# Nenya: Subtle and Eyes-Free Mobile Input with a Magnetically-Tracked Finger Ring

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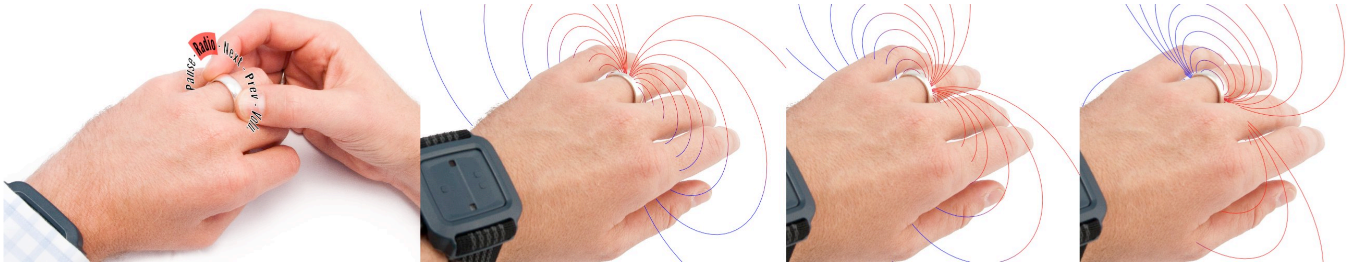

**Figure 1: The *Nenya* ring. Left: twisting the ring enters a 1D parameter; here rotation is used to select the menu item "radio". Users confirm a selection by sliding the ring along the finger. Center through right: Nenya's tiny size is due to it being magnetically tracked by the wrist-worn *baselet*. The lines illustrate how the magnetic field changes through a 90° ring rotation.**

## ABSTRACT

We present Nenya, a new input device in the shape of a finger ring. Nenya provides an input mechanism that is always available, fast to access, and allows analog input, while remaining socially acceptable by being embodied in commonly worn items. Users make selections by twisting the ring and "click" by sliding it along the finger. The ring—the size of a regular wedding band—is magnetic, and is tracked by a wrist-worn sensor. Nenya's tiny size, eyes-free usability, and physical form indistinguishable from a regular ring make its use subtle and socially acceptable. We present two user studies (one- and two-handed) in which we studied sighted and eyes-free use, finding that even with no visual feedback users were able to select from eight targets.

**ACM Classification:** H5.2 [Information interfaces and presentation]: User Interfaces. - Input Devices and Strategies.

**General terms:** Design, Human Factors, Experimentation

**Keywords:** mobile, wearable, subtle, eyes-free, screen-less, finger ring, jewelry, wristwatch, one-handed, two-handed.

## INTRODUCTION

Social situations present unique challenges for the usability of mobile devices. Whether asking a caller to "hang on a second" while paying at a grocery store register, letting a significant other know a meeting is running late, or updating one's location on a social network after arriving at a party, there are many situations wherein pulling out and using a mobile phone is considered inappropriate.

In this paper, we introduce the *Nenya* finger ring, a subtle, eyes-free input device designed for these types of scenarios.

## THE NENYA RING

Nenya is an ordinary-looking band-style finger ring (Figure 1). Users spin Nenya for 1D input, e.g., to select an item from a menu or to specify a parameter, and commit a selection by sliding Nenya along the finger.

Unlike previously proposed input methods designed for subtle use [3,7], Nenya provides high-fidelity input; unlike earlier ring devices [8,11], Nenya is unobtrusive, small, and wireless. Nenya can be used by itself as an eyes-free input method or in combination with subtle output devices, such as haptic displays or visual output such as *eye-q* [4].

### Tracking

The thin, unpowered Nenya ring is a strong permanent magnet, with the magnetic poles located on opposite sides of the ring, as shown in Figure 1. Such rings can be purchased inexpensively ($8–$20). Also shown in Figure 1 is the Nokia-developed wrist-worn wireless tracking base bracelet, or *baselet*. The baselet includes a HMC5843 3-axis magnetometer sampled at 25Hz; inspired by Harrison and Hudson's *Abracadabra* [6], we use the magnetometer to track the ring's position via magnetism. A Bluetooth radio allows the baselet to transmit ring input to the user's other devices, such as a wrist display or mobile phone.

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(a) (b)

**Figure 2. (a) One-handed use is more difficult, but is even more discreet. (b) We alleviate the additional friction of one-hand use by using a thin ball bearing with mounted magnets.**

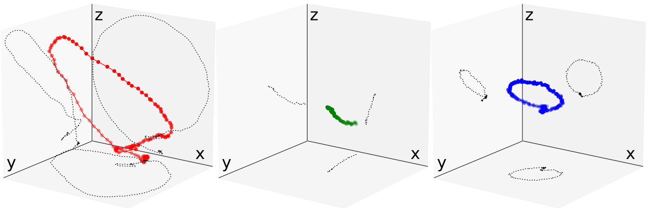
When users spin or slide the ring, the magnetometer in the baselet senses the change in the magnetic field. Figure 4 shows raw data for three different ring motions. In order to determine the angle relative to the finger at which the ring is being moved, our software ignores motion along the finger's length and only considers the two axes perpendicular to the finger (see the *x/z*-axis projection in Figure 4a).

To "click" users slide Nenya in the direction of the fingertip (Figure 4b, *x/y* projection), moving the ring away from the baselet. The magnetic field strength measured at the baselet thus decreases; when it falls under a threshold, the baselet detects a click.

Since the magnetometer in the baselet senses the *absolute* orientation of the ring, Nenya can be used as a *positional* input device. We leverage this ability to enable eyes-free use. We added a small disc magnet as an explicit *tactile landmark* [2], which allows users to read the ring's position by touch. Once users are familiar with a menu, they may re-enter it by turning the ring until the landmark is in the expected position. Note that more elaborate rings worn as jewelry naturally bear landmarks, such as mounted stones.

### Benefits and limitations

Nenya is designed for subtle use: (1) We have achieved a **tiny form factor** by handing off all active sensing to the baselet. (2) Users operate Nenya using **small, discreet movements**. (3) While users obtain best control manipulating the ring using their opposing hand, Nenya supports even more subtle **one-handed use** (Figure 3a). (4) Nenya can be operated **eyes-free**: in contrast to earlier magnetic tracking work [6,9], Nenya fixes the movement to the finger, preventing the user from drifting. Additionally, tactile landmarks on the ring allow users to access known functions without looking. (5) Nenya is already present on the hand, making it **always immediately available and fast to access** (see Ashbrook's *microinteractions* [1]). (6) Whenever the (social) situation requires, Nenya is **instantly interruptible**. Unlike with a mobile phone, Nenya immediately leaves both hands free when the user stops using it. (7) Nenya has a **familiar appearance**: it does not look different from rings people wear for decorative purposes or as wedding rings.



(a) (b) (c)

**Figure 3: Traces of ring motion sensed by the 3-axis magnetometer. The hand points into the *x/z* plane with the palm parallel to the *x/y* plane. (a) is a full ring rotation at the base of the finger; (b) is a slide from the finger base to the middle of the finger; and (c) is a full rotation near the middle of the finger.**

Nenya does have some limitations. First, the magnetic tracking method requires users to wear the baselet. However, the sensor and radio are small enough to be incorporated into a standard wristwatch or more decorative bracelet, which will improve its attractiveness and wearability. Second, our system is currently susceptible to false positives when the user is in motion; however, more advanced pattern recognition techniques should alleviate this problem. Finally, the involved magnetism requires that users be careful not to damage objects sensitive to magnetism, such as the magnetic stripes on credit cards, and avoid getting the ring stuck on metal objects during daily use.

## RELATED WORK

Our work on Nenya is related to subtle and eyes-free input and rings in particular, as well as magnetic tracking.

### Subtle and Eyes-Free Interaction Technology

Work on both subtle and eyes-free input includes Electromyography (EMG), a method that supports nearly undetectable use [3]. Current versions accomplish this using multiple electrodes placed on the user's arm. Rekimoto's GestureWrist [14] is a watch band-integrated capacitive sensor that detects hand shape. Users operate it using large-scale gestures. Blaskó proposed eyes-free parameter entry through touching the surface of a wristwatch [2], but his system was more suited to discrete rather than analog input.

### Rings

In 2001, researchers at IBM presented industrial design concepts of digital jewelry, including a bracelet and a ring featuring a single-button input [13]. Kim et al. created design concepts exploring the affordances of commonly worn objects, including rings, for controlling a mobile music player [10]. Functional ring form-factor devices were either wired (e.g., [8,11]) or included batteries for wireless communication and were thus bulky [12].

### Magnetic Tracking

Han et al. tracked a finger-mounted magnet for handwriting input [5]. Similarly, Harrison and Hudson used a finger-attached magnet for radial and 2D input for a watch device [6], and Ketabdar et al. tracked a magnet in the space around a mobile phone [9]. Nenya's improved form factor allows subtle use due to its tiny form factor and small motions; eyes-free use based on constraining the motion of the magnet to a fixed axis around the finger; and one-handed usability as demonstrated in the second study below.

## USER STUDIES

In order to determine users' ability to provide input using the ring, we performed two target selection studies. The first tested two-handed use; the second study examined one-hand use. Our goal was to explore how many targets can be fit onto a full rotation menu on the ring, and how quickly and accurately users can select from it. Both studies used the setup illustrated in Figure 5.

## USER STUDY 1: TWO-HANDED USE

Participants twisted the ring with the opposing hand (Figure 1). We performed testing under both visual and auditory-only (eyes-free) feedback conditions to simulate different use cases. A questionnaire followed the study.

### Task

The participants' task was to rotate the ring such that the yellow pointer shown in Figure 5 was inside the green target; the yellow pointer mirrored the ring's motion. When satisfied with their selection, participants committed by pressing a foot switch located under the desk. (This method was used rather than "pull-to-click" to separate target homing and click response times.) Upon successful selection, the red and green wedges swapped places. After 10 clicks, the screen displayed a new target configuration. We measured task time and error rate for target sizes of 45°, 60° and 90°, with distances between targets up to 180°.

### Conditions

**In the *visual* condition** participants performed the task while looking at a screen similar to that in Figure 5. **In the *audio* condition**, no visual feedback was provided, and a computer-synthesized voice read the number of each wedge when the pointer entered it. The audio was clipped if the participant pointed to a new wedge before the current wedge's audio had finished playing. **In the *combined* condition,** participants saw both the wedge display *and* heard the synthesized voice. We included this condition, which redundantly encodes feedback, to determine if the extra feedback gave users any advantage.

### Interface & apparatus

Participants wore the ring on their left ring finger and the baselet on their left wrist (Figure 1). As described earlier, the ring included a disc magnet as a tactile landmark; its position was calibrated to correspond to the direction of the pointer on the screen. Participants picked a ring from a set in US sizes from 6.5–14 (17–23mm) in ½-size steps.

**Figure 4: Participant targeting in the visual condition. The yellow pointer (in target 3) mirrors the ring's position. The target information "7 <--->3 (8)" (indicating *green target at 7, red at 3, 8 wedges total*) was shown as a memory aid for the eyes-free condition.**

### Experimental design

The experiment was a 3x3 within-subjects factorial design, with three wedge size conditions (45°, 60°, and 90°, corresponding to 8, 6 and 4 divisions of the circle), and three feedback conditions (visual, auditory, and combined). Each wedge size/feedback combination had eight randomly generated target start/end positions, and each combination was repeated twice, so every participant performed 144 trials overall. The feedback conditions were grouped, and after each completion of the 24 trials (all three wedge sizes x eight configurations), participants took an enforced 30-second break. The order of feedback conditions was counterbalanced across participants. Before the study, participants received 8 minutes of training per condition. All participants completed the study in 30 minutes or less.

### Participants

We recruited 18 participants (10 female, two left-handed), aged 20–62 (mean 35) via an ad placed on Facebook. We rewarded each participant $100 for their time.

### Results

There were no significant differences ($p < .05$) between the two visual conditions (visual and combined visual/audio); the availability of visual information may have overwritten the audio cues. We therefore combine data from these two conditions for the remainder of the analysis. A multi-way ANOVA found significant differences between the sighted and non-sighted conditions for error, movement time, and effective width. Figure 6 summarizes the results. There was a significant interaction between feedback condition and width for movement time; *post-hoc* testing showed the difference to be between all widths in the audio condition, with width (°)/time (s): 45/2.61, 60/2.21, 90/1.77. No other significant differences were found between target sizes. The distance between targets was significant, especially when the distance was large; a 180° distance took longer than shorter distances in all conditions (visual: 1.0s, audio: 2.7s).

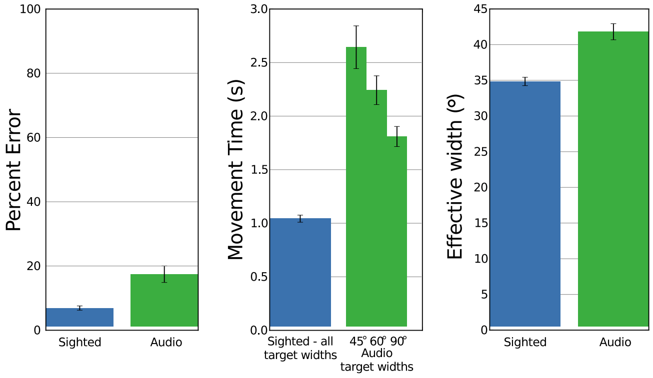


**Figure 5. Study 1 error rate, movement time, and effective width for feedback conditions, with 95% confidence intervals.**

We computed the *effective width* (defined as 4.133 times the standard deviation of the movement endpoints) to inform the minimum target size that we might be able to employ. The upper limit of effective width was 42° in the audio-only condition, which suggests that users can select from up to eight choices (45°) in a menu.

Although our procedure is similar to a Fitts' law-style task, we found a poor fit to the Fitts' equation ($R^2$=0.09). This is likely due to the non-ballistic nature of twisting the ring.

In a post-study questionnaire, participant response to Nenya was positive. Several participants expressed that they would enjoy having similar technology for personal use. We asked participants about strategies used during the audio condition. Several participants mentioned developing visio-spatial mental models, referring to "clocks," "windshield wipers," and "radio dials". Another common strategy was to simply listen for the audio cue that they were seeking, without creating a mental spatial model. Combined with a lack of edge or boundary condition for rotation, this strategy suggests that the devices could be used for both absolute and relative input.

## USER STUDY 2: ONE-HANDED USE

We performed a second, exploratory study to evaluate one-handed use with a reduced number of participants. While we did not plan on performing any statistical analysis due to small number of participants, we were interested in getting a rough understanding of how single-handed use would affect performance. Participants wore the bearing-based version of Nenya (Figure 3b) on their left ring finger and manipulated it as shown in Figure 3a. The experimental setup matched our first study; however, we tested only the visual condition. We recruited a new set of eight participants (one female, all right-handed; ages 27–48, mean 35) from our institution. The study lasted about 20 minutes.

### Results

Feedback from participants was weaker in this condition, and clearly pointed out that single-hand operation of Nenya is substantially harder than two-handed use. However, performance data did not appear very different. Reporting mean/std, at 8.9/10.7%, error rates were slightly higher than with two-handed use. Effective widths in contrast seem comparable, averaging 35.9/17.0°. Movement time was only marginally higher than with two-hand use (1.1/.55s).

## CONCLUSIONS

Our two studies show that Nenya is usable with two hands and, with reduced performance, also with a single hand. The upper limit of effective width for the two studies (42°) suggests that users can control up to eight choices (45°) in a menu.

As future work, we plan to explore additional degrees of freedom, such as tilting the ring or moving the finger itself rather than the ring. We also plan on creating smaller versions of the baselet.

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