Evaluation of HeadTurn - An Interaction Technique Using the Gaze and Head Turns

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ABSTRACT

Smart glasses equipped with eye tracking technology could be utilized to develop natural interaction techniques. They could be used to conveniently interact with an electronic appliance in the environment from a distance. We describe a technique, HeadTurn, that allows a user to look at a device and then control it by turning the head to the left or right. We evaluated HeadTurn using an interface that linked head turning to increasing or decreasing of a number shown on a display. The task was to adjust then number to a given value. We studied the optimal rate at which number should change once the angle of head turn exceed a predefined threshold. We varied the rate of change of the number (217, 290, and 435ms per change) and the feedback (visual, haptic+visual). In the haptic condition, a 20 millisecond vibration was given through vibrating eye glass frame with each number change. Participants completed number selections faster with shorter intervals but also overshot the target more often. Seven out of 12 participants preferred the middle number changing speed (i.e., 290 ms). There were no statistically significant differences in task completion times. The optimal change rate of the numbers seems to be a compromise between faster selection and overshooting. Haptic feedback made the interaction slightly faster but the difference was not significant. The participants rated their experience with the technique as positive in general.

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INTRODUCTION

When people select an object for manipulation, be that on a display for virtual objects or real world objects in the environment, they will usually start by directing their attention to the object. In practice this often means looking at the object of interest. Therefore, gaze-based pointing is a natural selection tool in human-computer interaction. Implementing gaze-based pointing requires that the target of gaze can be automatically identified.

For long, researchers have studied how to utilize gaze-based interaction (e.g. [28, 8, 22, 12]). Users with disabilities have been a small, but important user group for gaze-based interaction techniques. It has also been recognized that situational impairment makes everybody a potential user of gaze-based user interfaces in some mobile situations. For example Sibert et al. [22] state that: *"Eye gaze interaction is a reasonable addition to computer interaction and is convenient in situations where it is important to use the hands for other tasks."* Another potential usage scenario is when controls are visible but out of reach.

Besides physical and situational impairments, well-built gaze-based interaction may be motivated by convenience. Gaze tracking enabled glasses could be worn almost all the time. Reaching a pocket for a mobile phone or finding the TV remote control unit is often more difficult than gazing to initiate a control sequence.

Gaze-Based Interaction

The gaze tracking equipment is becoming more widely available and more affordable [6], making it possible to utilize it in everyday interaction with computers (see, for example, the Tobii EyeX[1]). Wearable gaze trackers are more difficult to design and somewhat more expensive, but they also are becoming more affordable [14].

The research on gaze-based interaction is increasingly focusing on the mobile environment [18]. It is expected that gaze interaction with mobile devices could partially compensate for some of the problems in designing user interfaces for small devices. However, practical implementations of gaze trackers built into mobile devices are not yet available. One of the reasons is that the visual cues that allow measuring the eye ball orientation precisely are so small that very high camera resolution and good lighting are needed for remote gaze tracking. Eye tracking glasses have an advantage in that the cameras can be placed much closer to the eyes. Thus, a tracker in the glasses can fairly easily measure the orientation of the eye ball. A head mounted tracker, however, needs to also observe the world via a forward-looking camera and identify interactive objects, map the gaze point onto these objects, and connect to them to interact through a wireless network.

Instead of building such a smart tracker, the alternative is to build an eye contact sensor in all objects. It has been shown [23] that such sensors are relatively simple to build. However, embedded eye contact sensors only allow eye contact detection, whereas smart eye tracking glasses allow many other uses of the gaze in addition to it.

Gaze-based input can be used in (at least) two roles (see, for example, Huckauf and Urbina [7]). The first is to select the object to be controlled by looking. The second is to initiate a command by gaze. There are several possible methods of giving commands by gaze. The best known methods are based on dwell time [28] or gaze gestures [4]. Object selection is natural and straightforward. Looking at the object of interest is a natural part of the behaviour when orienting one's attention in preparation to interact. Giving commands via eye movements is more problematic because gaze-based interaction with objects is not a part of our usual behaviour. Regardless of how the interaction technique is built, it will be somewhat artificial and needs to be learned. Dwell time has been extensively studied [15] and it is in general use. Gaze gestures are less used but in theory they offer a benefit of not requiring as accurate gaze tracking as dwell based methods [10, 21].

Regardless of the way that the interaction is implemented, in purely gaze-based user interfaces the gaze will have a dual role (observe and interact). Because of this systems where the object of interest is selected by gaze (looking) and then manipulated by other methods have been studied. The manipulation can be triggered in various ways, for example using a keyboard [12] or doing finger gestures on a handheld touch device [26, 27]. These techniques are probably the most efficient approach when a separate physical interaction device is available. The work in this paper relates to developing techniques for situations where it is more convenient to interact using the eye tracker data only. We are thinking of short interactions like turning on the TV or another appliance, adjusting the volume setting on speakers, fine-tuning the lighting in a meeting room, opening a locked automatic door when carrying the groceries, etc.

[1] http://www.tobii.com/en/eye-experience/

Head based control

Head movements are also a part of everyday life. Nodding and head shaking are universally used gestures (albeit with different meanings in different cultures). These gestures are already present in infants aged 13-18 months [11]. If we use movement patterns similar to these gestures, we will probably develop better interaction solutions than with less natural techniques.

Head movements have been studied intensively as a means for interaction, especially for controlling devices by disabled users (see for example [2, 5, 13]). Crossan *et al.* used head tilting for interaction in mobile situation for able-bodied participants [3]. None of these studies included gaze tracking, though. Mardanbegi *et al.* [16] and Špakov and Majaranta [25] studied object selection based on simple head gestures (gazing an object and using head nodding, head turns and head tilting for selecting). To our knowledge these are the only studies where gazing was used together with head move detection to implement an integrated control method. Špakov and Majaranta [25] studied head movements only to trigger an action while gaze was used for pointing, while Mardanbegi *et al.* [16] studied also a continuous control, changing the volume on a tablet interface by a head tilt[2]. Following Mardanbergi *et al.* [16] we suppose that the control method is indeed capable of serving also for more complex interaction that would extend beyond simple triggering.

Špakov *et al.* [24] corrected the cursor position by head movements in a continuous way (similar to Jalaliniya *et al.* [9]). The larger the head turn, the larger the cursor offset from the position returned by the tracker. The work in this paper can be seen as an extension for controls of the techniques by Špakov *et al.* [24] and Jalaliniya *et al.* [9]) and adding to the existing work by Mardanbegi *et al.* [16].

Haptic Feedback

Good feedback is especially important in gaze-based user interfaces because the natural feedback from eye movements is poor in comparison to manual operation of user interfaces. Visual feedback is the usual method with most systems that have a display. In some cases an audio feedback can be used, to replace the visual feedback or to complement it. While these two modalities cover most of the use cases, in some situations they can not be used (no display, distractions for gaze, too much noise, too quiet). A haptic feedback, based on the sense of touch is then a good alternative. We included haptic feedback in our experiments because earlier results [1, 10] showed that haptics can sometimes improve gaze-based interaction by making it more efficient and pleasant.

[2] From the paper we assume that the amount of tilt is directly used to define the amount of change in volume.

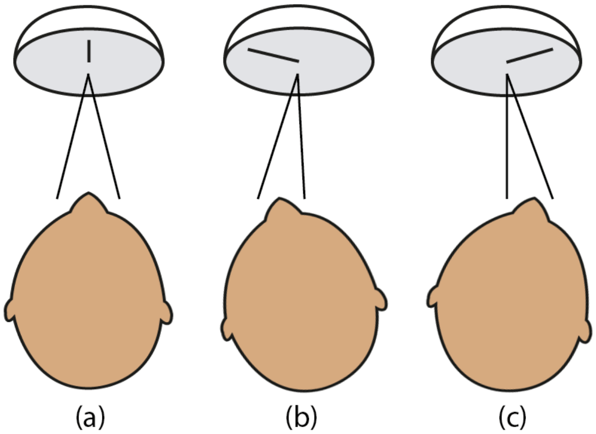

Figure 1. The operating principle of the HeadTurn technique illustrated with a volume control. The output volume of a sound system is changed by first gazing the control such as a speaker (a) and then while keeping the gaze on the control turning the head either left or right (b, c).

INTERFACE CONTROL BY GAZING AND HEAD TURNING

The new interaction technique, HeadTurn, is based on a gaze tracker that can be used also to sense the head orientation relative to the gaze direction. The idea is that the user of the technique will gaze on a control (that can take any form) and then turn his/her head either right or left to change the value of the associated control parameter, as illustrated in Figure 1.

The technique is analogous to a rotary control. Gazing at the control is analogous to touching the rotary knob. Turning the head while keeping the gaze on the control is analogous to turning the hand while it is in contact with the knob. If the user stops gazing the control (removes the hand from the knob) the head turn stops to have an effect on the control.

The head turn could affect the controlled parameter in various ways. The most obvious method is a "direct" control, where the angle of the head turn is directly translated to a new value. This seems to be the method that Mardanbegi *et al.* [16] experimented with. For example, if the original parameter value at the start $t = 0$ is A_0 and the angle of head turn (relative to the original direction at the start) is α_t, the new parameter value would be $A_t = A_0 + \beta\alpha_t$, where β is a scaling factor. Another simple method would be a "variable speed"-based control where the parameter's change speed would be controlled by the angle of the head turn. For example, if the original parameter value at the start $t = 0$ is A_0 and the angle of head turn at time t is α_t, the updated parameter value would be $A_t = A_0 + \sum_{i=0}^{t} \gamma\alpha_i$, where summation starts from the time of gazing, summation terms are observed at regular intervals and γ is a scaling factor. In both methods the adjustment is stopped by moving the gaze away from the control.

A variant of the latter method ("constant speed") is to translate the head turn angle to a fixed change speed using a step function. Employing such a step function requires users to first make a sufficiently large headturn ($\alpha_t > \alpha_{threshold}$) and hence it is tolerant to small head turns that might happen involuntarily or by accident. In this case the new parameter value at time t would be $A_t = A_0 + \sum_{i=0}^{t} s_i$ where change speed s_i is defined in Equation 1 by head turn angle α_i.

$$s_i = \begin{cases} \delta, & \alpha_i \geq \alpha_{threshold} \\ -\delta, & \alpha_i \leq -\alpha_{threshold} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

We experimented informally with different mapping functions and found both "direct" control and "speed" control functional. They have different strengths and weaknesses. Both also vary in usability depending on the mapping function employed. The "direct" control method allows very quick movements across different values, but the resolution (how many values can be separated) is limited by the accuracy of the tracking for head turn. Under noisy tracker data it can be annoying to try to hit a specific spot in the adjustment range. The "variable speed" mode allows fast movements, but requires a careful control when approaching target value. The "constant speed' with sufficiently high threshold and low speed is very robust to tracker noise, but frustratingly slow in moving across long distances.

Feedback

In all interaction a timely and topical feedback is important [19] for efficiency. HeadTurn will naturally generate feedback in various ways, depending on the task that it is utilized for. For example, if the controlled parameter is an audio volume, the change in the volume is an obvious feedback. Similarly a change in any visible parameter is a feedback. The system may also be augmented with additional feedback to emphasize the act of control. For example, tick sound at specific intervals, or graphics showing the present setting on the range of possible settings. In the studies described in this paper we used haptic feedback. The details of the feedback methods that we used will be described below.

THE EXPERIMENT: SELECTING A NUMBER

The goal of our experiment was to measure user performance and usability of the HeadTurn technique in one of the simplest configurations. Based on these results we would be able to conclude if further work would be worthwhile. The "constant speed", being a simple method and modified as described below, was the value control mode in this experiment. The optimal speed value δ of the step function was not known. We made it an independent variable in the experiment to find the optimal value.

The task given to participants was to repeatedly find and select a given target number using the HeadTurn technique. We created an application where the user would see a number that s/he can increase by gazing it and turning his/her head to the right and decrease by gazing the number and turning his/her head to the left. A screenshot of the application is shown in Figure 2. The target number was shown above the controlled number. Below the controlled number there was another box that the participant had to look at to confirm that s/he had found the target number.

When the participant was gazing the number and turned his/her head far enough to either side the controlled number would start changing. The first change would happen immediately

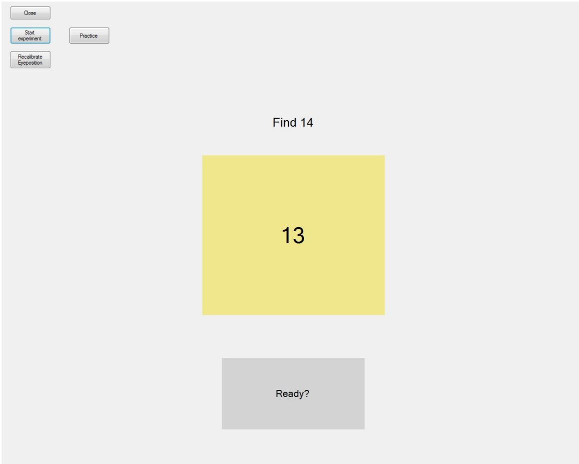

Figure 2. Screenshot of the Experiment 1. The participant was expected to look at the middle box, at the number, and either increase or decrease the number by head turning to reach the target value, shown above the box. The participant confirmed the selection by looking at the box below.

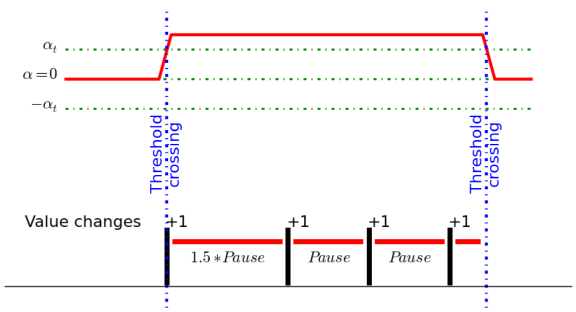

Figure 3. The schematics of the timing of value changes. The head turn angle (upper part of the image) is observed and as soon as the angle crosses either the upper threshold or the lower threshold the first value change is triggered. After that, as long as the angle stays on the other side of the threshold the value changes will be triggered with regular pauses in between, except that the first pause is 1.5 times the length of the regular pause. As soon as the head turn angle comes back to the neutral area the value changes will be stopped.

when the head turn angle exceeded the threshold value. After that the next changes would happen when the time from previous change would exceed a set time interval. However, the first time interval that followed the first change was 1.5 times as long as the regular time intervals to make it easier to change the number by one. Adjustments by one were especially important when participants overshot or undershot the target. As soon as the participant turned his/her head back (head turn angle below the threshold) or would look elsewhere from the control the number changing would stop. See Figure 3 for schematics of the value change timing by head turns.

The length of the time interval between the number changes was the first independent variable. The presence of haptic feedback was another independent variable. The haptic feedback consisted of a haptic pulse that was given at the same time as the number was changing. Haptic feedback has been used successfully as a confirmation in other gaze-based interactions

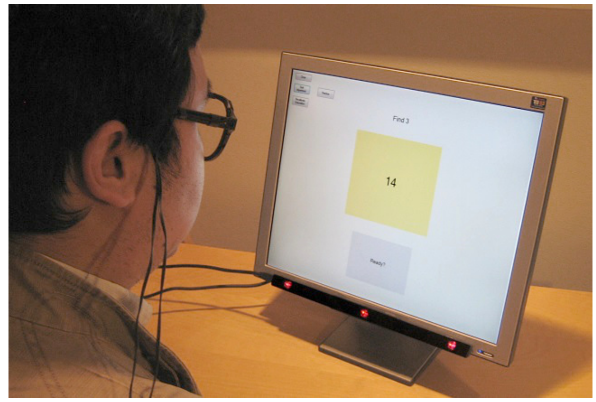

Figure 4. The experimental setup. The gaze tracker was attached to the bottom of the display. The haptic actuators were attached to the ends of the temples of the glasses. The participant was expected to look at the number in the middle box, and make that number match the target value shown above the box by turning his or her head. The participant confirmed the selection by looking at the box at the bottom of the display.

(e.g., in [10]) and we wanted to find out if it had any effect on this new technique.

Participants

We recruited 12 participants (6 male, 6 female) from the university community. The mean age was 33. All had a normal self reported sense of touch. The participants had normal or corrected to normal vision but seven of the corrected vision participants did not wear corrective eyeglasses during the test. The reason was that the haptic actuators were attached to an eye glass frame. Wearing their own glasses and the haptic frame was not practical in most cases. All participants confirmed that they saw the task display well enough even without their glasses. Nine of the 12 participants had used gaze tracking applications before this experiment.

Apparatus

We used Tobii EyeX[3] gaze tracker to collect gaze data. The tracker was attached to a separate 19 inch display where the application was shown (see Figure 4) The experiment software was a Microsoft Windows form application built using .NET 4.5 framework running in a PC with Windows 7.

The EyeX Engine[4] provides the gaze coordinates on display that we used to detect if the participant was looking at the middle box. We used the eye position in the tracker's camera view to estimate the head turn angle in a manner similar to Špakov *et al.* [24, 25]. Although this position does not represent the head turn angle, it is linearly proportional to it when the angle is small. To keep the angle estimation correct, we instructed our participants to minimize their lateral head movements during the experiment, and to use rotational head movements only when they were changing the number.

The haptic actuators used in the experiment were attached to a glass frame (see Figure 4), similar to the one used by

[3]http://www.tobii.com/en/eye-experience/eyex/
[4]http://www.tobii.com/en/eye-experience/dev/eyex-engine/

Rantala *et al.* [20]. The haptic stimulus was felt behind the ears where the glass bows touched the skin. The total weight of the glasses was 23 grams. Tactile stimulation was given using Minebea Linear Vibration Motors (LVM8, Matsushita Electric Industrial Co., Japan). Pure Data (PD) software and a Gigaport HD USB sound card were used to create the audio signals sent to the actuators.

Haptic Stimuli

The actuators were driven using a 150 Hz sine wave. 150 Hz is the upper limit of comfortable vibration frequency in the head area [17]. The duration of the signal was set to 20 ms so that the perceived sensation would resemble a tap, and not be felt as vibration. The chosen stimulus duration was found long enough to be felt by all participants in pilot testing.

Experimental Design

The experiment consisted of six different blocks, 20 trials each. There were three different number changing time intervals, 217 ms, 290 ms, and 435 ms, with two feedback conditions, either haptic feedback or no haptic feedback (a 3x2 design). The corresponding maximum number change frequencies were 4.6, 3.45 and 2.3 changes per second. The fastest speed was chosen in the pilot tests so that it would be almost too fast for practical use. The slowest and middle speeds were 50% and 75% of the highest frequency.

The test was counterbalanced so that each participant got a different order of the trials. There were exactly 6 ways to order the timing conditions and two orders for the haptic/ no haptic blocks. The trials with the same number changing speed were always done one after the other, but half of the participants would start with haptic and the other half with no haptic feedback.

Trial completion times and the number of corrections were recorded for each condition. The trial completion time was measured from when the target became visible to when the gaze entered the confirmation box. Then number of corrections was computed by subtracting the minimum amount of number changes (110) from the observed number change count.

We used a nine point bipolar Likert scale (-4 to 4) for the subjective evaluation of the technique. After each block the participants assessed the technique on five or six scales (see Table 1). A final survey was given after all the blocks. It included one Likert scale item of pleasantness or unpleasantness of the haptic feedback produced in the tests and a forced choice to choose which number changing speed they preferred. Finally, the participants were asked to write their comments on the haptic feedback and preferred number changing speed.

Procedure

The session began by briefing the participant on the purpose of the experiment. Then a consent form and a background information form were completed. The participants were seated in front of a monitor with an eye tracker. The distance to the monitor was approximately 30-50 cm. The eye tracker was calibrated and the participants were familiarized with the head turning technique. It was emphasized that a small head rotation is all that is necessary to change the numbers and that they should try to avoid any extra movements during the trials. During the introduction each participant tested the task with haptic feedback to get a grasp of the technique.

Attribute	Extremes
Successfulness	poorly - well
Easiness	hard - easy
Pleasantness	unpleasant - pleasant
Practicality	impractical - practical
Number changing speed	too slow - too fast
Haptics (if present)	disadvantageous - advantageous

Table 1. Questionnaires in Experiment 1.

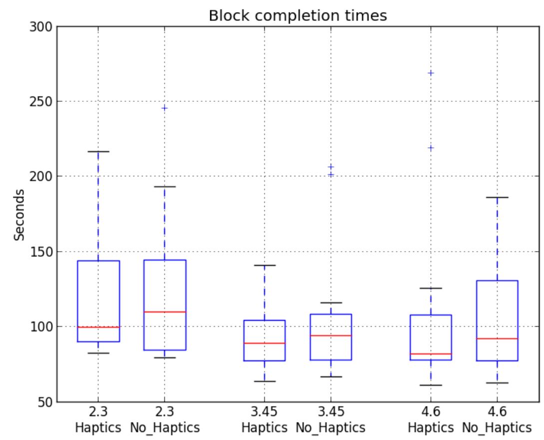

Figure 5. The block completion times in the Experiment. Completion times were slightly higher without haptic feedback, but not significantly so. The number changing frequency is shown below each column, as well as the haptics condition. The completion times with middle speed were about the same as with the highest speed.

The experimental task was completed as described above. The target numbers in a block of trials included all numbers from 0 to 20 in a random order excluding 10 which was the starting number. Before each block of trials the participants first completed 5 practice trials identical to the actual test trials. After each block the participants rated it. The procedure described was repeated for all the six test blocks. For each participant the experiment took in total around 40 minutes.

Results

Objective measurements

Block completion times (sum of all trial completion times) and average times per number change were used for analysis. The block completion times (shown in Figure 5) varied naturally with the different number changing frequencies. The block completion times when haptic feedback was given were slightly shorter than without haptic feedback, but no significant differences were found (ANOVA).

The average time for a number change is shown in Figure 6. The tendency towards faster actions with higher frequency is

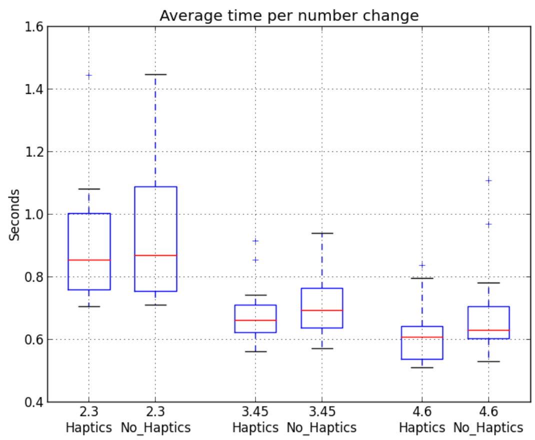

Figure 6. The average time per number change in the Experiment.

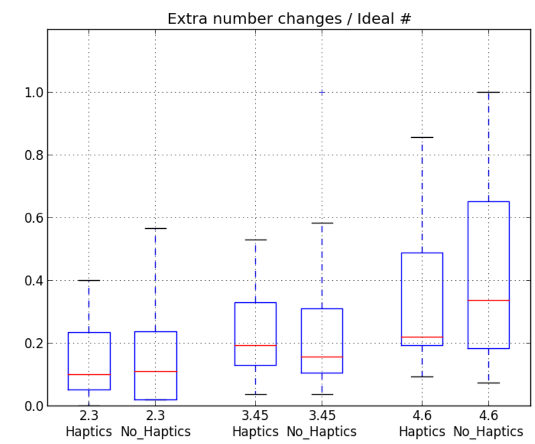

Figure 7. The ratio of extra number changes to the minimum number of number changes needed (110). For example, for 10 extra number changes the ratio would be $10/110 = 0.09$. The amount of extra activity grew with increasing number changing speed.

clearly visible. Again, there were no significant differences between the haptic conditions (ANOVA). The number of corrections per block is shown in Figure 7. The median number of corrections increases with increasing number changing frequency.

Subjective results

The participants' overall experience of the head haptics was positive (median 2, mean 1.6 on a -4 to 4 scale). Eight of the twelve participants made positive evaluations of the head haptics while two made negative and another two made neutral evaluations. Seven of the twelve participants preferred the middle number changing speed the most, three preferred the fastest, one the slowest, and one could not decide.

Questionnaire answers were not significantly different between the conditions except in one case. This was "Subjective evaluation of speed" (Friedman test, $p < 0.001$). The two conditions with the lowest number changing interval resulted

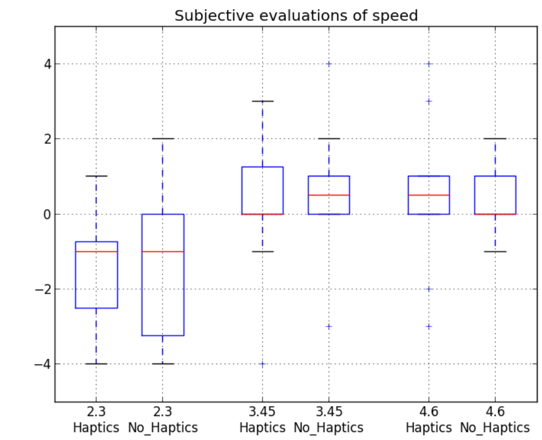

Figure 8. The subjective evaluation results of "Speed". The evaluations of both of the slowest number changing speed conditions differ significantly from all other conditions. The scale is from "too slow" -4 to "too fast" 4.

in lower evaluations (Wilcoxon paired-samples test, $p \leq 0.05$) in all cases than the four conditions with faster intervals (see Figure 8). Most of the participants felt that the slowest speed was too slow for the purpose.

Free form comments

Eleven of the twelve participants said that the haptic feedback was helpful, useful, functional or appropriate for the tasks in some way. Six participants mentioned some negative aspects of the feedback, mainly the excessive amount of haptic stimulation and delayed haptic feedback in higher number changing speeds.

In free-form comments the middle number changing speed was described as the most precise (4 participants). It was also said to be the most versatile speed (2 participants) as it works with or without haptic feedback and is good for small and large distances. The slowest speed was said to be too slow (4 participants) although one participant preferred it for its precision. The fastest speed was liked by some because the slower speeds were experienced too slow (2 participants).

DISCUSSION

With increasing number change rate, the task completion time naturally decreases. However, overshooting the target value also becomes more common when speed increases. The overall best results are a compromise between these two factors. While the block completion times varied slightly the two factors almost balance each other; there were no significant differences in the block completion times.

The subjective evaluation indicated that the middle speed in the experiment was the most preferred. Seven out of twelve participants mentioned it as the most preferred speed. The slowest speed was judged too slow subjectively while number of error corrections seems higher for the fastest speed. Between them the middle speed was obviously a reasonable compromise.

Overall, most of the participants reacted positively to the haptic feedback. However, there were also some negative comments, and probably the implementation details should be revised. Important issues are, e.g. the responsiveness, to minimize any delays, and the amount/strength of haptic feedback to avoid annoyance.

Our experiment involved only adjusting integer values in a range ± 10. Instead of numbers the list that is traversed could contain anything. For example, it could be a menu containing commands. In such a case all menu items should be visible to make finding the desired item easier.

The same technique would probably work also with an auditory menu allowing the control of displayless devices. Based on the work by Špakov et al. [24] also two-dimensional control structures could be used. Speech input as well as input from handheld devices could be combined with HeadTurn to create even richer interaction possibilities. For instance, a crude selection of some parameter scale could be done by speech, e.g. looking an audio volume control and saying "loud". Then HeadTurn could be used to fine tune the selection, by looking the control and turning head slightly.

Overall, we see a wide range of further possibilities in this theme. However, additional work is required to refine the interaction technique for natural contexts, which are often mobile. More sophisticated implementations could benefit from machine learning and from developing algorithms based on user data. We emphasize that this study is mainly an initial proof of concept.

CONCLUSION

This paper has two main contributions. First, the gaze tracker based system built to control the parameter values in a given range worked well. The participants tended to rate their experience as positive and were able to complete all trials. This motivates further implementations and research in using head turn interaction with smartglasses.

Second, the selection tasks were completed slightly faster when the interval between number changes was shorter. On the other hand, the participants also overshot the target more with shorter intervals. As a good compromise, majority of the participants (7 out of 12) preferred the middle number changing interval (290 ms). Therefore, we conclude that 290 ms would be a good starting point for selection speed when designing head turn interaction.

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