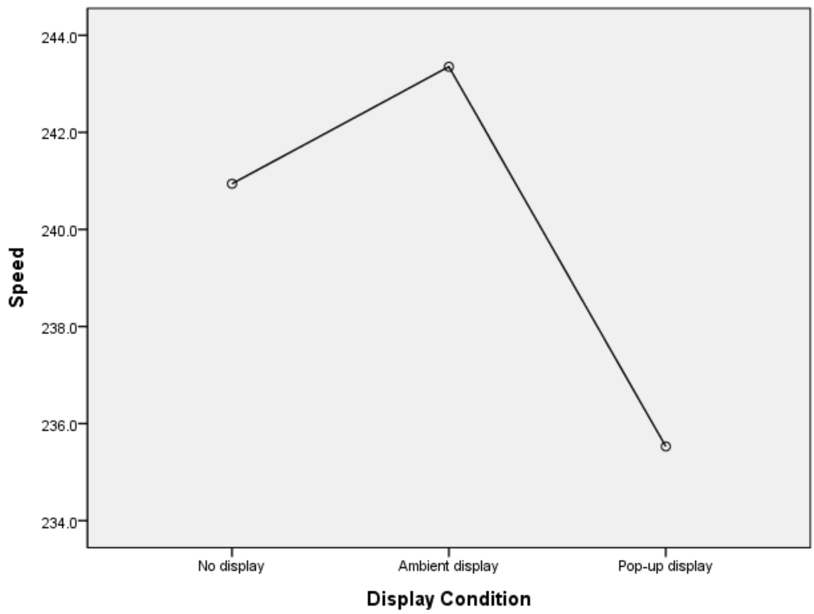


Figure 12. Mean speed of the simple task

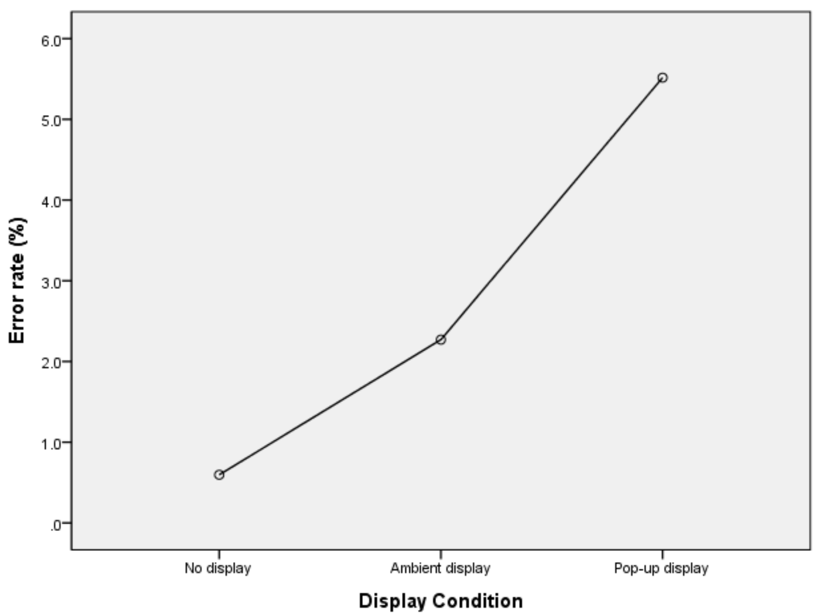


Figure 13. Mean error rate of the simple task

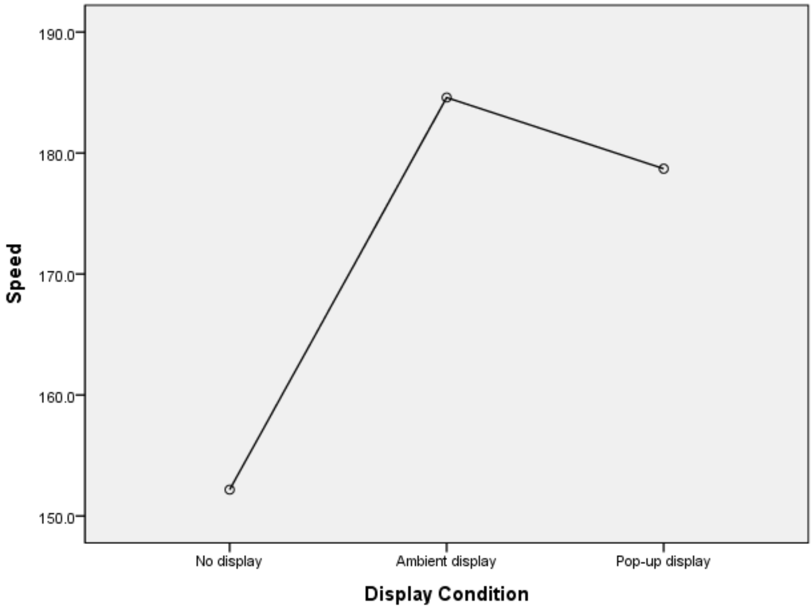


Figure 14. Mean speed of the complex task

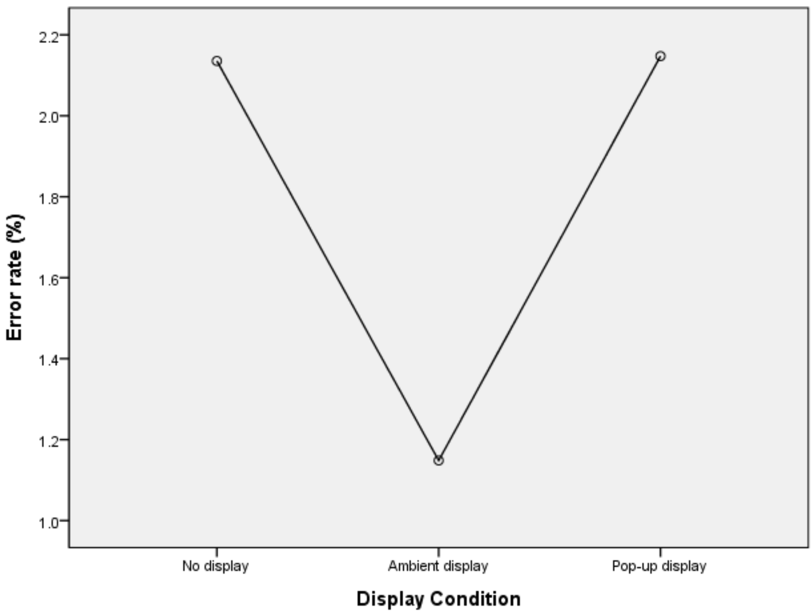


Figure 15. Mean error rate of the complex task

In the simple task, in comparison with the speed of the no−display condition (M=240.94, SD=50.00), that of the ambient display condition (M=243.35, SD=64.36) was faster, whereas that of the pop−up display condition (M=235.53, SD=65.22) was slower.

In comparison with the error rate of the no−display condition (M=0.60, SD=1.23) in the simple task, the error rate of the pop−up display condition was the second highest (M=5.51, SD=14.64) and that of the ambient display condition was the lowest (M=2.27, SD=5.23). However, as shown in Table 4, one−way RM ANOVA results showed that there is no main effect of display condition on the speed and the error rate.

In the complex task, there was the main effect of display condition on the speed (Wilks' Lambda=.418, F (2,32) = 17.825, $p<0.01$). Pairwise comparison results (α=0.05) showed that the speed in the ambient display (M=184.59, SD=12.80) and the pop−up display condition (M=178.71, SD=9.18) were significantly faster than that in the no−display condition (M=151.18, SD=9.45) ($p<0.01$, $p<0.01$, respectively). However, pairwise comparison results (α=0.05) showed that there was no significant difference in the speed between the ambient and pop−up display conditions.

The error rate of the complex task was the highest in the pop−up display condition (M=2.15, SD=0.62), the second highest in the no−display condition (M=2.14, SD=0.56), the lowest in the ambient display condition (M=1.15, SD=0.36). One−way RM ANOVA results showed that there was the partial main effect of display condition on the error rate (Wilks' Lambda=.418, $F(2,32) = 2.167$, $p = 0.131$). Pairwise comparison results ($\alpha = 0.05$) showed that there was significant difference between the pop−up display and the ambient display ($p < 0.05$), but no significant difference was found between the ambient display and the no−display condition as well as the pop−up display and the no−display condition.

4.2.3 NASA-TLX Score

One-way Repeated Measure ANOVA of display condition on NASA-TLX score was conducted. The assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhous-Geisser estimates of sphericity.

NASA-TLX score was lower in the ambient display condition (M=33.09, SD=22.33) than in the pop-up display condition (M=38.83, SD=21.91), but there was no significant effect of display condition on NASA-TLX score except for the subscale of effort (Table 7). The subscale of effort was significantly lower in the ambient display condition (M=4.94, SD=5.09) compared to the pop-up display condition (M=7.84, SD=7.40) (Wilks' Lambda=.107, $F\ (1,17) = 4.59$, $p < 0.05$). However, participants reported that it was more physically hard and they were in a hurry and frustrated to do the computer work while using the ambient display (M=7.10, SD=9.34, M= 4.75, SD=7.85; M=3.70, SD=6.72, M=1.98, SD=7.85; M=8.15, SD=10.13, M-7.53, SD=8.64).

Table 6. Means and standard deviations on NASA-TLX score

Measure	n	NASA-TLX	
		M	SD
Ambient display			
Mental	18	5.68	5.47
Physical	18	7.10	9.34
Temporal	18	3.70	6.72
Performance	18	3.52	3.33
Effort	18	4.94	5.09
Frustration	18	8.15	10.13
Total	18	33.09	22.33
Pop-up display			
Mental	18	8.28	6.76
Physical	18	4.75	7.85
Temporal	18	1.98	3.40
Performance	18	8.46	9.08
Effort	18	7.84	7.40
Frustration	18	7.53	8.64
Total	18	38.83	21.91

Table 7. One-way RM ANOVA of NASA-TLX score

Effect	NASA-TLX		
	F	p	η^2_p
Mental	.650	.431	.096
Physical	1.803	.197	.083
Temporal	1.539	.232	.109
Performance	2.090	.166	.213
Effort	4.589	<.05	.106
Frustration	2.022	.173	.002
Total	.041	.843	.037

4.2.4 The Detectability of Feedback alarm during Computer Tasks

One-way Repeated Measure ANOVA was performed to compare the difference in the detectability between the two displays. The assumption of sphericity had been violated, therefore degrees of freedom were corrected using Greenhous-Geisser estimates of sphericity.

Table 8. One-way RM ANOVA of the detectability of feedback alarm

Effect	Detectability of Feedback alarm (7-point-Likert scale)		
	F	P	η^2_p
Display condition	5.272	<.05	0.237

Participants reported feedback alarm from the ambient display was more detectable (M=4.06, SD=1.66) than that from the pop-up display (M=2.50, SD=2.09). In Table 8, the significant difference of the detectability between the two displays were found (Wilks' Lambda=.763, $F(1,17)=5.272$, $p<0.05$).

4.2.5 UTAUT score

One-way Repeated Measure ANOVA was used to compare the scores of constructs of UTAUT questionnaire depending on display condition.

The results show that there was the main effect of display condition on the construct of the performance expectancy on posture correction (Wilks' Lambda=.0.18, $F(1,19) = 13.578$, $p < 0.05$). Participants expected that they would rectify poor postures more often and quicker when using the ambient display (M=5.13, SD=1.02) compared to when using the pop-up display (M=3.95, SD=1.73). Moreover, there was a tendency that the score of attitude toward using the ambient display was higher than that of the pop-up display (p=.079).

Table 9. Means and standard deviations on UTAUT score

Measure	n	Acceptance (7-point-Likert scale) M	SD
The ambient display			
Performance expectancy on posture correction	20	5.13	1.02
Effort expectancy to use the display	20	5.51	1.06
Attitude toward using technology	20	4.99	1.44
Social influence	20	4.40	1.29
Anxiety	20	3.48	1.93
Behavioral intention to use the display	20	4.15	1.60
The pop-up display			
Performance expectancy on posture correction	20	3.95	1.73
Effort expectancy to use the display	20	5.49	1.07
Attitude toward using technology	20	4.01	1.72
Social influence	20	4.30	1.52
Anxiety	20	3.53	1.58
Behavioral intention to use the display	20	3.55	1.82

Table 10. One-way RM ANOVA of UTAUT score

Measure	Acceptance (7-point-Likert scale)		
	F	*P*	η^2_p
Performance expectancy on posture correction	13.578	<.05	.417
Effort expectancy to use the display	.003	.956	.000
Attitude toward using technology	3.450	.079	.154
Social influence	.137	.716	.007
Anxiety	.013	.911	.001
Behavioral intention to use the display	1.385	.254	.068

4.2.6 Short Interview

Table 11 summarizes short interview on the two displays.

Table 11. Summary of interview: (a) the ambient display

The Ambient display (PostureCloud)	• "The feedback was visible without glance" • "I could recognize feedback while paying little attention to the display" • "It was disturbing because I could see the feedback continuously even when I did not want to" • "Light was too bright for me" or "Light was too dim for me" • "When I was focused on the computer tasks, it was difficult to detect feedback alarm"

Table 11. Summary of interview: (b) the pop-up display

The Pop-up display	• "Graphics of postures made me easier to detect and understand the feedback" • "It was easy to detect because it was on the computer screen, where I was doing the computer tasks." • "When my gaze was on the left corner of the computer screen, the display was less visible than the ambient display" • "It was too small to detect while doing the computer tasks" • "When I was focused on the computer tasks, it was difficult to detect feedback alarm"

Chapter 5. Discussion

5.1 Summary and discussion

This study set out with the aim of developing and assessing the effectiveness of an ergonomically designed ambient display on rectifying poor postures. It was to evaluate if displaying motion with light to peripheral vison can change the postural behavior of the user who is in the middle of computer work with little disturbance. The evaluation of the ambient display was conducted in terms of posture rectifying effect and the level of disturbance on the computer task in comparison with typical pop-up display. Our findings provide evidence that the ambient display was the better alternative to the pop-up display to provide postural feedback information in the computer work context.

Rectification of Poor Sitting Posture

Overall, the results showed that the ambient display was similar to the pop-up display in terms of rectifying poor postures (Table 2 and Figure 11). In Figure 11, there was a dramatic drop in the percentage of time of poor postures when participants used either of two feedback displays compared to the no-display condition. The results of paired-samples t-tests showed that there were significant differences in the percentage of time of poor postures between the no-display conditions and the other two display conditions in all computer task types. This results suggests that the presence of feedback display lowers the occurrence of poor postures.

However, the percentage of time of poor postures between the ambient display and the pop-up display condition was similar. Paired-samples t-test of the two display conditions in the simple task revealed that there was a tendency of lower percentage of time of poor postures in the ambient display condition than the pop-up display condition. In the complex task, paired-samples t-test of the two display conditions showed no significant difference in the percentage of time of poor postures between the displays.

As shown in Table 2, the results of one-way RM ANOVA revealed the interaction between the computer task type and the display conditions on the percentage of time of poor postures. In no-display condition, the percentage of time of poor postures was higher in the complex task than in the simple task. However, the order was reversed in the ambient and pop-up display conditions (see Figure 11) The interaction seems to be due to the computer task types as confounding variable. During the simple task, the participants needed to continuously gaze at the numbers on the left side of the screen. During the complex task, they had to look at both left and right side of the screen to check the problems and write down the answers. Because the displays were placed on the right, it would have been easier for the participants to detect feedback from the displays during the complex task compared to the simple task.

The detectability of feedback alarm during computer task

Quantitative and qualitative analyses found that the feedback alarm of poor postures from the ambient display was easier to detect while the participants were engaged in the computer tasks. The results of the detectability of feedback alarm in Table 8 indicated that the ambient display was significantly more detectable of its feedback alarm in comparison with the pop-up display.

Similar results regarding the detectability were found from the interview. There were some opinions on the pop-up display such as "When my gaze was on the left corner of the computer screen, the display was less visible than the ambient display "and "It was too small to detect while doing the computer tasks." On the contrary, the feedback alarm from the ambient display was comparatively easier to notice during computer work; some participants mentioned that “The feedback was visible without glance” and “I could recognize feedback while paying little attention to the display.”

Performance of the computer tasks and its mental workload

The results of the computer task performance indicated that the ambient display had its advantage of less interference in the computer task compared to the pop-up display. The error rate of the complex task was significantly lower in the ambient display condition compared to the pop-up display condition. In the simple task, the speed among display conditions were not significantly different from each other. This result suggests the ambient display was more practically useful in performing complex computer tasks.

As for the speed of the simple task, no effect of display condition on the speed was found. Similarly, in the complex task, there was no significant difference in the speed between the ambient and pop-up display conditions. However, the speed of the complex task was significantly faster in the ambient and pop-up display conditions compared to the no-display condition.

While it is not entirely clear why the speed of the complex task was faster in the ambient and pop-up display condition compared to in the no-display condition, some possible explanations are provided: one possibility is the increased attentional cost - without a display, the participants may have monitored themselves constantly. With the help of the feedback display the cost may have been lowered in the ambient and pop-up display condition. Another possibility is a possible learning effect due to the experiment procedure shown in Figure 10. The no-display condition was presented prior to the display conditions; however, it is difficult to think that there was a large learning effect since the experiment tasks represented common skills (typing and subtracting) rather than unusual tasks.

Moreover, in the ambient display condition mental workload in performing the computer tasks was low. NASA-TLX score of 33.09 indicated that performing the computer tasks while using the ambient display was not hard task for users (Grier, R. A. 2015). Although there was no significant difference in NASA-TLX scores between the ambient display (M=33.09, SD=22.33) and pop-up display (M=38.83, SD=21.91), the subscale of effort to perform computer work was significantly lower in the ambient display condition (M=4.94, SD=5.09) than in the pop-up display condition (M=7.84, SD=7.04) (see Table 6). Considering higher detectability of feedback alarm of the ambient display in comparison with the pop-up display, it is encouraging because mental workload for the computer tasks was low despite the saliency of feedback alarm of the ambient display.

Acceptance toward Technology

Among six constructs of acceptance questionnaire, the ambient display showed advantages in the performance expectancy on posture correction and attitude toward using the display. As shown in Table 10, the participants felt that using the ambient display would be more effective to change their postural behavior than the pop-up display. The average performance expectancy score was 5.13 out of 7 points and was significantly higher than the score of pop-up display, which was 3.95.

Attitude toward using the ambient display (M=4.99, SD=1.44) was more positive compared to pop-up display (M=4.01, SD=1.72). This suggests that the participants preferred the ambient display. According to the Unified Theory of Acceptance and Use of Technology, the more acceptable the technology is, the more likely it is used (Akbar, F. 2013). Therefore, the results for the two constructs, performance expectancy and attitude, of acceptance lend a support to the advantages of the ambient display.

Insights from the qualitative analysis

Qualitative analysis on the interview provided some insights of the ambient display regarding user' s divided attention. One insight was that continuously salient ambient display may not be desirable. It was found that the constant visibility of the ambient display during the computer tasks was disturbing to some participants. The multiple resource theory assumes that the ambient vision costs almost no attention (Wickens 1984). However, the presence of the display in ambient vision may cost some degree of attention due to the mere presence effect. The studies on the mere presence effect of mobile phone suggested the presence of mobile phone itself captures attention even when it is not used and lowers the performance of a primary task (Przybylski, A. K., and Weinstein, N. 2013; Thornton, B. et al.; Ito, M., and Kawahara, J. I. 2016). Similar effects may occur when the ambient display is continuously visible to computer workers.

Another insight is that former salient display may turn not be not salient enough for users if they have little attention left for ambient vision. Some participants raised the problem of difficulty to notice the two displays when they were focused on the computer tasks. This problem of attention tunneling was also suggested in the study of Yin Zheng and Morrell (2013). When there is high perceptual workload, inattentional blindness tends to occur (Cartwright-Finch, U., and Lavie, N. 2007; Simons, D. J., and Jensen, M. S. 2009) Also, when a user is highly focused on the computer work, or captured by other sources, attention tunneling may hinder the user from noticing postural feedback display immediately. This attention tunneling is resolvable by increasing saliency (Wickens, C. D., and Alexander, A. L. 2009).

5.2 Theoretical Implications

The multiple resource model suggested by Wickens and C.D. (2008) has been validated to be a useful model for designing interfaces for multitasking environment and applied to the development of various interfaces. Some studies were conducted on adopting ambient vision in information-rich environment as an alternative for other modalities. For example, Nikolic, M. I., and Sarter, N. B. (2001) adopted ambient light display in the cockpit as media to represent automated system' s status. However, its use was limited to providing primary-task relevant information, not solely for the secondary task. To author' s knowledge, few empirical support exists for the visual channel of the multiple resource model.

The importance of this study in relation to the multiple resource model is that it provides a piece of empirical evidence to the fourth dimension of the multiple resource model, that is, the division between the foveal and ambient visual channels. In this study, the feedback for posture correction was displayed in ambient vision by the ambient display, while computer tasks primarily required foveal vision. In performing the computer tasks while using the feedback displays, the ambient display utilizing ambient vision turned out to be superior to the display using foveal vision. Quantitative and qualitative analysis on the dual-task of computer task and following the feedback to rectify the poor postures suggests the fourth dimension of multiple resource model is valid in predicting the performance of two for more tasks. Consequently, it is plausible to apply ambient visual display in the multitasking context to convey an information of a task independent to the primary task.

5.3 Future Study Directions

Some future directions are provided here. First, future research will have to look into a long−term effect of the use of the ambient display on habit change. Long−term study on office workers may be done to examine the effect of the ambient display on breaking a habit of poor postures.

Second, future study on the effect of ambient display in the broader range of age will have to be done. The performance of the tasks requiring divided attention is known to be affected by ages (Wright, R. E. 1981; Ponds, R. W. et al. 1988; Brouwer, W. H. et al. 1991). Because using ambient display during computer work is a type of multitasking, the performance of both tasks may be mediated by age (Wood, J. 2006; Voorveld, H. A., and van der Goot, M. 2013; Kievit, R. A. 2014).

Lastly, future study will continue to explore the better design of the ambient display. This study on the ambient display revealed that it may have the risks of the mere presence effect and the failure to be noticed if little attentional resource is left to users. The solution would be the context−based adaptive ambient system. In other words, the future display should adjust its saliency adaptively to user's state. The display may recognize the current user's workload and delayed posture correction after the onset of feedback alarm. When the workload is low and there is the absence of poor postures, the display would be in low saliency mode. However, as postural correction is delayed due to attention tunneling, the display system would increment its saliency so that users could notice its alarm. The level of saliency of each scenario would be able to be adjusted by user’ s preference.

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Appendix A Feedback Algorithm

Input: Classification algorithm output (P=0 is non-poor posture, P=1 is poor posture)

```
1. Let C0 be the number of consecutive non-poor posture and C1 be the number of consecutive poor posture
2. If P=0
3.      C0=C0+1 / Count the number of consecutive non-poor posture
4.      C1=0
5.      If C0<10
6.              Turn on level 1 positive feedback (white)
7.      If C0>=10 and C0<20
8.      Turn on level 2 positive feedback (increase temperature of white)
9.      If C0>=20
10.     Turn on level 3 positive feedback (increase temperature of white)
11. If P=1
12.     C0=0
13.     C1=C1+1 / Count the number of consecutive poor posture
14.     If C1>=2
15.             Turn on negative feedback (flashing)
16. Else
17.     Continue prior positive feedback
```

Appendix B The NASA-TLX Questionnaire

Please indicate the degree of workload you felt to conduct the computer tasks while using the display.

1. (Mental Demand) How much mental and perceptual activity was required to do the computer tasks while using the display?

Very low						Very high
1	2	3	4	5	6	7

2. (Physical Demand) How much physical activity was required to do the computer tasks while using the display?

Very low						Very high
1	2	3	4	5	6	7

3. (Temporal Demand) How much time pressure did you feel to do the computer tasks while using the display?

Very low						Very high
1	2	3	4	5	6	7

4. (Overall Performance) How unsuccessful were you in performing the computer tasks while using the display?

Very successful						Very unsuccessful
1	2	3	4	5	6	7

5. (Frustration Level) How irritated, stressed and annoyed versus content, relaxed and complacent did you feel during the computer tasks while using the display?

Very low						Very high
1	2	3	4	5	6	7

6. (Effort) How hard did you have to work (mentally and physically) to accomplish your level of the task performance while using the display?

Very low						Very high
1	2	3	4	5	6	7

Appendix C UTAUT Questionnaire

Please indicate the degree to which you agree or disagree with below statements.

Performance Expectancy on Posture Correction

[PE1] Using the display helps me to rectify my poor sitting posture.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[PE2] Using the display helps me to rectify my poor sitting posture more often.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[PE3] Using the display helps me to rectify my poor sitting posture more quickly.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Effort Expectancy

[EE1] Learning to use the display is easy for me.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[EE2] It is clear to understand the feedback of the display.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[EE3] It is easy to use the display.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Attitude toward Using Technology

[AUT1] The way the display works is a good idea.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[ATT2] The way the display works is interesting.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[ATT3] I enjoy the way the display works.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[ATT4] I like the way the display works.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Social Influence

[SI1] People who are important to me think I should use the display.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[SI2] People who I care about think I should use the display.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Anxiety

[ANX1] I fell nervous in using the display during computer work.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[ANX2] The display is somehow intimidating to use.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

[ANX3] I could make mistakes in computer task due to the display.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Behavioral Intention to Use the Display

[BI] I intend to use the display in the near future.

Strongly Disagree						Strongly agree
1	2	3	4	5	6	7

Appendix D The Questionnaire on the Detectability of Feedback alarm

Please indicate the degree of the perceived detectability of feedback alarm of each display during computer work.

1. How easy was to detect feedback alarm of the ambient display?

Very easy						Very hard
1	2	3	4	5	6	7

2. How easy was to detect feedback alarm of the pop-up display?

Very easy						Very hard
1	2	3	4	5	6	7

*The score was later reversed for the analysis.

국문초록

반복적으로 부적절한 앉은 자세를 장시간 취하는 행동은 근골격계 질환을 유발하는 요인 중에 하나로 알려져 있다. 하지만 장시간 앉아 컴퓨터 작업을 하는 사무직 종사자의 경우 컴퓨터 작업을 하면서 자신의 자세를 지속적으로 감시하는 데 어려움이 있다. 이에 따라 앉은 자세를 실시간으로 감지하고 이에 대한 피드백을 제공하는 시스템을 개발하는 연구들이 진행되었으나 어떠한 피드백 제공 방식이 컴퓨터 작업자에게 적합한지에 대한 연구는 아직 미흡하다.

본 연구는 디자인 문제를 컴퓨터 작업 방해를 최소화하고 컴퓨터 작업 중에도 알아차리기 쉬운 디스플레이 개발로 정의하고 주변시를 활용하는 피드백 디스플레이를 인간공학적 원리에 따라 개발했다. 또한 해당 디스플레이와 기존 연구들의 디자인을 차용한 디스플레이와의 비교 연구를 통해 주변시를 활용한 디스플레이의 자세 변화 효과와 컴퓨터 작업 방해 정도, 인지 부하 정도, 피드백 감지의 용이성, 디스플레이에 대한 수용성 등을 실험적으로 검증하였다.

본 연구에서 개발한 디스플레이는 디스플레이가 없는 조건에 비하여 부적절한 앉은 자세의 비율을 유의미하게 낮추었으며 기존 디스플레이와 유사한 효과를 보였다. 또한 컴퓨터 작업의 방해 정도, 인지 부하, 피드백 감지의 용이성, 수용성 측면에서 기존 디스플레이와 비교하여 유의미하게 우수한 결과를 얻었다.

본 연구의 의의는 인간공학 이론에 근거하여 사용자의 작업을 덜 방해하는 효과적인 디스플레이 개발에 성공했다는 점이다. 향후 보다 다양한 연령대에서의 디스플레이 효과 검증 연구와 해당 디스플레이를 사용한 사무직 종사자의 자세 습관 교정 효과 연구, 그리고 사용자의 상태에 맞추어 피드백 제공 방식을 조정하는 adaptive ambient display에 대한 연구 등이 이루어질 수 있을 것이다.

주요어 : 피드백, 디스플레이, 앉은 자세, 주변시, 컴퓨터 작업자
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