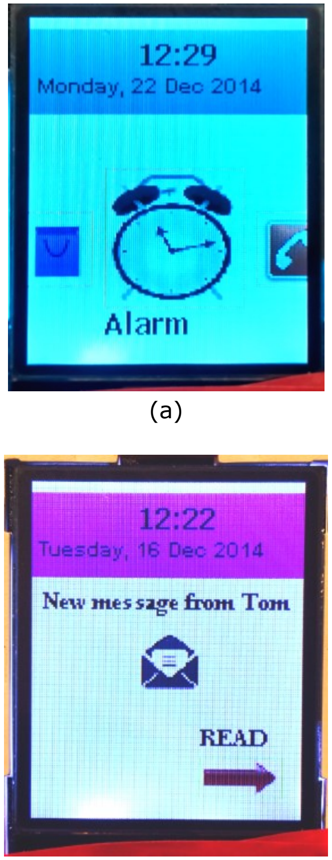

(a)

(b)

Figure 2. (a) Menu Navigation application. (b) An example notification with the clock bar in purple color providing visual feedback for glance.

In the following section, we describe an experiment to understand and compare user preferences for using visual or haptic modalities to provide "glance" feedback *i.e.* feedback when the user is looking at the device, to confirm its readiness for subsequent interaction. We also report the users' subjective opinions on using gaze-based interaction on wristwatches. We conclude by presenting different ways of using gaze-based interaction in smartwatches and combining it with other available modalities for more natural usage.

Experiment

The experiment was designed to resemble an everyday scenario in which the user looks at the watch to perform an action, the watch provides either visual or haptic glance feedback (depending on the condition) and the user proceeds with subsequent interaction using gaze gestures. Gaze gestures were chosen as they are known to be more robust to tracking inaccuracies than dwell-based methods and are suitable for interaction with small objects on the display [1].

We implemented two applications: a menu application with horizontal navigation and item selection using gaze gestures (Figure 2a), and a notification application, which presented users with haptic notification of events (incoming calls, messages *etc*.) at random intervals of time (Figure 2b). The main objective was to understand possible differences in the user's subjective evaluation between the two feedback conditions (i.e., visual or haptic) and between the two applications. In the menu navigation task, the participants were required to perform multiple gestures to accomplish the task. For the notification task, the participants were only required to perform a single gesture. We anticipated that the complexity of subsequent interaction would have an effect on how the users perceive the benefit of glance feedback. The secondary, and more general objective was to understand the user's perception of using gaze-based interaction on smartwatches.

Apparatus

The prototype wristwatch was built on the Microsoft .NET Gadgeteer 4.2 platform [10] using FEZ Raptor mainboard and N18 color display module (128x160 pixels, 1.8 inches). We used the Ergoneer Dikablis head mounted gaze tracker along with the prototype wrist device to simulate a gaze-tracking capable smartwatch. A visual marker was placed adjacent to the watch display for easy recognition of the position of the watch using the scene camera on the tracker (Figure 3). The display was attached to a layer of soft foam for comfortable wearing. A linear resonant haptic actuator (Precision Microdrive C10-100) was mounted on the layer of foam between the display and the skin to provide haptic feedback. The gaze tracker was connected to a Windows 7 laptop which recognized the gaze events and sent commands for updating the watch display to the FEZ Raptor using a USB connection.

Gaze Gestures

We used two stroke off-screen gaze gestures as used by Kangas et al. [2]. Using off-screen gestures made the input area larger than the display area of the watch. Each gesture started from the display of the watch. The first stroke of a gesture moved over the edge of the display in leftward, rightward or upward direction. The second stroke returned back to the display. Three gestures were used based on the direction of the first stroke: *LEFT*, *RIGHT* and *UP* gestures. We used an 800 milliseconds time-out for a

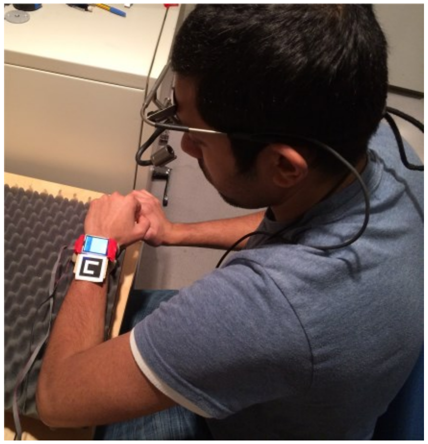
Figure 3. Experiment setup using the Ergoneer Dikablis gaze tracker and the prototype wrist device.

gesture completion to differentiate between normal eye movement and gaze gesture commands. The time-out value was set based on pilot tests.

Glance feedback conditions – Haptic and Visual
A momentary visual or haptic glance feedback was provided as soon as the gaze tracker detected a gaze sample on the watch display. For visual feedback, the clock bar turned from grey to purple for 500 milliseconds (Figure 2). The feedback was given again for any subsequent glance following a minimum of 1.5 seconds of gaze outside the display. The haptic feedback was designed to resemble a short tap by using a duration of 30ms and a driving signal of 175Hz sine wave. The delay between a user glance and visual or haptic feedback was measured using a camera-based technique. The delay was approximately 150ms for visuals and 200ms for haptics. Both delays were within the 250ms limit for natural association of gaze events and haptic feedback [3].

Participants
12 volunteer participants from the university community (6 male, 6 female) with a median age of 23 years (range: 20-42 years) took part in the study. None of the participants had previous gaze-tracking experience.

Procedure
Participants were introduced to the gaze tracker, the prototype wristwatch and the experiment. Next they signed an informed consent form and filled in a background questionnaire. After calibrating the gaze tracker, the haptic and visual feedbacks were played a few times to ensure that they were easy to notice. The participants were instructed to keep their hand on the arm rest (as shown in Figure 3) but were free to move their head.

All participants used the menu application first. The task was to navigate to a specific menu item (using *LEFT* and *RIGHT* gaze gestures) and select the item (using *UP* gesture). The list was in alphabetical order and cyclical. After a successful selection, the system would pause for three seconds, before automatically returning to the menu. During this pause, the participant was given a piece of paper with the name of the item to select next. This required the user to look away from the watch display and ensured that they received glance feedback for the next interaction. In each feedback condition, the participant was asked to perform 10 menu item selections. The menu navigation task was followed by the notification task. Participants looked away from the watch display and then received a series of 10 haptic notifications. The haptic pulse was 100ms long. As soon as the notification was received, the participants looked at the display, received the glance feedback and then viewed the notification using *RIGHT* gesture. The system waited for a random period of 8-10 seconds before sending the next notification. After each condition, participants rated the interaction in terms of ease of use, comfort and confidence using 7-point Likert scales. In both tasks, the order of feedback conditions was counterbalanced.

Results
Figures 4a and 4b show the subjective evaluation results of menu navigation and notification based tasks, respectively. There were no clear differences in the ratings between visual and haptic glance feedback in the menu navigation task. The overall user preference was also mixed. 4 participants preferred haptics, 6

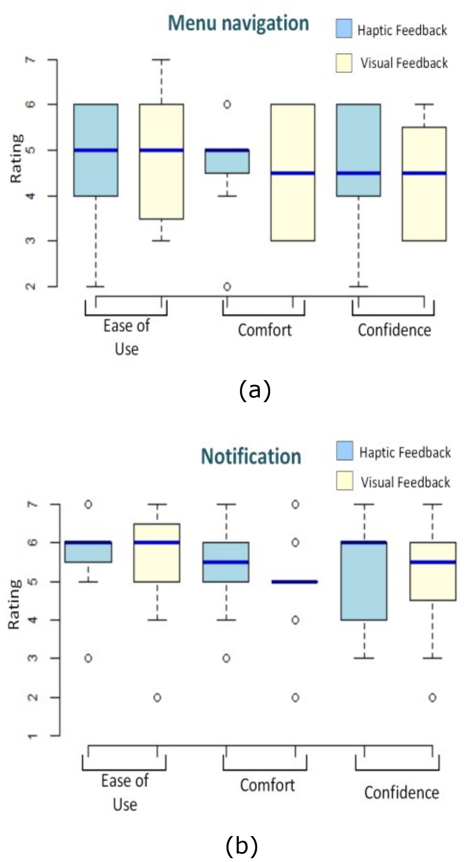

Figure 4. Subjective evaluation of visual and haptic glance feedback conditions for (a) menu navigation task (b) notification based tasks.

preferred visual feedback and 2 participants stated that both modalities worked equally well. In the notification based task, however, a majority of participants (9/12) preferred haptic glance feedback, 2 preferred visual feedback, and 1 stated that both modalities worked equally well. The Wilcoxon signed-rank test showed that the participants rated haptic feedback as significantly more comfortable ($p < 0.05$) in the notification task. Participants who preferred haptics commented:

P6: *"Haptics was more clear and noticeable"*
P2: *"[With haptics] it was easier to make sure that eye contact was registered."*
P11: *"Vibration felt more natural"*

Participants who preferred visual feedback felt that visual feedback was more appropriate because the user is already looking at the display. Two participants also reported the multiple vibrations in the notification-based task as distracting. When asked which of the two tasks they would like to perform with eyes, 9 out of 12 participants preferred the simple notification based tasks over the complex menu navigation task. The remaining 3 participants preferred to do both. In general, participants felt positive about gaze-based interaction on smartwatches.

P3: *"[With gaze based interaction] you do not need to use your hands. Gazing is easier and faster in some scenarios."*

Discussion and future work

In this paper, we presented a study of a gaze-based interaction in smartwatches. The interaction was rated positively and our results suggest that it is a practical interaction modality with such devices. Participants preferred to do simple and occasional tasks with gaze rather than continuous tasks. Haptics was the preferred feedback modality for glance events in the notification-based task. In the notification-based task, there was more text content on the display and this may have affected the subjective evaluation of the visual feedback condition. Providing visual feedback to gaze events can be difficult in small screen devices with rich display content. Haptics can be useful in such scenarios to offload the visual channel resulting in a more comfortable interaction. The current study showed that the combination of gaze input and haptic feedback could be beneficial in smartwatches and encourages further research in more natural usage environment.

The length and complexity of the gaze gesture interaction may have influenced the perceived usefulness and choice of the one-time glance feedback. Further research is required to understand the effect of glance feedback on objective measures like task completion time and error rate. In our study, the accuracy of gaze-tracking was maintained as high as possible by recalibrating the tracker between tasks whenever required. However, in a mobile environment, the accuracy of tracking may deteriorate with time. Further study is required to understand its effect on the task and glance feedback preferences.

There exist challenges to incorporate glance awareness and gaze-tracking into smartwatches. Such devices would need a continuously active gaze-tracking sensor (on the watch or the glasses), which would increase battery usage. The camera viewing angle would pose limitations on the positioning of the device in relation to the head. The limited processing power may induce delays in detecting the gaze, affecting the interaction.

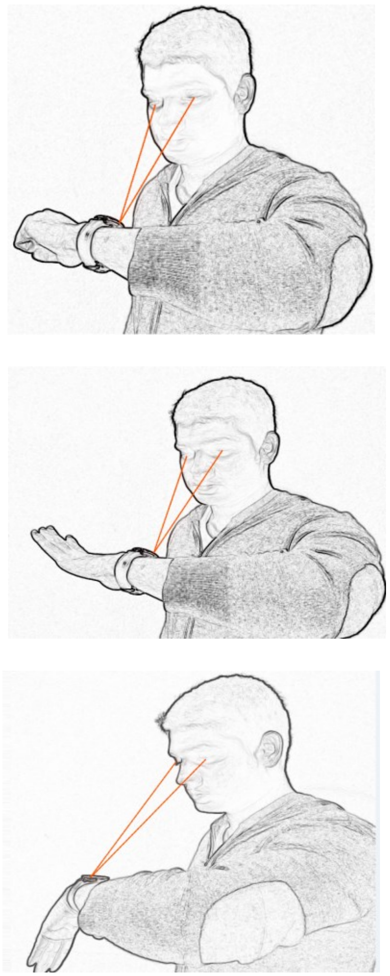

Figure 5. Combining glance awareness with hand gestures.

Despite the technical challenges, we feel that gaze-tracking in such devices could open up exciting and natural usage scenarios. Some of which are presented below:

Display activation upon user glance: The watch may dim the display when the user is not looking at the device. Such techniques not only reduce battery usage but also enhance information security.

Auto-scrolling of text and dynamic notification playback: The device may automatically scroll long messages, or display different notifications one after the other, without user input.

Automatic deletion of notifications: The watch can automatically remove already seen notifications.

Discrete hands-free interaction with the watch: The user could do gaze gestures to perform simple occasional tasks, like accepting an incoming call.

Gaze-only interfaces limit the complexity of interaction. In future, we plan to study natural ways of combining gaze-based interaction with other available interaction modalities in the wristwatch for more complex tasks. Figure 5 shows possible ways of combining glance awareness and gestures with the wearing hand.

Acknowledgements
This work was funded by the Academy of Finland, projects Haptic Gaze Interaction (decisions 260026 and 260179) and Mind Picture Image (decision 266285).

References

[1] Hyrskykari, A., Istance, H., and Vickers, S. Gaze Gestures or Dwell-Based Interaction? In *Proc. of ETRA 2012*, ACM Press (2012), 229–232.

[2] Kangas, J., Akkil, D., Rantala, J., Isokoski, P., Majaranta, P., and Raisamo, R. Gaze Gestures and Haptic Feedback in Mobile Devices. In *Proc. of CHI 2014*, ACM Press (2014), 435-438.

[3] Kangas, J., Rantala, J., Majaranta, P., Isokoski, P., and Raisamo, R. Haptic Feedback to Gaze Events. In *Proc. of ETRA 2014*, ACM Press (2014), 11–18.

[4] Kim, J., He, J., Lyons, K., and Starner, T. The Gesture Watch: A Wireless Contact-free Gesture based Wrist Interface. In *Proc. of ISWC 2007*, IEEE (2007), 15–22.

[5] Knibbe, J., Plasencia, D., Bainbridge, C., Chan, C., Wu, J., Cable, T., Munir, H. and Coyle, D. Extending Interaction for Smart Watches : Enabling Bimanual Around Device Control. In *CHI 2014 Extended Abstracts*, ACM Press (2014), 1891–1896.

[6] Kratz, S. and Micheal, R. HoverFlow: Expanding the Design Space of Around-Device Interaction. In *Proc. of MobileHCI 2009*, ACM Press (2009), Article 4.

[7] Lyons, K., Nguyen, D., Ashbrook, D., and White, S. Facet: A Multi-Segment Wrist Worn System. In *Proc. of UIST 2012*, ACM Press (2012), 123–130.

[8] Pascoe, J. and Thomson, K. On the Use of Mobile Tools in Everyday Life. In *Proc. of OZCHI 2007*, ACM Press (2007), 39–47.

[9] Perrault, S., Lecolinet, E., Eagan, J., and Guiard, Y. Watchit: Simple Gestures and Eyes-free Interaction for Wristwatches and Bracelets. In *Proc. of CHI 2013*, ACM Press (2013), 1451–1460.

[10] Villar, N., Scott, J., Hodges, S., Hammil, K., and Miller, C. .NET gadgeteer: A Platform for Custom Devices. In *Pervasive Computing 2012*, Springer (2012), 216-233.

[11] Xiao, R., Laput, G., and Harrison, C. Expanding the Input Expressivity of Smartwatches with Mechanical Pan, Twist, Tilt and Click. In *Proc. of CHI 2014*, ACM Press (2014), 193–196.