A Comparison of Menu Configurations and Pointing Devices for use with Wearable Computers while Mobile and Stationary

Joanne E. Zucco,
Bruce H. Thomas
Wearable Computer Laboratory
Computer and Information Science
University of South Australia
+61 8 830 23447, +61 8 830 23464
{Jo.Zucco,Bruce.Thomas}@unisa.edu.au

Karen Grimmer-Somers
Center of Allied Health
School of Health Sciences
University of South Australia
+61 8 830 22769
Karen.Grimmer-Somers@unisa.edu.au

Andy Cockburn
Computer Science
University of Canterbury
Christchurch, New Zealand
+64 3 364 2987
andy@cosc.canterbury.ac.nz

Abstract

Wearable computing technology offers tremendous possibilities to support users in performing a variety of tasks that go beyond traditional desk-based computer interaction. Recent wearable systems share many capabilities with desk-based workstations, but often differ in the way user input is acquired and processed. This paper investigates four commercially available pointing devices and four on-screen menu configurations to assess which are most appropriate for performing menu selection tasks using a wearable computer system in a mobile and stationary scenario. We conducted a controlled user study to compare a trackball, touchpad, gyroscopic mouse and Twiddler2 in combination with pull-down, linear (fixed and pop-up) and pie pop-up menus. Our results indicate that pie pop-up menus are the most effective menu structure irrespective of the input device used, and that the trackball device outperforms the remaining devices in terms of speed and error rate.

1. Introduction

Effective input devices and interfaces are essential to the usability of a wearable computing system and can have a large impact on its adoption. Since many of the traditional input devices cannot be used effectively in a wearable scenario, many wearable computing prototypes employ their own particular input mechanisms or adopt variations of well-known input paradigms prevalent in desk-based computer interaction. Likewise, in the absence of a standardized menu system (or interaction model) for wearable computers, menu systems designed specifically for wearable computers typically require a dedicated input device for interaction. Without access to specialized software (or hardware), many wearable systems make use of commercially available products such as Microsoft Windows. Although we may find that optimal menu interaction models for wearable computers may differ from those used in desktop computers, we believe that it is important to evaluate currently available pointing devices and menu interaction models in a wearable context. Currently, Microsoft Windows is the predominant interaction model for commercial wearable computer systems.

Research into effective input devices [1, 2] and user interfaces [3-5] for wearable computers is critical to the usability and adoption of a wearable system. In previous studies [6], we compared a trackball, a gyroscopic mouse and a Twiddler2 performing cursor movement and selection tasks for use with wearable computers while the user was stationary. We also investigated drag-and-drop tasks [7] in mobile and stationary contexts, where a wrist-mounted touchpad was used in addition to the three aforementioned devices. This paper reports on an extension of this work by exploring the effectiveness of the pointing devices and menu structures for wearable computers, while users were mobile and stationary. While several other researchers have explored and incorporated the use of menus in their wearable computer interface [8, 9], this study examines the effectiveness of different menu configurations in a wearable context.

The *aims* of our study were to determine the following, based on task completion time and error rate:

1. Whether there is a difference between the pointing devices while walking and stationary, and if so, establish a ranking of effectiveness.
2. Whether a particular pointing device is better suited to a particular movement condition.
3. Whether there is a difference between the different menu structures while walking and stationary, and if so, establish a ranking of effectiveness.

1550-4816/09 $26.00 © 2009 IEEE
DOI 10.1109/ISWC.2009.15

IEEE computer society

4. Whether a particular menu structure is better suited to a particular movement condition.
5. Whether a particular pointing device is better suited to a particular menu structure.
6. Determine whether users have a preference of pointing device and menu structure.

In doing so, we hope to be able to provide valuable insights into the usability of pointing devices and menu structures within a wearable context. We seek to produce findings that will guide users and designers in selecting a pointing device and menu structure that is well suited and appropriate for the task(s). Our results reveal that the choice of pointing device and menu structure have a significant impact on both completion time and error rate, where the trackball device and the pie pop-up menu showed the best overall results, irrespective of movement conditions. Users' comments also indicate that both are among the most-preferred interaction mechanisms.

2. Related work

The following section explores relevant knowledge in the usability of pointing devices for wearable computers, menu selection techniques and/or configurations, and the use of menus in a wearable context.

2.1. Wearable computer input device studies

Chamberlain and Kalawsky [2] compared a touch screen stylus with an off-table mouse (a trackball, as in our study) while performing target selection tasks. Their results showed that users were faster and had a lower workload when using the touch screen stylus, while the mouse resulted in fewer errors.

Wither and Höllerer [10] investigated handheld input devices and head orientation for controlling a 3D virtual cursor from a distance. Their results indicated that the finger trackball and head orientation with two buttons performed similarly. Both were reported to be considerably faster than the Twiddler2 and head orientation alone with one button. Users preferred the finger trackball.

2.2. Menu user studies

Mitchell and Shneiderman [11] compared dynamic and static menus, and found that initially dynamic menus were significantly slower than static menus. However, practice reduced the performance difference to a non-significant level.

A comparison of selection times for walking and pull-down menus found that the time required to access items from a pull-down menu was less than that required for a walking menu [12]. This study showed that while the use of impenetrable borders and expanding target areas facilitated menu selection, the impenetrable borders were the most effective in decreasing menu selection time.

Callahan et al. [13] evaluated pie and linear pop-up menu configurations of eight items using an optical mouse. Pie menus were found to perform better than linear menus on all occasions.

Ahlström et al. [14] conducted a study evaluating two menu selection techniques known as Jumping Menus and force enhanced menus using traditional pull-down menus as a benchmark. The authors found that Jumping Menus produced the most errors. The force enhanced menu enabled users to complete their tasks faster than the Jumping Menu, which was faster than the standard menu.

Cockburn and Gin [15] evaluated a menu selection technique to improve the selection of items in cascading menus. Compared with traditional menus, enlarged activation area menus allowed cascade items to be selected up to 29% faster.

2.3. Menu interaction in a wearable context

The Vu-man2 [8] is a wearable computer designed and manufactured by Carnegie Mellon University. It provides users with campus navigation, displaying information on a Private Eye head mounted display. Controlled by a cursor, the interface allows the user to select items from a map or pull-down menu.

The following work develops and uses dedicated input devices to interact with the menus presented on-screen. Cross et al. [9] implemented a pie-menu interface to support minimal interaction for the military undertaking urban operations. The system included an x4 wearable computer, a Micro-Optical display and a three button input device (up, down and select). Blasko and Feiner [3, 4] present a menu interface prototyped by a TouchPad device. The device is separated into four strips, each which correspond to a finger of the hand. Four top-level menus are presented at the bottom of the screen. The on-screen menu is designed to be used specifically with the device, whereby each strip corresponds to a menu. KeyMenu [5] is a pop-up hierarchical menu which uses the Twiddler device to provide a one-to-one mapping between buttons on the keyboard and the menu items presented on the screen. The menu is displayed in a grid of three columns and four rows. Pressing a key on the Twiddler activates the corresponding menu item.

3. Experimental design

Design: A 5×4×2 repeated-measures design.
Equipment: The ***pointing devices*** evaluated in this study represented the fundamental commercial devices currently available. A detailed description of the devices can be found in Zucco et al. [7]. The devices comprised a trackball (1.9cm diameter; 1 pixel per 10 degrees; www.3g-tw.com), a gyroscopic mouse (70 pixels per degree inclination; www.gyration.com), a Twiddler2 mouse – trackpoint joystick (145 pixels per second when applying maximum force to the trackpoint; www.handykey.com), and a touchpad (15 pixels per inch; www.cirque.com) (see Figures 1–4). In order to obtain the pixel measurement, we set the pointer speed to zero and turned acceleration off (Windows XP). We used a table top mouse as a benchmark for comparison with traditional user interaction techniques.

The ***menu structures*** are comprised of pull down (fixed at top), linear (fixed at bottom), linear pop-up, and pie pop-up (see Figures 5-8). Each menu consisted of two levels: eight top-level menu items and sub-menus containing eight menu items for each top level item. A sub-menu was activated by clicking on its parent item. In addition, the linear pop-up menu allowed a sub-menu to be activated by keeping the cursor over the item's region for a short period of time (we used 333ms [15]). The target menu item was selected by clicking on the desired item. Selecting a top-level item on the linear fixed menu resulted in the sub-menu replacing the top-level menu (an additional menu item was added to the end of the menu to allow users to return to the top-level menu if necessary). The pull down and linear fixed menus require travel time to position the cursor over the menu. Although this may be seen to disadvantage the menus, we chose not to alter the standard operation of the menus. We are interested in evaluating the normal operation of the menus. In this study, we define an error as an incorrect menu selection, a click outside of the menu structure/hierarchy or an accidental collapse of a sub-menu once open. The menu item the participant was required to select was identified by highlighting it green, thus removing the cognitive load associated with reading the menu labels to find the correct target. This practice has been used in other menu studies [14, 15].

Menu sizes are modeled on menus from Microsoft Windows XP. The top and sub-level menu items of the pull down menu (Figure 5) occupied 70 and 140 pixels in width respectively, whereas the linear fixed menu (Figure 6) was 70 pixels wide at both levels. The linear pop-up menu (Figure 7) was 140 pixels wide at both levels, and the radius of the pie pop-up menu (Figure 8) was 140 pixels.

Mobility: Participants were evaluated while standing (stationary) and walking.

Outcome measures: We are interested in the dependent measures of task time and error rate.

Study organization: To reduce any potential learning effect, each participant performed three blocks of tasks presented in random order. One block consisted of nine tasks, one for each combination of device and mobility (the table-top mouse cannot be used while walking). Each task within a block used a different pointing device and mobility allocated in random order. 20 menus were presented to the participant: four menu structures repeated five times in random order. The menu item to be selected was presented in random order. Participants rested for at least two minutes after completing each block. A group represented an entire training or experimental session for a participant, with the constraint that there was an equal number of participants who operated each pointing device as the first device of a session.


Figure 1. Trackball

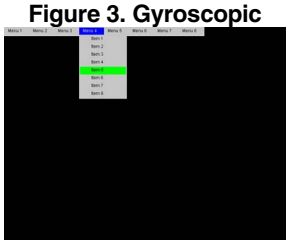


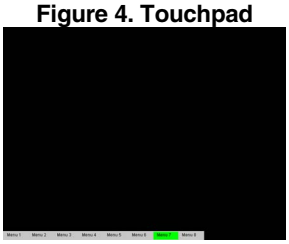
Figure 2. Twiddler2

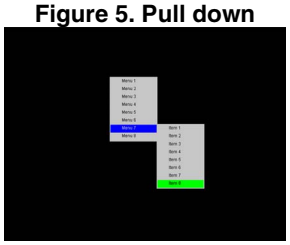

Figure 3. Gyroscopic

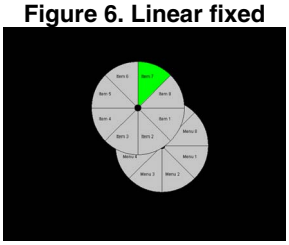


Figure 4. Touchpad


Figure 5. Pull down


Figure 6. Linear fixed


Figure 7. Linear pop up


Figure 8. Pie pop up

3.1. Hardware, software and data collection

The experiment was conducted on a Toshiba Portégé M200 Laptop running the Microsoft Windows XP operating system. The output device was a Sony Glasstron see-through head-mounted display with resolution 800×600 SVGA. The laptop, wireless receiver for the gyroscopic mouse and power converter for the HMD, were attached to a small backpack and operated with battery power.

An application written in Java coordinated the entire session of tasks. To display a menu, participants were required to select a green start button placed in the center of the screen (size 48x48 pixels). Once the start button had been selected, it was removed, and a menu placed on the screen. Fixed menus were immediately shown on-screen, whereas pop-up menus appeared only after users clicked on the screen.

The data recorded included total task and menu selection times in nanoseconds (up to 1ms resolution) and the number of errors. Menu selection was timed starting with a click on the green start button and ended when a menu item in a sub-menu was selected. The application continued to present the menu until it was successfully completed.

3.2. Procedure and participant population

Results were gathered from 20 convenience-sampled computer-literate students and staff at the University of South Australia. Of these, there were 17 males and 3 females; 2 left handed and 18 right handed; mean age 29.05 years.

All participants undertook a training session (approx. 40 mins) and the experimental session (approx. 90 mins). Participants were instructed to use the devices with their dominant hand and to select the menu items as quickly and accurately as possible. Eighteen stations were positioned along the walls of a quiet, straight hallway, designated by paper posters on the wall. The application prompted the participants to walk to the next indicated station, which provided instructions regarding which pointing device to use and the mobility required for the task. If undertaking the task while stationary, participants would remain at the station. If walking, participants were asked to walk at a normal pace 15 meters along the corridor and back, repeatedly, while completing the task.

Analysis: Unless otherwise stated, we used Analysis of Variance (ANOVA) models to determine significance. Trials with errors were left in the dataset for analysis. Mauchly's test was used to determine whether sphericity had been violated (degrees of freedom were corrected using Greenhouse-Geisser estimates where sphericity had been violated). Statistical significance was set at 0.05. A Bonferroni correction was employed for all *post hoc* analysis.

4. Results

4.1. Pointing device time

Table 1 summarizes the timing and error measurements obtained from our study, partitioned by mobility (walking, standing, and both) and ordered by mean time. Across all devices (excluding the table-top mouse), mobility conditions and participants, the mean total time for one task was 141.23 seconds (SD 42.77). Our analysis revealed that there was no effect of group number on mean total time per task ($F(3.27,310.90) = 1.95$, $p>0.05$). A significant effect on mean total time per task is found for the following:

- Block ($F(1.61,255.75) = 15.22$, $p<0.05$).
- Participant ($F(3.73,85.83) = 2.86$, $p<0.05$).
- Mobility ($F(1.00,19.00) = 136.59$, $p<0.05$).
- Device ($F(1.69,32.05) = 56.37$, $p<0.05$).

Furthermore, there was a significant interaction between mobility and device ($F(1.67,31.74) = 58.17$, $p<0.05$), where the standing position allowed consistent, faster completion times than the walking position.

We also found that differences between all pairs of devices were significant, except between the touchpad and Twiddler2 device. The devices can therefore be ordered, with the trackball being fastest, followed by the touchpad and Twiddler2 which were both faster than the gyroscopic mouse. The table-top mouse was provided as a benchmark and was 39% faster than the trackball.

The mean total time for one task while standing was 109.11 seconds. While standing, device had a significant effect on mean time per task ($F(3,57) = 9.40$, $p<0.05$), in particular we found a significant difference between the trackball and gyroscopic mouse, and trackball and Twiddler2. While walking, the mean total time for one task was 173.35 seconds. Device significantly effects mean time per task ($F(1.57, 29.81) = 60.79$, $p<0.05$). A pair-wise comparison indicated a significant difference between devices for all but the touchpad and Twiddler2.

4.2. Pointing device error rate

Across all devices (excluding the table top mouse), mobility conditions and participants, the mean errors for one task was 4.86 (SD 5.42). No effect of group number on mean error per task was found ($F(3.30,313.71) = 2.13$, $p>0.05$). Block repetition

identified a significant effect ($F(1.57,249.42) = 5.93$, $p<0.05$), but only between blocks 1 and 3 ($p<0.05$). Likewise, further analysis evaluating block effect on time per task revealed a significance between blocks 1 and 2 ($p<0.05$). Although the training session was used to overcome a training effect, a learning effect is evident. Further work in the way of a longitudinal study needs to be done in order to explore the findings.

Differences between participants were also identified ($F(5.44, 125.17) = 2.76$, $p<0.05$). Mobility ($F(1.00, 19.00) = 35.17$, $p<0.05$), device ($F(1.38,26.16) = 17.61$, $p<0.05$) and interactions between both ($F(1.57, 29.81) = 10.08$, $p<0.05$) all proved significant. In particular, the trackball performed best, followed by the touchpad and Twiddler2 (no significant differences could be identified for this pair); the gyroscopic mouse suffered from the highest error rate.

Variations observed between devices obtained from the standing condition proved significant ($F(1.67, 31.73) = 10.01$, $p<0.05$), in particular when comparing the gyroscopic mouse with the trackball and the Twiddler2. The mean error rate for one task while standing was 2.77. A considerably higher error rate of 6.95 was reported for the walking condition. Devices also showed significant variation ($F(1.45, 27.60) = 14.89$, $p<0.05$) while walking, with the gyroscopic mouse performing worse than all other devices.

4.3. Menu structure time

Table 2 summarizes the results obtained for the menu structures covered in our experiment (partitioned by menu structure and ordered by mean time for each mobility condition).

The mean time for menu selections across all conditions (excluding the table-top mouse) was 3.93 seconds (SD 0.60). Overall, the choice of menu structure had a significant influence on mean time for menu selection ($F(3,57) = 101.13$, $p<0.05$), where the pie pop-up was fastest, followed by the pull-down fixed menu, the linear fixed menu ranked third, and the linear pop-up menu reported the slowest time. All differences were significant (error trials were removed from the analysis). As found in the analysis of mean pointing device time, standing menu selection outperformed walking menu operation ($F(1.00,79.00) = 502.13$, $p<0.05$). We identified significant interactions between mobility and menu structure ($F(3,57) = 32.49$, $p<0.05$) and between pointing device and menu structure ($F(4.47,84.92) = 8.02$, $p<0.05$). The latter is illustrated in Figure 9. Furthermore, there is a significant interaction between input device, menu structure and mobility ($F(4.37,83.09) = 5.11$, $p<0.05$), as is shown in Figure 10 for standing operation and in Figure 11 for the walking condition.

The mean total time for menu selections while standing was 3.38 seconds and while walking was 4.49 seconds. Menu structures resulted in a significant effect on mean time while standing ($F(2.16, 41.06) = 53.85$, $p<0.05$) and while walking ($F(3,57) = 97.73$, $p<0.05$). In both cases, the pie pop-up was fastest, followed by the pull down fixed, the linear fixed and the linear pop-up menu. All differences with the exception of the linear fixed and the linear pop-up were significant.

Table 1. Mean device time and error rate

Device	Mean time (seconds)		Mean error rate	
	Mean	St. Dev.	Mean	St. Dev.
Mouse	60.68	6.24	2.32	2.32
Both mobility conditions				
Trackball	108.08	15.23	1.86	0.80
Touchpad	126.03	21.78	3.38	2.09
Twiddler2	137.41	27.88	3.72	3.36
Gyroscopic	193.40	42.93	10.47	7.71
Standing				
Trackball	98.70	16.23	1.58	1.14
Touchpad	109.64	19.04	2.62	1.62
Gyroscopic	111.28	16.99	4.87	4.05
Twiddler2	116.81	16.94	2.02	1.53
Walking				
Trackball	117.45	16.77	2.15	1.06
Touchpad	142.43	29.29	4.15	3.53
Twiddler2	158.01	43.34	5.42	6.10
Gyroscopic	275.52	77.33	16.07	12.94

Table 2. Mean menu selection time and error rate

Menu	Mean time (secs)		Mean error rate	
	Mean	St. Dev.	Mean	St. Dev.
Both mobility conditions				
Pie Pop-up	3.45	.39	.08	.06
Pull down Fixed	3.76	.49	.30	.19
Linear Fixed	4.16	.57	.50	.33
Linear Pop-up	4.35	.52	.14	.07
Sitting (mouse)				
Pull down Fixed	1.86	.16	.14	.20
Pie pop-up	1.88	.19	.03	.06
Linear Fixed	1.95	.17	.25	.28
Linear Pop-up	2.23	.20	.05	.06
Standing				
Pie pop-up	3.08	.40	.03	.03
Pull down Fixed	3.22	.41	.15	.10
Linear Fixed	3.52	.46	.28	.21
Linear Pop-up	3.69	.54	.09	.06
Walking				
Pie pop-up	3.82	.44	.13	.10
Pull down Fixed	4.31	.63	.43	.30
Linear Fixed	4.80	.74	.72	.52
Linear Pop-up	5.01	.56	.18	.11

4.4. Menu structure error rate

The mean error rate for menu selections across all conditions (excluding the table-top mouse) was 0.25 (SD 0.25). Menu structure had a significant impact on the mean selection error rate ($F(1.51, 28.63) = 26.03$, $p<0.05$). The pie pop-up resulted in the lowest error rate, followed by the linear pop-up menu, the pull down fixed menu, and the linear fixed menu (all differences were significant). Overall, the mean error rates are lower while standing than while walking ($F(1.00,79.00) = 48.66$, $p<0.05$). The mean error for menu selections while standing was 0.14, while walking was 0.37. Menu structure was also significant while standing ($F(1.40, 26.65) = 20.00$, $p<0.05$) and while walking ($F(1.57, 29.84) = 21.68$, $p<0.05$). All pairs were found to significantly different in the standing condition. However, in the walking condition, differences between the pull down and the linear fixed menu were not significant, nor were those between the linear pop-up and pie pop-up menu structures.

4.5. Participant survey

Participants were required to complete an exit questionnaire where they were asked to rate the devices on a 7 point scale in terms of overall reaction and experience using the device. The first eleven questions were concerned with attributes such as smoothness, speed, and accuracy, while the remaining five questions were concerned with neck, shoulder, arm, wrist and finger fatigue. The mean rating across all participants and attributes for each of the devices is as follows (scale of 1 very difficult to 7 very easy): trackball 5.64 (SD 0.48), touchpad 5.51 (SD 0.46), Twiddler2 4.55 (SD 0.79), and gyroscopic mouse 3.65 (SD 1.28). Participants were asked which device and menu they preferred to use in a wearable context (addressing Aim 6): eleven preferred the trackball, eight the touchpad, while one preferred the Twiddler2. Eighteen preferred the pie pop-up menu, while two preferred the pull down menu.

5. Discussion and recommendations

5.1. Pointing devices

Our study confirms that there is a significant difference in speed and accuracy when performing menu selection tasks with pointing devices (addressing Aim 1). Over both movement conditions, the trackball performed with the fastest mean time and lowest error rate per task (addressing Aim 2). The touchpad and Twiddler2 performed comparably with the second fastest mean time and error rate per task. The gyroscopic mouse ranked last with the slowest time and highest error rate. Analysis of the standing condition reports no significant difference between the touchpad, gyroscopic mouse and Twiddler2.

In our previous selection study [6] the gyroscopic mouse was the fastest and least accurate device. In our drag and drop study [7] the gyroscopic mouse was the fastest and most accurate device while stationary. The results obtained from this study suggest that the gyroscopic mouse is a less favorable choice when precise menu selection is required, such as the steering required for the linear pop-up menu. The gyroscopic mouse seems to favor coarse mouse movements, therefore, it may be a suitable choice if used with a pie menu.

Consistent with our findings in the walking drag and drop study, the gyroscopic mouse was the slowest and least accurate device. Observations from the drag and drop study were that while task time and error rate are valuable and necessary measures, they provide little information pertaining to the quality of walking. For example, participants were noticed to slow down considerably while walking with the gyroscopic mouse (the accelerometer is sensitive to vibration making it almost impossible to use while walking). The trackball was the second fastest device in our selection study [6]. In the drag and drop study [7], the trackball and touchpad were comparably the fastest devices while walking and the second fastest devices while stationary. These findings along with similar findings in our current study seemingly make the trackball or touchpad a favorable choice for use in a wearable context over all the interaction models (selection, drag and drop and menu selection) and over both mobility conditions (standing and walking). A noted disadvantage of the touchpad over the trackball is the need to use two hands for input. Although it is possible to place the touchpad in a number of different positions on a person's body [1], it is recommended that it be placed in a position that minimizes the effect of the movement of the body while walking. Participants preferred to occupy only one hand while interacting with the wearable computer and also considered the trackball and Twiddler2 more natural as their hand was able to be held in any position. Participants liked the idea of an isometric joystick for cursor control; however, the biggest challenge facing the Twiddler2 is its form factor. A more ergonomic design, perhaps in the way of the trackball device, would see a more favorable response by participants and better performance.

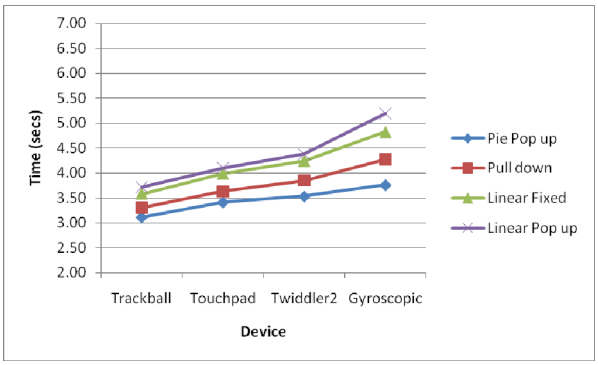


Figure 9. Menu x device interaction both positions

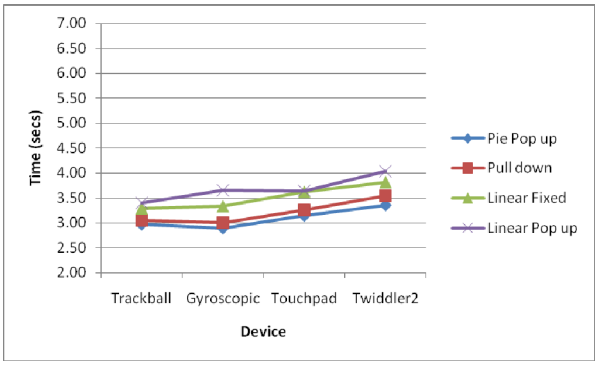


Figure 10. Menu x device interaction standing

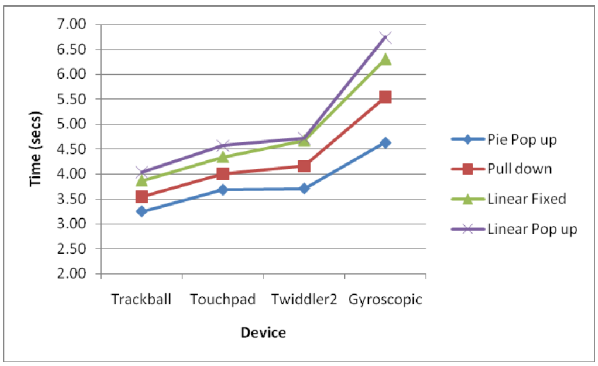


Figure 11. Menu x device interaction walking

5.2. Menus

This study demonstrated a significant difference in speed and accuracy when performing menu selection tasks with different menu structures (addressing Aim 3). Similarly to Callahan et al. [13], we found that pie menus performed better than linear menus in terms of menu selection time and error rate over both movement conditions (addressing Aim 4). All pointing devices reported the fastest time with the pie menu. The pull down fixed menu reported the second fastest time, followed by the linear fixed menu. The linear pop-up resulted in the slowest mean selection time and second lowest error rate, this is perhaps due to the precise steering required to select sub-menu items. Our findings also confirm Walker and Smelcer's [12] result, that pull down menus are faster than walking menus (the latter are equivalent to our linear pop-up). Walker and Smelcer [12] also observed that impenetrable borders were effective in decreasing selection time. This observation is perhaps an insight into why the pull down menu reported the second fastest time. The top and bottom of the screen in our case acted as an impenetrable border, whereby participants were able to make long movements towards the menu item without overshooting the target. Another reason perhaps is that participants were familiar with this style of menu. Of note is that the fixed linear menu suffered from the highest error rate. A possible explanation is that participants often failed to see the menu at the bottom of the screen, and then clicked on the screen thinking they were required to pop-up a menu. Larger linear menu items would make selection easier. In both the standing and walking conditions, the linear fixed and linear pop-up menus reported the slowest selection times with no significant difference between them; interestingly, both menu structures rely on moving the cursor horizontally to select sub-menu items.

5.3. Combined results of menus and devices

In light of the above, the trackball is seemingly the best choice of device for use with any of the menu structures and for use while walking or standing in a wearable context. Similarly, the pie pop-up menu is the best choice of menu for use with any of the pointing devices and for use while walking or standing in a wearable context. The combination of the trackball and the pie pop-up menu allows the fastest selection time and lowest error rate over both movement conditions (addressing Aim 5). The touchpad, Twiddler2 and gyroscopic mouse are comparably the next fastest devices when used with the pie pop-up menu over both conditions. As highlighted in Figure 10, the gyroscopic mouse led to a slightly faster selection time than the trackball for both the pie pop-up and pull down menus when standing. However, this difference is not statistically significant.

In the case where a pie menu is not appropriate as the interaction technique, the use of a pull down menu could form a suitable choice, performing with the next best time for use with any of the pointing devices while walking or standing. Teamed with the touchpad, the pull down menu reported the second fastest time. The gyroscopic mouse and Twiddler2 performed comparably, and reported the slowest times over both conditions (seen in Figure 9). The slowest menus over

all the devices in a wearable context are the linear fixed and linear pop-up menus. The precise steering necessary to select a sub-menu in the linear pop-up menu makes it a poor choice while walking.

Interestingly, some of the times reported by the trackball and touchpad in the standing condition, overlap with the times reported by the mouse. Further work, perhaps a longitudinal study, is needed to ascertain whether familiarity with the devices will produce speeds closer to table-top mouse speeds.

6. Conclusion and future work

We have presented a usability study comparing four menu structures and four pointing devices for use with wearable computers. The trackball and pie pop-up menu individually resulted in the fastest mean time and lowest error rate over both the walking and standing conditions. The results presented in this paper seek to provide insight and to guide users and designers of wearable systems. In light of this, the combination of the trackball and pie pop-up menu is a favorable choice for use in a wearable context. The subjective results reported by participants support the quantitative findings. In future work, we would like to draw upon the insights gained from our research in order to develop a pointing device suitable for use in a wearable context.

7. Acknowledgements

The project team acknowledges: the support and assistance of the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) and Wolfgang Mayer for his proofreading expertise.

8. References

[1] B. Thomas, K. Grimmer, J. Zucco, and S. Milanese, Where Does the Mouse Go? An Investigation into the Placement of a Body-Attached TouchPad Mouse for Wearable Computers, *Personal and Ubiquitous Computing,* vol. 6, pp. 97-112, January 2002.

[2] A. Chamberlain and R. Kalawsky. A comparative investigation into two pointing systems for use with wearable computers while mobile. In *Proc. of the 8th Int. Symp. on Wear. Comp.*, Oct 31 - Nov 03, 2004, p. 110-117.

[3] G. Blasko and S. Feiner. A menu interface for wearable computing. In *Proc. of the 6th Int. Symp. on Wear. Comp.*, Oct 7-10, 2002, p. 164-165.

[4] G. Blasko and S. Feiner. An extended menu navigation interface using multiple pressure-sensitive strips. In *Proc. of the 7th Int. Symp. on Wear. Comp.*, Oct 21-23, 2003, p. 238-239.

[5] K. Lyons, N. J. Patel, and T. Starner. KeyMenu: a keyboard based hierarchical menu. In *Proc. of the 7th Int. Symp. on Wear. Comp.*, Oct 21-23, 2003, p. 240-241.

[6] J. E. Zucco, B. H. Thomas, and K. Grimmer. Evaluation of three wearable computer pointing devices for selection tasks. In *Proc. of the 9th Int. Symp. on Wear. Comp.*, Oct 18-21, 2005, p. 178-185.

[7] J. E. Zucco, B. H. Thomas, and K. Grimmer. Evaluation of four wearable computer pointing devices for drag and drop tasks when stationary and walking. In *Proc. of the 10th Int. Symp. on Wear. Comp.*, Oct. 11-14, 2006, p. 29-36.

[8] A. Smailagic and D. P. Siewiorek, A Case Study in Embedded-System Design: The VuMan2 Wearable Computer, *IEEE Design and Test of Computers,* vol. 10, pp. 57-67, July 1993.

[9] J. Cross, C. Baber, and F. J. Houghton. Design of a minimal interface for two-way strategic information flow for urban operations. In *Proc. of the 9th Int. Symp. on Wear. Comp.*, Oct 18-21, 2005, p. 208-209.

[10] J. Wither and T. Hollerer. Evaluating techniques for interaction at a distance. In *Proc. of the 8th Int. Symp. on Wear. Comp.*, Oct 31-Nov 03, 2004, p. 124-127.

[11] J. Mitchell and B. Shneiderman, Dynamic versus static menus: an exploratory comparison, *ACM SIGCHI Bulletin,* vol. 20, pp. 33-37, April 1989.

[12] N. Walker and J. B. Smelcer. A comparison of selection times from walking and pull-down menus. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, Apr 1-5 1990, p. 221-226.

[13] J. Callahan, D. Hopkins, M. Weiser, and B. Shneiderman. An empirical comparison of pie vs. linear menus. In *Proc. of the SIGCHI Conference on Human factors in Computing Systems*, May 15-19, 1988, p. 95-100.

[14] D. Ahlstrom, R. Alexandrowicz, and M. Hitz. Improving menu interaction: a comparison of standard, force enhanced and jumping menus. In *Proc. of the SIGCHI conference on Human Factors in computing systems*, Apr 22-27, 2006, p. 1067-1076.

[15] A. Cockburn and A. Gin. Faster cascading menu selections with enlarged activation areas. In *Proc. of Graphics Interface*, Jun 7-9, 2006, p. 65-71.