RunAhead: Exploring Head Scanning based Navigation for Runners

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ABSTRACT
Navigation systems for runners commonly provide turn-by-turn directions via voice and/or map-based visualizations. While voice directions require permanent attention, map-based guidance requires regular consultation. Both disrupt the running activity. To address this, we designed *RunAhead,* a navigation system using head scanning to query for navigation feedback, and we explored its suitability for runners in an outdoor experiment. In our design, we provide the runner with simple and intuitive navigation feedback on the path s/he is looking at through three different feedback modes: haptic, music and audio cues. In our experiment, we compare the resulting three versions of *RunAhead* with a baseline voice-based navigation system. We find that demand and error are equivalent across all four conditions. However, the head scanning based haptic and music conditions are preferred over the baseline and these preferences are impacted by runners' habits. With this study we contribute insights for designing navigation support for runners.

Author Keywords
Navigation for Running, Head Scanning, Audio Feedback, Haptic Feedback.

CSS Concepts
• **Human-centered computing~Usability testing; Interface design prototyping**; Auditory feedback.

INTRODUCTION
Running is one of the most popular forms of exercise around the world [1]. It is an activity that does not require any special equipment, complex organisation or particular setting. It can be practiced in almost any environment. Runners have the freedom to just put on their shoes and start exercising. However, one of the main challenges related to running is navigation. People usually refrain from running in unknown places because they fear getting lost.

Currently there are no existing navigation support systems for runners that prevent getting lost without disrupting the running experience [28]. Indeed, running constitutes an example of Situationally Induced Impairment [37]: Runners are limited by their mobile state and it is difficult for them to perform any other task during the activity, such as navigation. Screen-based navigation support systems require a division of attention that can be dangerous or force runners to interrupt their activity. Haptic systems provide cues that are not intrusive but easily missed due to the intensive physical nature of the activity. Finally, voice directions are concise and comprehensible but can be disruptive for the running experience and missed due to external noise or lack of concentration.

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Providing effective and less disruptive navigation support for running thus constitutes an interesting challenge. In our work, we explore the creation of a natural, simple and intuitive navigation support system. We introduce *RunAhead*, a system that guides the runner by detecting when s/he is approaching an intersection, intercepting her/his head movements when scanning the different available path options, and providing simple feedback on the correct path to follow. We designed our system considering two types of runners, those who run listening to music and those who do not, preferring to be immersed in the environment. We combine our head scanning mechanism with three different feedback modes, two auditory and one haptic, and test the resulting three conditions against a baseline voice condition providing traditional turn-by-turn voice directions.

Our main contributions are: (1) the design of *RunAhead*, a navigation support system that exploits the runner's natural head movement when scanning different path options and combines it with less intrusive, simple binary feedback on the path to follow; (2) the evaluation and comparison of *RunAhead* and its different feedback modes with a baseline voice navigation system; (3) the implementation of a *RunAhead* prototype that is lightweight and comfortable for the user. Finally, we outline insights gathered from the evaluation of our prototype that can inform the design of future navigation support systems, not only for running, but also for other activities.

RELATED WORK
To situate our work, we start with a review of navigation support in general and discuss the use of scanning. Then, we focus on the specific context of running.

Navigation Support and the Use of Scanning

Existing approaches on navigation support mostly consist of providing turn-by-turn directions to efficiently guide the user along a given path. They provide audio, visual or haptic indications. While most solutions provide indications without specific user request, some have explored the idea of letting the user actively scan the environment to obtain information, in order to be less disruptive. In the following, we first review prior art related to the different feedback modes used and then focus on prior art involving scanning.

Audio support has been explored in terms of voice-based and sound modulation techniques. Products such as Google Maps, Waze and TomTom devices provide voice-based turn-by-turn directions as navigation support for pedestrians, cyclists, runners or for in-vehicle navigation. These systems guide the user through explicit spoken commands, such as “turn right”, and are often accompanied by visual support on a map showing the user’s position and surroundings, and the path to follow.

Sound modulation has also been explored for waypoint navigation and touristic POI discovery [24][25][27]. By modifying the properties of the audio, several solutions aim at indicating turn-by-turn directions [21][22] or conveying the overall bearing towards the target location and possibly other information, like the distance from the target [40][43]. These approaches usually modify the stereo properties of the sound and thus require the user to carry headphones to be able to decode the signal properly. Their aim is to succinctly attract the user towards the target location.

Visual navigation support mainly consists of visualizing the user’s actual position and the path to follow on a map, usually on a smart-watch or a phone, e.g. [6]. This visualization is often provided as a complement to voice-based turn-by-turn directions. It provides a fall-back solution whenever indications have been missed and, at a glance, allows to reassure the user that s/he is on the correct path. However, it requires the user to remove his attention from his primary task and explicitly look at the map [28].

Other visual methods such as encoding directional information as colour patterns also exist. Clairbuoyance [23] maps colour to directions integrating it in googles for swimmers, while [26][41] add LED based navigation systems fixed on the helmet to guide cyclists. Various commercial on-bicycle navigation systems also encode direction and distance as colour patterns [11] or provide turn-by-turn navigation [12]. Augmented Reality has also found its way in recreational navigation in games like Pokemon Go.

Haptic solutions use vibro-tactile feedback and vibration patterns to encode directional information like bearing and distance from the destination. Shoe-me-the-way [36], for instance, gives turn-by-turn directions through vibrating actuators near the ankles. Similarly, vibration cues were used and integrated on the handlebar of a bicycle to provide turn-by-turn directions [31]. Others have used the phone [33] or a waist belt to guide cyclists and pedestrians through vibrotactile feedback [39][42][19]. While haptic cues are less intrusive than visual ones, prior research shows that they are also easily missed or misunderstood [29][30][39].

The idea of allowing users to actively scan the environment for feedback has been explored in some prior research. In most cases, the user explicitly scans the environment by carrying, moving and pointing a hand-held device towards the direction to query [16][35]. In other cases, eye-tracking devices have been explored but only tested in a lab setting [20][34]. Other work has started to explore the head scanning movement as it is more easily traceable (than eye-tracking) in a real-world setting. Indeed, in a real-world setting, gaze tracking would require more intrusive hardware and more complex and expensive technology to be implemented. The use of head movements to detect gaze to query for information has been studied previously in the context of the shop-window, where information is projected on the window [18]. The aim of our solution is thus to investigate the possible benefits of transposing the idea of querying via head scanning movements to the context of navigation for running in order to address limitations of the previously listed methods, and to propose a more lightweight and less complex solution. To our knowledge, the benefit of exploiting the head movement to let the user query for navigation information has not yet been explored in this domain. Our work aims at contributing to the assessment of this method. We now review the state of the art in terms of navigational support for running, before discussing the details of our solution and user test.

HCI for running

Visual map-based feedback modes are particularly unsuitable in the context of running: with such a fast-moving activity, having to explicitly and regularly look at a map for directions adds too much effort and disrupts the activity. Still, some existing solutions, such as the RunGo App, use map displays to back up and complement voice directions. Similarly, others use it to support explorative running, such as RunNav [28], necessitating thus less frequent consultation. However, they still require runners to look at the screen for information, at least sometimes, and do not provide any support to follow a pre-defined running path. Other visual support, such as colour encodings or AR-based systems seem also less appropriate for a running context. Indeed, they would require runners to wear specific glasses or cumbersome devices to deliver the visual signal which would in turn disrupt the running experience.

Haptic solutions are not commonly used to give directions during running, but rather to provide a posteriori warnings when the runner is off track (e.g. Strava App and Garmin watches). Such a haptic vibration alert is typically given when the runner is more than e.g. 20 meters away from the planned path and should check on the map how to get back to it. While this kind of warning is useful it may easily go unnoticed, especially if the runner is immersed in the activity, not attentive and receptive to the vibration signal.

Audio appears as a suitable way to communicate information without requiring the user to carry out additional movements or to shift attention too much away from the running activity itself. Voice-based navigation is therefore used in most commonly available commercial systems. In the context of running, we found no prior research assessing sound modulation or sound cues to encode navigation information.

From our review of the state of the art we concluded that little is known about how to prevent runners from getting lost while minimizing the disruption of the running experience. Screen-based navigation support systems require a division of attention that can be dangerous or force runners to interrupt their activity. Haptic systems provide cues that are not intrusive, but may be easily missed due to the intensive physical nature of the activity. Finally, voice directions are concise and comprehensible, but can be disruptive for the running experience and missed due to external noise or lack of concentration. Thus, providing effective and less disruptive navigation support for running constitutes an interesting challenge.

DESIGN

In order to address the limitations of the previous work, our objective was to design and test a *natural*, *simple* and *intuitive* navigation support system for runners.

Natural Support: We start from the observation that, when arriving at an intersection, runners naturally perform a head scanning movement to look at and evaluate the possible path options and their suitability for running. We explored this hypothesis in a previous experiment where participants confirmed it [38]. We exploit this natural *head movement* to let the user *query* for information about the direction s/he is looking at.

Simple Support: We keep the navigation feedback simple by providing only *binary* signals, telling the user whether the path s/he looks at, at an intersection, is the good one or not. We do not attempt to communicate additional information (e.g. distance to next intersection) as this would require a more complex encoding which may result in a signal that is too difficult to decode during the activity.

Intuitive Support: We aim at defining intuitive signals that runners can instinctively map to the correct meaning. For instance, in one of our feedback modes we only switch between *high* and *low* sound volume which is immediately understood as *good* and *bad* direction.

Furthermore, based on findings from our previous research [38], we acknowledge the need to alert users when taking a wrong path. Indeed, technical problems are always possible, navigation cues may be unclear, missed or misunderstood. Therefore, we add an un-ignorable audio warning signal [5] when the runner leaves an intersection on a wrong path.

RunAhead Navigation Support

Turn-by-turn navigation is based on a pre-defined path to follow. It provides the user with instructions on which path option to take at each intersection. At each intersection, there is at least one good and one bad path option available and the navigation aid aims to guide the user towards the good one.

Our design is based on the definition of a circle around each intersection, and on mapping the enclosing angles of the good path options onto this circle (Figure 1). When the runner enters such a circle, the *RunAhead* head scanning mechanism activates, continuously monitoring the direction in which the runner is looking, or, more precisely, in which s/he has turned the head. It then compares the angle of this direction with the enclosing angles of the good path option and provides navigation feedback depending on whether the runner is looking in the direction of the good path.

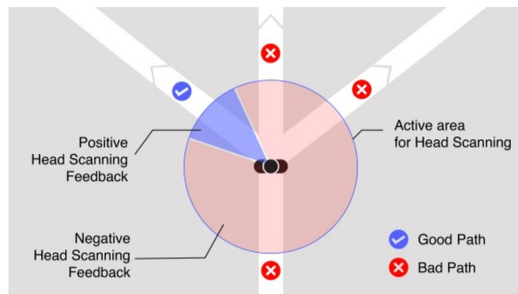

Figure 1. Intersection with Good and Bad Paths. Once the runner enters the circle, the Head Scanning Mechanism is activated; once s/he leaves the circle, a safety check is applied and a warning issued if the runner took a wrong direction.

Once the runner leaves this circle, the head scanning mechanism becomes inactive and the navigation system double checks whether the runner has left the intersection on the correct path or not. Indeed, the runner may have left the intersection on one path, but looking in a different direction. If the runner has not taken the good path, the system generates a warning signal to urge the runner back to the intersection to follow the correct path. Otherwise, the feedback system inactivates until the runner reaches the next intersection, or, more precisely, the circle around it.

RunAhead Feedback Modes

We have investigated three feedback modes providing navigation cues in response to the head scanning mechanism, two audio based and one haptic. We do not consider visual feedback because, as mentioned, it would be too disruptive for the activity. For audio, we propose two systems suitable for two types of runners with the opposite habits of running *with* or *without* music. We added the haptic feedback mode for two main reasons: First, according to our research, runners who choose to run without music do so to be immersed in the environment. Adding an audio signal only for navigation purposes may therefore not be the best choice for these runners, since this would disrupt this immersion in the environment. Second, this allows us to test, more generally, how runners react to haptic (and thus more succinct) feedback compared to audio when it is associated to the head scanning movement.

Music: For runners who exercise with music, we decided to use the volume as a simple way to communicate whether the runner is looking at the good path or not. If yes, the music volume remains normal and unchanged. Otherwise it is set to low. Other systems, such as Android OS, already use this kind of feedback to provide notifications alerts, e.g. for SMS. We consider changing the volume a good way to provide information as it takes advantage of an existing element, the music, instead of introducing something new that might disrupt the running experience.

Audio Cues: For runners who practice without listening to music, we designed a second audio feedback mode, providing audio cues as navigation aids. In this case, we assigned one sound cue to the good paths and another one to the rest. We had initially decided to provide only negative feedback signals, as this was similar to our approach with music. However, after an initial pilot test, we eventually added a positive feedback signal to explicitly confirm correct directions and reassure the runner. This positive sound is played once when facing a good path and again only after having looked away, in a bad direction. The negative sound is repeated regularly as long as the user does not look at the good path. For our experiment, we selected the audio cues to be easily mapped to good or bad feedback.

Haptic: Following the idea that the feedback should be simple and binary, we designed our haptic feedback mode to use vibration only as a negative signal, i.e. when and as long as the runner looks in a wrong direction at an intersection. Thus, the *absence of vibration* implicitly constitutes the positive signal, given when the user looks at the good path. The rationale behind this choice is to be coherent and the least disruptive possible (since there is no vibration between intersections). Even though previous research seemed to illustrate that haptic cues can be easily misunderstood or missed, *RunAhead* somewhat palliates this as follows: first, it provides only *simple binary* haptic signals, which makes them easy to understand; second, unlike other systems using haptic feedback as an alert that may be given *any time during the run*, it uses haptic feedback *only at intersections*, i.e. precisely when the runner is actively looking for information. Therefore, the runner's attention should be instinctively focused on our system preventing her/him from missing the signal.

Defining a Baseline

To compare our navigation system using head scanning with existing solutions for runners, we also added a voice-based turn-by-turn navigation system as a baseline. The rationale behind this choice is that voice-based solutions are currently the most commonly used navigation support systems for running. Initially, we considered using an existing application as baseline. However, as the paths in the park we selected for our user tests were not always present in the map used by that application, and also to make the comparison fair and equal, we finally decided to use the GPS component of our own system to trigger voice directions. Directions are triggered when the runner approaches an intersection. i.e. enters the circle around it (Figure 1). Imitating existing navigation systems that give directions in advance, our baseline system then once plays a corresponding audio clip (one of *turn right, turn left, turn soft right, turn soft left, continue straight ahead*). Finally, we augmented this baseline system with the safety mechanism described above that alerts runner when leaving an intersection on a wrong path. Table 1 summarizes the different conditions tested in our experiment.

Table 1 The four conditions tested in our experiment: three versions of *RunAhead* combining Head Scanning with different feedback modes and one Base condition using voice.

Condition	Head Scanning	Feed-back	Feedback Detail
RunAhead-Music	Yes	Music	Volume change: normal/low
RunAhead-Audio Cues	Yes	Audio Cues	2 sound clips: "Yeah!"/Gong
RunAhead-Haptic	Yes	Haptic	Vibration: off/on
Baseline-Voice	No	Voice	Speech instructions

Design Requirements

To successfully implement the solution previously described, the system needs to meet a number of requirements. From a functional perspective, the system needs to detect the runner's location and calculate her/his distance to the intersections across the tour. Additionally, it must track the runner's head orientation with respect to the north and compensate the head rotation on the X and Y axis to provide consistent feedback regardless of the movements inherent to the running activity. The system also has to be able to provide the various auditory and haptic feedbacks.

From a technical perspective, the system needs to be completely wireless and include its own power source. It has to respect ergonomic principles, be compact, lightweight and have the right shape to be comfortably carried by the runners without hindering the activity. It must also be robust enough to withstand the nature of the activity as well as the context of use.

IMPLEMENTATION

In a prior study [38] we used the phone sensors to track both the GPS location and bearing of the participant's head by attaching the phone to a helmet, worn by the participants during the run. This solution had limitations in terms of user experience, being too heavy and warm for the running activity. To overcome these issues, we developed a custom device for the head tracking functionality (Figure 2). This device is connected wirelessly to a phone also carried by the runner (in the hand or an armband) that takes care of location tracking, data storage and processing, and of providing the corresponding auditory or haptic feedback.

Next, we describe our prototype in detail to ensure the reproducibility of our study.

Custom device

RunAhead uses an Arduino MKR Wifi 1010 board [13], which integrates low power Wi-Fi and a Li-Po charging circuit, allowing the board to run on a rechargeable LiPo battery of 3.7v and 650 mAh. To this board we connected a CMPS-12 sensor, which combines the readings of a 3-axis magnetometer, a 3-axis gyroscope and a 3-axis accelerometer to make a tilt compensated compass. This sensor runs algorithms that remove the errors caused by tilting the PCB and returns stable readings despite changes in roll and pitch resulting from head movements inherent to a person running. The software was written in the Arduino IDE. The board was programmed to create a WiFi hotspot and send the unidirectional value of the heading returned by the sensor, normalized to a range from 0 to 360 degrees.

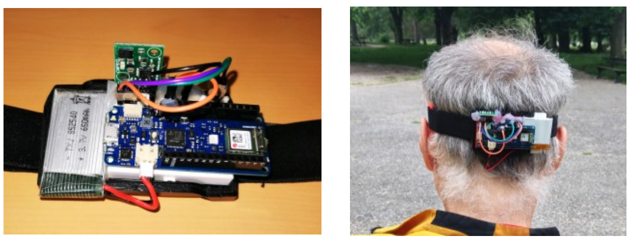

Figure 2. *RunAhead* Custom Device for head tracking.

To fix the components on the head of the participants we adapted a commercial headlight [14] that includes a plastic casing fitting our space requirements and a flexible and adjustable strap to fix the device to the head. The resulting device is compact, stable and convenient for the users, who judged it comfortable during the experiment. During tests conducted under rainy weather, we covered the device with a plastic film to protect the components from the water.

Mobile Phone

For our test, we used a Huawei phone, model Mate 20 Lite, running Android OS version 9. In order to carry the phone while running we used a commercial armband. To develop the *RunAhead* app we used Processing language [15] and the Android mode of the Processing Development Environment (PDE). This allowed us to easily deploy Processing sketches, implementing the *RunAhead* app on the Android phone.

At start up, the phone first connects to the Wi-Fi hotspot created by the Arduino board. Our Processing sketch, the *RunAhead* app, then starts receiving and processing the GPS location from the phone and the compass values from our custom device. Using this information, it executes the head scanning mechanism explained previously and triggers the corresponding feedback and alerts as described previously. For each tour, the app therefore stores a table containing the location of all the intersections and the angles of the corresponding good and bad paths. Once the participant reaches the end of the tour, the app plays a celebration audio. To implement the baseline voice condition, we simplified the *RunAhead* app to ignore the compass and only exploit the GPS values.

The app delivers all auditory (music, voice and audio cues) and haptic (vibration) feedback through the phone. Audio feedback is delivered through the speakers of the phone, where we adjust the volume to the maximum. For the music version we selected 3 songs from a YouTube playlist [4] for runners while for Audio Cues we selected two sound clips, one positive ("Yeah!" [2]) and one negative (Gong [3]). In the case of haptic feedback, we decided that the participant should hold the phone in the hand to clearly feel the vibration. This was a temporary solution for the experiment; in the final version, this could be done using a smartwatch or custom device designed to be comfortably worn by the user.

EVALUATION

In order to evaluate our system, we conducted a within subject controlled experiment in a public park. We wanted to evaluate how *RunAhead,* combining head scanning with its three different feedback modes, and the voice-based baseline compared in terms of effectiveness, demand and usability. Therefore, we asked participants to complete a set of running tours under the four conditions (Table 1). During the experiment, we collected qualitative and quantitative feedback about their experience.

Participants

We distributed flyers in running events and used social media and snowball sampling to recruit our participants. Potential participants filled an online questionnaire stating the distance and number of times they usually run per week, whether they listen to music when running, whether they use a navigation support system and which one, the locations where they typically run, and whether they had any hearing or sight problems. We also communicated details about the test, the distance to run, the overall duration of the experiment, and the available dates.

We recruited 24 participants (11 male and 13 female), aged from 17 to 56 years (M = 35.1, SD = 10.5). Most participants ran regularly, with 13 participants running more than 2 times a week, while 5 participants were occasional runners running less than once a week. Generally, in each of their runs, 12 participants ran between 5-10 km, 11 participants ran more than 10 km and 1 ran less than 5 km. 6 of our participants always listened to music when running, 9 only did so only sometimes and 9 never listened to music. To compensate them for their efforts, every participant received a voucher equivalent to 25 USD.

Apparatus

To prevent any learning bias in our experiment we defined four different running tours to be completed by all the participants and permuted the order of the four conditions. Hence, each participant ran the four tours in the same order, but with permuted conditions. We identified weather, time and crowd as other possible confounding variables and noted them down to analyse their effects on the study.

Defining and Mapping Tours

We selected a public park as a safe location to conduct our test. Among the parks in the neighbourhood we chose one considering the following criteria: it should be sufficiently large to define a number of significantly different running tours, and easily accessible and sufficiently unfamiliar to our participants to avoid any bias in the experiment.

We started using Google maps to define running tours within this park. However, when we visited the park we noticed important discrepancies between Google maps and the actual park: several paths were not present, so we had to map the paths and intersections manually. To map our running tours, we thus manually noted the GPS location (latitude and longitude) of each intersection as well as the degrees of each path leaving it. When defining the angle range for each path, we added a default margin of 25 degrees on either side. We reduced this margin for paths that were separated only by small angles to avoid overlapping (Figure 3). We also adjusted the default radius (empirically set to 15 meters considering a running speed of 8-10 km/h) of the area around each intersection used to trigger the feedback: We increased it for intersections involving more and/or larger paths, and decreased it where subsequent intersections were close to avoid any interference. In the future, we also plan to dynamically adapt the radius of the circle to the runner's speed.

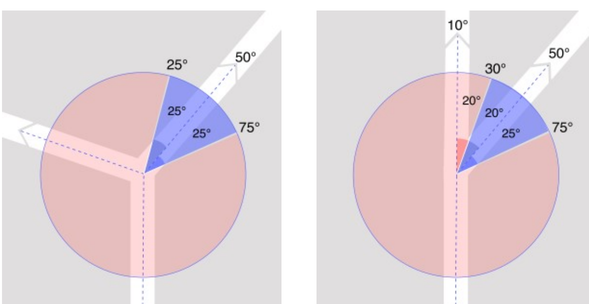

Figure 3 Angle Range defined for the good path. A default margin of 25 degrees on either side (left). This margin is reduced when neighbouring bad paths are close by (right).

We defined the four running tours that included between 9 and 14 intersections and covered a distance of around 1 km each. All tours started and ended in the same area. Even though they shared a few segments, we varied their order and directions so that the four paths were sufficiently different to not bias the results. Indeed, during the pilot test, the participants did not even recognize any repetition of segments across the different tours.

Hypotheses

Through our experiment, we evaluated the following hypotheses:

1. Using head scanning, *RunAhead* is as effective as the voice baseline in guiding runners through a predefined path, i.e. it is neither generating more errors nor being more demanding in user attention.
2. *RunAhead* improves the running experience compared to voice turn-by-turn navigation.
3. The preference of navigation feedback is affected by the runner's habits of listening to music or not.

Measures

To evaluate our hypotheses, we collected three measures: number of errors, task workload, and system usability.

Errors can occur at each intersection and have a binary value: an error occurs if a runner leaves an intersection in a wrong direction. As our prototype was dependant on compass and GPS readings which were not always reliable, we decided to evaluate the errors triggered by technical issues separately from the explicit user errors. We thus distinguished *System Errors* (wrong indication from the system) from *User Errors* (wrong decision made by the user while the system was working properly). To identify and count errors, we analysed both, the runners' GPX traces and the video recordings made during the experiment (Figure 5). We identified the errors through the deviation of the GPX traces from the pre-defined tour paths (Figure 4). We then reviewed the video recordings of the test runs, including the instructions and warning signals provided by the system to the user, to cross-analyse the errors and categorised them according to their cause.

We measured the *task workload* required to complete the task through the NASA Task-Load Index (TLX) [8] and the *system usability* using the System Usability Scale (SUS) [9]. For each condition, the participants were asked to fill the two corresponding questionnaires right after they had completed each running tour. Finally, we collected the preference and individual opinions of the participants on the four conditions and their overall experience through semi-structured interviews.

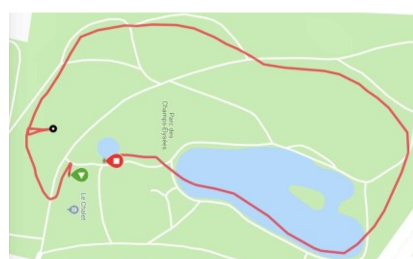

Figure 4 GPX trace of a participant where the black dot marks a deviation from the route

Procedure

For the experiment, we welcomed each participant at the entrance of the park and walked with her/him to the starting area of the tours, where we sat on a park bench for the initial explanation. We gave an overview of the experiment, the data to be collected, its storage and processing. Then we asked the participant for her/his consent. Next, we described the four conditions in detail, supporting the explanation with illustrations depicting how each one works. Complementing this explanation, we trained the participant at one dedicated intersection. There s/he experienced each condition, as well as the warning signal triggered when leaving an intersection on a bad path.

Once the participant was comfortable with the systems, we summarized the specifics of the task to her/him. S/he was instructed to follow the tour according to system indications, to run at a moderate pace and take breaks as needed to complete the required number of runs without exhaustion. S/he was informed that completion time was not an evaluation metric. We explained that the paths were mapped within the boundaries of the park, that s/he was to follow only obvious paths, no short-cuts (e.g. grass surfaces), and that the four tours started and ended in the same area. S/he was also informed that one experimenter would follow her/him to record the runs with a GoPro but without making any contact (Figure 5). Only in case of extreme error would the experimenter intervene. We also informed the participant that the sensors were not 100% accurate and that the system could thus end up giving erroneous signals which s/he was supposed to handle on her/his own. Only after everything was clear we directed her/him to the starting point of the first tour, started the *RunAhead* app and hence the test.

Figure 5. *RunAhead* participant running a tour, followed and video-taped by an experimenter wearing a GoPro.

During the experiment, the participant ran the four pre-defined tours, one with each of the conditions. After each tour, we gave her/him time to recover, providing water and energy bars. During this time, we also recorded her/his first impressions about the condition s/he had just experienced and gave her/him the NASA TLX & SUS questionnaires to fill. We gave an oral explanation of the questions providing also a printed version s/he could refer to at any point. S/he was also free to ask questions anytime if necessary. After completion of the four tours we debriefed through a semi-structured interview focussing on her/his overall experience. We asked which condition s/he preferred and why, and what strategies s/he employed to complete the task in case of error. We questioned the suitability of the different conditions for running in unknown places and explored usage scenarios.

RESULTS

Quantitative Results

Errors. For each condition, we calculated the mean System and User Error probability per intersection over all corresponding runs (Table 2). For both types of error, the Friedman test showed that there was no statistical significance across conditions, (System Error: χ^2=2, p=0.57; User Error: χ^2=0.85, p=0.84). The results illustrate that the feedback is easily understood by the runners. Indeed, there were very few User Errors. As Table 2 shows, most errors were System Errors which were caused by sensor inaccuracies, as discussed later.

Table 2: System / User Error probability per intersection.

System	System Error	User Error
RunAhead-Music	7.3 %	1.1 %
RunAhead-Audio Cues	7.0 %	0.8 %
RunAhead-Haptic	6.7 %	1.7 %
Baseline-Voice	4.3 %	0.8 %

Perceived Load. The analysis of the NASA TLX questionnaire responses showed that the perceived load was similar across all four conditions (Figure 6, left). A Friedman test showed no statistically significant difference between the conditions. (χ^2 (3) = 4.45, p=0.22).

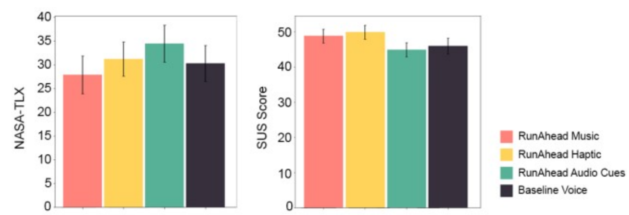

Figure 6 NASA TLX task load (left) and SUS usability score (right) results. Mean value and Standard Error for each condition.

Usability. From the SUS responses, we calculated the mean usability score for each condition (Figure 6, right). The Friedman test showed that there was a significant difference between the conditions (χ^2(3)=8.20, p=0.04). A post Hoc Nemenyi test showed that *RunAhead*-Haptic was perceived as significantly more usable than *RunAhead*-Audio Cues (Z=-2.33, p<0.05). There were no significant differences between the other conditions.

Qualitative Results

We audio recorded all participant interviews collecting in total over 200 mins. We coded them to extract the preferred feedback mode for each participant. We further analyzed the interviews to extract quotes and create affinity groups classifying them into common themes. We identified the following themes: Characteristics of Feedback, Semblance of Control and Usage Scenarios. We discuss the preferred feedback modes and identified themes below.

Preferred feedback modes

Most of our participants (10 out of 24) preferred haptic as it was perceived as the least intrusive. They described it as "*useful and not dominant"*. Two participants said that vibration may be difficult to perceive during strong efforts, e.g. over long distances. However, our participants did not make significantly more errors with *RunAhead*-Haptic. We think that this is because the user is actually searching for information at intersections and turning the attention towards the system.

Music was the second most preferred system (7 out of 24). Participants usually running immersed in music said that lowering the volume "*works perfectly*" as it "*brings them back to reality*" immediately. As they generally run to disconnect and to be immersed in music, they might more easily miss indications of other nature and find voice directions too intrusive. The change of volume was immediately clear for everyone, even for those usually not running with music. Several participants stated that hearing the music *continuously*, also between intersections, made them feel "*more confident they were on the right path*".

Voice came out third, preferred by 4 participants. It was perceived as easily understandable and clear because of "*already familiar car navigation systems*". However, it was also described as "*practical but frustrating*". It annoyed the participants as they often felt that it embodied another person giving them orders.

Audio Cues was least preferred by our users (only 3 out of 24 participants). Still, our participants appreciated the clarity of the distinct explicit positive and negative feedback signals. This was especially the case for those who do usually not run with music. However, most participants found the sound cues annoying over the course of the tour. This might also be because the intersections were very close to each other and they had to listen to the cues very often. Some even described it as "*more authoritative than voice*".

We also found a difference in preference with respect to the running habits: among the 15 participants who regularly or sometimes listen to music, Music and Haptic was equally preferred (n=6 for Music and n=6 for Haptic). Among the 9 participants running without music, 4 preferred Haptic, 2 preferred Voice and 2 Audio Cues while one participant preferred Music. The latter was a surprise to us. When asked for the reason, the participant stated that he usually ran without music because "*he had never spent the time to prepare a dedicated playlist for running*".

Characteristics of the Feedback

RunAhead's three feedback modes differ in the characteristics of the signals they provide and this impacted their likeability. In the Music feedback condition, we provide noticeable positive and negative feedback at the intersections. Using volume to provide information was liked by most participants for not being too intrusive but still clear. However, some participants felt it impacted their experience of enjoying the music. P8 said:

> "I sometimes listen to music while running but then I am very sensitive to volume [change] … anyway, I prefer the haptic channel"

A positive side effect of this mode was that the music between intersections was perceived as continuous positive feedback, which made participants feel reassured at all times, even if, initially, it was not intended as such. P6 said:

> "Maybe it is the music, ... I felt more relaxed and confident with this one ... as long as there was music it [the path] was good"

With the Audio Cues condition, there is explicit positive and negative feedback given at the intersections, with no feedback in-between. Introducing our two sounds was not highly appreciated by the participants. Even though they were very clear and left little room for misunderstandings, the repeating and rapidly alternating cues when head scanning the possible paths were perceived as too annoying.

Finally, in the Haptic condition, we only provide explicit negative feedback (vibration) at the intersections, while the positive feedback is implicit (no vibration). The subtlety of this condition was highly valued as it did not disrupt the activity. Furthermore, some runners who practice with music liked this option because they prefer to enjoy their music without interruption. However, the fact that this condition was only providing negative feedback was a drawback for some participants. Also, it felt contradictory for two participants who were used to another device that uses vibration to provide *positive* feedback [7]. P16 said:

> "I am used to A.R.V.A. which beeps when you come closer to the target, and here it is the opposite; that made it more difficult for me"

Semblance of Control

With *RunAhead* people felt more active and in control since they could query for directions. P15 stated:

> "With the head movement …I felt more in control as I could be active myself looking at the possible options ... I am anticipating, more confident …, more active than with the voice"

Participants asked for (even) more control than just querying at the intersections. In particular, they wanted to be able to activate the navigation mechanism explicitly, P22 said:

> "sometimes you see the intersection well in advance and you would like to … ask in advance for direction"

Additionally, some participants wanted to be able to ask for confirmation that they were on the correct path, when between intersections.

In case of error, we observed that participants developed their own learning strategies to stay in control. They would go slow, stop at the first negative signal or just go ahead and come back if necessary. Running in a circle at an intersection was also a common strategy, allowing to scan without stopping. Overall, our participants didn't consider occasional errors a problem. P17 said:

> "having to come back to an intersection once or twice in unknown places is not such a big deal: that's what you do already anyway in unknown places"

Also, our alert after leaving an intersection in a bad direction worked very well for all the systems and was well appreciated by the users. It helped them correct their navigation path without deviating too far in a bad direction.

Usage Scenarios

Our participants agreed on the appropriateness of our system for running in unknown places. P6 stated:

> "If you don't know the place, if you had this ... it is very good."

While it helped people to run in unknown environments without having to prepare (as one would have to do otherwise) and/or getting lost, it does not support any learning about the environment. Also, it does not constitute a tool for exploration. P24 stated:

> "When following a navigation system [in general] it is not the same as exploring on your own: you follow the indications a bit blindly - you will not learn to recognize the environment/path later the same way."

Our participants were quite imaginative and suggested possible alternative uses for our system. P23 stated:

> "If there is a guided tour you could listen to the facts about the city and the system would tell you where to go at the same time".

The majority of our participants mentioned its suitability for hiking and cycling. One suggested that the system could be used for gamifying treasure hunts while another proposed to use it to share his running paths:

> "I would definitely give it [the system] to people visiting me, with my best tours loaded ..."

DISCUSSION

Below we discuss our findings and outline challenges and opportunities for future systems.

RunAhead is effective in providing navigation support

We consider a navigation support system as effective if it does not generate errors and is not demanding in terms of user attention. When comparing the system and user errors made by the participants with *RunAhead* compared to the baseline, we did not observe any significant differences. While *RunAhead* could potentially have generated more system errors, as it relies on additional data (path option angles) and sensors (compass), this was not the case.

With respect to user errors, we found that, in all conditions, they were mainly related to the characteristics of the intersections in which they occurred. Intersections with very close adjacent or even parallel paths proved challenging with all conditions. Head scanning proved particularly error-prone for sharp, close to U-turns: here, the participants often turned their heads only slightly, and not enough to reach the required angle to get the correct feedback, thus failing to identify the right path. The baseline system, generated errors specifically at one intersection with many path options, making it difficult to map the voice command to the single correct path. In one case, an error was also triggered by a contextual factor: a noisy truck made it impossible for the participant to hear the audio feedback. The other confounding variables monitored during the experiment did not have any impact on the effectiveness of the systems.

With respect to demand, our participants did not perceive *RunAhead* as more demanding than the baseline. All participants completed their tasks successfully without intervention of the experimenters. Thus, considering the results on demand and error, our hypothesis 1 is confirmed.

Using Head Scanning improves the running experience

All our users were familiar to voice navigation due to its similarity to traditional GPS navigation aids in cars. They were quick to understand the baseline system and comfortable using it. However, most participants did not find the voice commands appropriate for running. On crossings with multiple options, voice indications were sometimes perceived as difficult to map to the correct path, especially without visual support like the map in the car. One participant also had problems in distinguishing right from left which was an issue with the speech commands. Also, most participants perceived voice commands as too directive, causing stress, annoyance and frustration.

Our solutions proposed with *RunAhead*, using the head scanning movement to trigger navigation feedback, were appreciated by our participants. Some expressed concerns regarding the fact that they don't necessarily "*always run in the direction they look*". They felt the system was sometimes too sensitive, generating false alarms. However, most of them also stated that the second time they tried it, it was easier and more instinctive to use. We believe that with more exposure to our system, runners will find it even more natural. The participants preferred *RunAhead*'s feedback modes as they considered them *"fun, playful, less annoying and more pleasant"*. They also described the condition with music to be *rewarding* and *boosting motivation*.

Most participants stated that they prefer *RunAhead* with Haptic or Music feedback modes over the Baseline-Voice condition. This is not true for the *RunAhead*-Audio Cues. This also corresponds to the results of our usability analysis proving that the issue was with the feedback mode rather than the head scanning mechanism. These results partially confirm our second hypothesis.

Different feedback suits different types of runners

We observed that our participants were more congenial with our system as it gave them options of different feedback modes where one or more corresponded to their preferences. Participants usually running with music liked both versions of *RunAhead*, Haptic and Music, almost equally. The music condition did not come across as the preferred choice. We believe that the fact that our participants did not choose the music themselves may have had an impact, as observed in prior research [17]. Participants running without music strongly preferred the Haptic version of *RunAhead*, compared to the one with Audio Cues and the baseline Voice condition. Only one liked the Music condition. This result is in line with their running habits. Overall, these findings partly prove our third hypothesis: There was a strong correlation between people who do not listen to music and their feedback mode preference. However, this was not clearly the case for runners who usually listen to music. Future tests with more personalization options could be beneficial to revisit our hypothesis.

Design Opportunities

Adapt to intersections. In case of intersections with too many options and large angles, the head scanning movement, i.e. turning the head all around from backwards left to backwards right, seems to be too cumbersome. We might use stereo feedback to indicate on which side to scan for the right path, e.g. more to the left or to the right with respect to the current head direction.

Actively ask for signals and reassurances. Some of our participants expressed moments of uncertainty. This was due to the absence of information about the nearness to the intersection and whether the head scanning system was active or not. We could give the user the control to request feedback and information about the status of the system when necessary.

Detecting intention of movement. Some participants stated the feeling of being constrained or annoyed by unnecessary feedback when moving their heads to look around at the environment while the head scanning mechanism was active. This issue could be solved if we could detect the intention of the head movement, e.g. we could explore the use of machine learning techniques to provide feedback only when needed, or give the user the possibility to de-activate the feedback once s/he recognized the good path.

Make system behaviour explicit. Our participants faced some system inaccuracies. From an interaction perspective, we can provide tools to deal with those errors in a better way by making the system inaccuracies more explicit. It may be helpful to inform the user about the level of confidence in the signal. The system would tell the user ‘Hey, I am lost too!’ to help her/him react and deal with it.

These issues outline the aspects of our design that should be improved in the future.

Limitations

The choices we made during this study were dictated by practical, ethical and liability considerations.

Context of Use. Our test was set-up in the controlled environment of a park where we could ensure the safety of our participants. Hence, we lack knowledge of how our system will perform in other contexts like the city centre. As one participant said, it may be a problem when you have to look around to check for cars at crossings. More studies in different contexts are required to understand different types of head scanning movements and to distinguish them. Additionally, we might encounter new technical challenges in contexts where buildings and other structures affect the readings of our sensors. Further tests are needed to understand and address such potential issues.

Complex and too many intersections. We set up our tours to test the clarity and understandability of our navigation cues. Therefore, the tours included many intersections over proportionally only little distance between them, compared to what a realistic tour would look like. We also faced issues with intersections that were too close to subsequent intersections. A more elaborate processing method would be required to handle such complex intersections properly.

System inaccuracies. Compass drift caused around 20% of the System Errors, and GPS inaccuracies most of the rest. This resulted in late feedback and false warnings during the test. Even though these errors won't be completely avoided, there are strategies to get better results, e.g. using map matching techniques to improve GPS localization.

Personalisation. A few participants said that, with *RunAhead,* they would have liked the option of choosing their own Audio Cues or Music, or to invert the haptic signal, i.e. vibrate when the path looked at is correct and not otherwise. Others also suggested to combine the music and the haptic feedback modes into one to make the resulting feedback even clearer. We will implement this in the future.

CONCLUSION

In this paper, we presented *RunAhead*, a system that uses head scanning as a new way to query navigation information during running. With *RunAhead*, we provided three different ways of delivering feedback on the quality of the path looked at, two audio based (Music and Audio Cues) and one Haptic (vibrations). We described the design considerations behind the system and its implementation. We experimented *RunAhead* and compared it with a baseline system providing voice turn-by-turn navigation. The analysis of the collected data showed that two versions of *RunAhead* (Music and Haptic) were preferred to the baseline. Overall, the Haptic version came out first, being perceived as the least intrusive. In future work, we plan to improve *RunAhead*, taking into consideration the insights from this study. We would also like to test it in other contexts and explore the suitability of our system as an exploratory tool rather than for turn-by turn guidance only.

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