Exploring Runners' Preferences of Drone Based Feedback to Support their Well-Being

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ABSTRACT

While drones are frequently used to capture aerial footage of runners, their utilization to enhance well-being of runners through real time feedback has not been fully explored. In this paper we investigate runners' feedback preferences regarding drone-feedback and its implications for drone-feedback design. Using an embodied storming approach, we engaged 25 participants in a running activity to gather their preferences on running-related feedback delivered through drones. Our analysis uncovered runners' top three preferred feedback parameters were pace, trunk lean, and time. Additionally, participants preferred instructive feedback for posture/technique-related parameters, and activity-related feedback focused on their current state. Furthermore, we present results from a reflexive thematic analysis, highlighting design considerations for drone feedback and its impact on designing drones for runners. We hope that these findings will inspire future researchers to explore the use of drones in promoting runners' well-being.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**; **Empirical studies in HCI**; **Field studies**.

KEYWORDS

running, running well-being, human drone interaction, multi modal interaction, embodied storming, thematic analysis, user preferences evaluation

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1 OVERVIEW

It is evident that the sport of running is enriched with a wide range of interactive technologies in various forms, such as applications, smartwatches, and wearable sensors that monitor different aspects of runners' physical health during activity [14, 29, 49]. These technologies generally enable runners to track their activity levels and obtain bio-mechanical data to understand their running patterns, identify performance changes and detect potential injuries [27]. While most technologies are positioned on or attached to runners' bodies, to facilitate real-time sensing and feedback runners can also benefit from technologies situated around their bodies that can provide real-time feedback on their movements and running activity. In this context, the systematic review of research in the human-drone interaction field by Herdel et al. [26] and Tezza and Andujar [59] discusses the potential of drones to support users in various exertion activities, one of which is running.

In the context of running, the work of Graether and Mueller [23] proposed the use of drones as companions for runners, highlighting drone's ability to communicate through motions. Mueller and Muirhead [43] expanded on this concept, exploring various design dimensions for drones accompanying runners. Their research showcased the impact of simple drone motions on runners' behaviour. But by incorporating additional technologies and refining drone design there is potential to create drones capable of accompanying runners while offering detailed feedback on their running performance [46, 63].

Mayer et al. [39], Romanowski et al. [51] and Baldursson et al. [7] have presented various scenarios where drones equipped with additional technologies like cameras, speakers, projectors and laser pointers could support runners. Romanowski et al. [51] conducted a limited study that showed how camera drones can be used to cheer marathon runners. Despite the valuable insights provided by this work on the applications and functionalities of modified drones, they do not explore runners' preferences for feedback through drones, creating a significant knowledge gap. However, the work of Baldursson et al. [7] involves runners in the loop of designing feedback, but their study only focused on users' perceptions of pace feedback developed through a research-through-design approach, without exploring runners' preferences for feedback on pace that would best suit their needs.

To address this gap, we aim to involve runners in the design process, seeking insights into their preferences for how a drone should present feedback on running parameters and its implications on the design of drone-feedback. Building upon existing works and drawing inspiration from them, our aim will be to provide feedback-design recommendations for drones that serve as coaches,

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supporting runners' well-being and performance during their runs, a function identified by several works [17, 43, 46, 56].

Overall, runners can benefit from a drone that captures and analyzes their movement, and thereafter provides the runner with suitable feedback in real-time [2, 27]. While earlier works have shown methods to capture and analyze movements through videos in real-time [12], little work has been done to investigate how a drone should present feedback on runners' movements to them in real-time. In particular, to the best of our knowledge, no one has attempted to understand runners' preferences on the presentation of real-time drone feedback during a run. Thus, in this work, we carried out a user study to uncover when and how a drone could present runners with relevant running parameter feedback. In this paper, we contribute to the HCI community the following:

- A set of design considerations for drone-feedback presentation.
- A methodology and its implementation that helped generate the design considerations through an ideation activity substantiated by the reflections on a running activity.

2 STUDY DESIGN

The study setup entails four main steps, as outlined in Figure 1. The following describes the design of each of the steps in detail.

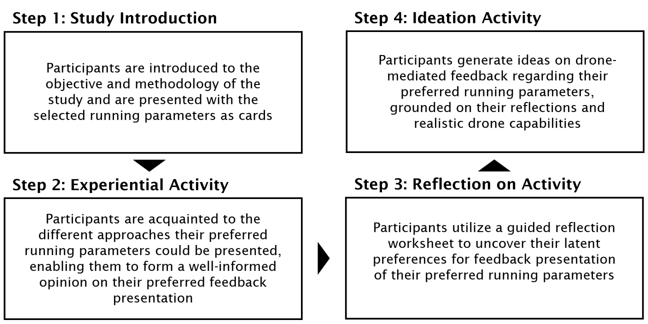

Figure 1: Workflow of the Study with an Overview of the Aim of the Activities Conducted in Each Step

Step One - Study Introduction: In the *first* step, participants were introduced to the methodology followed in the study along with the running parameters in the form of cards (Figure 1 in supplementary material). The aim was to ensure participants had sufficient information about the study and selected running parameters, enabling them to become familiar with both and ask any questions.

To design the study, we had to select a set of running parameters that can be obtained through the real-time processing of drone video and those runners already track using wearable devices [32, 35, 37, 45]. This set was used as the basis for the study, to investigate how drones could provide feedback to support runners. By carrying out a non-exhaustive review [1, 3–5, 8, 21, 27, 30, 33, 34, 38, 41, 50, 64], we collated a set of parameters divided between activity and bio-mechanical categories. The activity parameters included distance, time, speed, heart rate, cadence, and energy burned. The bio-mechanical parameters included cadence, contact time, vertical oscillation, sagittal trunk lean, and contralateral pelvic drop. These parameters were selected as they have an impact on the physical health and play a role in motivation [60], enhancing performance [18], and preventing injuries [19, 67] in runners.

When conducting human-drone interaction (HDI) studies that provide design recommendations, contextual information about the intended drone application is crucial for obtaining aligned feedback and enhancing study validity [26]. The works of Mueller and Muirhead [43] and Seuter et al. [56] serve as good examples where runners are placed in realistic scenarios to elicit responses that reflect their physical, mental, and cognitive capacities, as they engage in physical activity. Moreover, the utilization of running technologies has not only helped runners gain a deeper understanding of themselves as athletes but has also fostered a sense of embodiment, which in turn influences their feedback preferences [9, 58]. Building on this, we incorporate the concepts of the embodied storming [55] and exertion framework [42] to create the activity in the study that fosters experiential awareness and enables meaningful reflection. Through this approach, we aim to help runners gain a deeper understanding of their preferences for running feedback which would then inform the design of the drone's feedback presentation.

Step Two - Experiential Activity: Moving to the *second step*, participants engaged in an activity that provided them context of different parameter feedback presentation methods while experiencing various exertion zones of running. This activity was inspired by the visuals presented in the work of Mueller et al. [44] and simulated the transition between exertion zones during an outdoor running session: warm-up, pre-exhaustion, exhaustion, and cool down. Participants' exertion levels were assessed using the rate of perceived exertion scale (1-10) [65] (Figure 2 in supplementary material) and heart rate measurements recorded with a Polar H10 heart rate sensor were analyzed to confirm the exertion transitions [54]. The aim was to acquaint participants with various methods of presenting their preferred running parameter, enabling them to form a well-informed opinion on their preferred feedback presentation. Feedback on their preferred parameters was presented without disclosing the technology involved. This deliberate approach aimed to ensure that their feedback preferences were based on genuine requirements rather than influenced by the mention of drones. Figure 2 shows the setup of the study with images that show examples of how feedback was presented to the participant.

Step Three - Reflection on Activity: In the *third step*, participants engaged in reflecting on the previous activity using a worksheet (Figure 3 in supplementary material). The worksheet was designed to facilitate reflection using the four exertion lenses as proposed by Mueller et al. [42]. These included reflecting on the change of body's internal state (Responding), movement of body parts relative to one another (Moving), sensations and experience felt by body (Sensing), and impact on body due to others in environment (Relating). Prompts related to emotions, sensations, preferences, expectations versus reality, alignment with goals and motivation, and the influence of the study environment were provided to assist participants in their reflections. The aim was to uncover participants' latent preferences for feedback presentation of their preferred running parameters, grounded in their reflections.

Step Four - Ideation Activity: Transitioning to the *fourth step*, participants were informed that the drone would be the technology that presents the feedback and were provided examples about

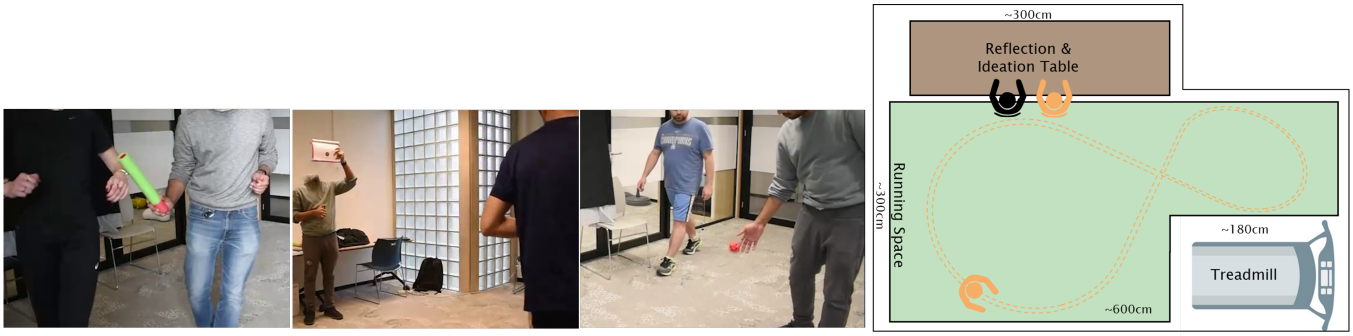

Figure 2: Left to Right: Examples of how feedback was presented to runners (Haptic, Paper Visual, Bouncing Ball Visual) and Layout of the Study Setup

drone's capabilities. This included a demonstration using video from a DJI Mavic Pro to estimate lower body angles and present real-time feedback (workflow of the demo presented to the participants is included in supplementary material, Figure 4), as well as examples of how drones could present feedback through various modalities (Figure 5 in supplementary material). These examples included *audio* (speakers [61], and noise [6]), *visuals* (lights [22], screens [22, 25, 66], projectors [7, 13, 36, 53], and movements [15, 20]), and *haptics* (drone tactile [36, 57, 68], and sleeves [24, 62]). Participants' likability of drones was assessed before and after the presentation of information about the drone's capabilities using the Godspeed questionnaire [10]. The aim of this step was two-fold. First, to understand whether the participants' likability of drones changed positively after receiving more information, indicating the new information allowed them to see the drone as capable of supporting them during the run. Second, to understand participants' preferences, regarding how they would like drones to present feedback on their preferred running parameters, grounded in their reflections and realistic possibilities of how drones could present the feedback. The study was designed with the safety and health of the participants in mind and was reviewed by our university's ethics board.

2.1 Procedure

In the *first step*, after being introduced to the study, participants gave their consent, and video and audio recording of the session commenced. Participants selected their preferred parameters for feedback during the run, using the information presented to them on the provided cards. The participants started the *second step*, by running in a figure-eight pattern in the designated area (Figure 2). Visual feedback was presented on paper using simple designs and bouncing/moving ball movements (for parameters like cadence and vertical oscillation) (Figure 2). Audio feedback was provided verbally, while haptic feedback was simulated by tapping specific areas of the participants' body using a foam stick (Figure 2). Activity parameters were presented as numbers and levels, while bio-mechanical parameters were conveyed through alerts indicating sub-optimal states and instructions for technique improvement. After receiving the feedback, participants rated its comprehensibility and their ability to act upon it on a scale of 1 to 10. Their responses were noted down for review in the next step. Perceived exertion rates and heart rate values were recorded at the beginning and end of each phase. To expedite reaching the target exertion levels, participants were asked to run on a treadmill, and during the cool-down phase, they were asked to run slower or walk. After completing this step, the participants took a break until they were comfortable to continue and were provided with their preferred healthy snack and drinks. In the *third step* they received a worksheet to reflect on the activity and their responses during the activity. Finally in the *fourth step*, first the participants' pre-existing likability of drones was assessed, then they were provided information about the drones' capabilities and were asked to express their ideas on how drones should present feedback on their preferred running parameters, while considering their reflections and the examples of drones' possibilities. They were provided with another worksheet (Figure 6 in supplementary material) to help guide this process. The study, conducted with 25 participants in two different countries, followed consistent procedures and lasted approximately 1.5 hours.

2.2 Participants

We recruited participants through flyers, emails and snowball sampling (word-of-mouth). We established some requirements that participants had to meet, such as enjoy running, run for at least 15-20 minutes on ground, being physically fit (to prevent post-study body soreness), and willing to run on a treadmill. Prior to the study, interested participants were sent a pre-study survey to gather information about their characteristics and physical activity (age, gender, running technology usage, Sports Motivation Scale-2 responses [47], running statistics, and physical activity levels over a week [52]). On the day of the study, we collected their height and weight before beginning the study. The participants we recruited (15 male, 10 female) ranged in age from 19 to 52 years (mean: 30.32; median: 26; std. dev.: 9.7) and were recruited at the university. The participants had varying years of running experience (few weeks to 25 years), and have run covering average distances between 3.5 to 42 km at speeds between 5.5km/h to 13km/h in the week leading up to the study. 19 out of the 25 participants utilized some form of technology to keep track of their run (smartwatch:11, smartphone: 7, both: 1). The sports motivation index (SMI) calculated using the SMS-2 scale [48] helped determine that 23 out of 25 participants had higher motivation levels to practice running (SMI: 7 to 63). All participants were relatively physically active (mean energy burn/day: 702kcal/day; median: 624; std. dev.: 387.8) and fell within the healthy range of BMI (mean: 24; median: 22; std. dev.: 3.8). The participants had no prior experience running with a drone.

3 DATA ANALYSIS AND RESULTS

All data collected during the study was anonymized to ensure the protection of participants' identities before storing the data. For this paper we analyzed the data collected during the second, third and fourth steps of the study. The analysis of the rate of perceived exertion and heart rate recorded during the second step showed that, apart from one participant who was a long-distance runner, every participant reached the necessary exertion rates during each phase of the running activity suggesting that their feedback ratings (understandability and ease of acting on feedback) accurately reflected their mental, physical, and cognitive loads. The responses to the Godspeed questionnaire from step four showed that the participants' likability towards drones was initially neutral-positive (pre-information: avg.: 3.28 std.: 0.98). After receiving information about drones, their attitudes either remained neutral or became slightly more positive (post-ideation: avg.: 3.52 std: 0.95), indicating that participants' ideas were not negatively influenced by a lack of information or a belief that drones couldn't support their running activity. Notably, likability did not significantly differ between participants with drone experience and those without. The audio recordings of the discussions were transcribed and analyzed alongside participants' worksheet responses.Through an initial round of data analysis and coding, we have identified the running parameters that participants prefer to receive feedback on from the drone, as well as their preferred presentation format for the feedback.

Figure 3 illustrates the distribution of participants' preferences. Pace was the popular parameter (28), followed by time (20), trunk lean (20), and heart rate (18). Most participants showed a preference of being informed about their current state using numbers, percentages, or levels for activity-related parameters but there were few who desired instructional feedback to achieve target pace. For biomechanical parameters, most participants preferred instructional feedback for technique improvement, with only a few requiring feedback on their current non-optimal state. Figure 3 also shows feedback through visual projections for pace emerged was the more commonly generated feedback idea. Interestingly, none of the participants suggested using audio feedback through drone noise or haptic feedback through drone touches. This could be due to the participants' expressed dislike for drone noise and the physical presence of the drone near them. Participants also expressed a clear preference for audio feedback delivered through earphones, as it was deemed less distracting and required less response latency and cognitive effort. The data in Figure 3 indicates that some participants preferred haptic feedback for parameters sensed by the body, such as heart rate and bio-mechanical parameters related to posture and running technique. They believed that amplifying or accentuating these sensations could make the feedback feel more natural and lead to quicker reactions, despite acknowledging a learning curve.

The transcribed and collated data was analyzed further following the reflexive thematic analysis methodology [11] to conceptualize drone feedback design considerations. To ensure objectivity in the analysis, two coders (co-author and research assistant) conducted the coding and grouping of codes. Following the methodology the coders positioned themselves within the following perspectives when reviewing the data: inductive over deductive (orientation to data), semantic over latent (focus on meaning), experiential over critical (qualitative framework), and realist-essentialist over relativist-constructionist (theoretical framework). The thematic analysis was conducted using Miro (screenshot of the process followed is included in supplementary material, Figure 7). Through the analysis, we conceptualized some design considerations for drone feedback by categorizing them into two main themes: feedback presentations (how) and feedback timing and frequency (when). These considerations are further elaborated in the subsequent section.

4 DRONE FEEDBACK DESIGN CONSIDERATIONS

After analyzing the data and reviewing existing research [26], we discovered that designing effective feedback presented using a drone requires careful consideration of feedback presentation, timing, and frequency. Our study revealed diverse and well-intentioned feedback presentation preferences among runners, which were rooted in maintaining their "flow" during the run. To maintain this psychological state which supports runners' performance, drone feedback should be designed to be unambiguous and aligned with their preferences [16].

Based on the thematic analysis of the insights gathered from runners in our study, we articulate some design considerations for feedback presented using a drone. These considerations include five aspects for feedback presentation: Non-distracting, Interpretable, Intuitive, Privacy-Conscious, and Environment-Aware feedback. Additionally, we derived eight design considerations for timing and frequency of the feedback: Triggered by Moving Body & Expectations (Incorrect Motion, To Achieve Desired/Target Motion, Signaling (Gestures) During Run), Time, Distance, and Physiological Changes, as well as Frequency of Feedback (Self Selected and Triggered Always). It is important to note that these design considerations are proposed based on our initial study and could be refined through further intensive and longitudinal research. However we hope these insights help ground and position future studies.

4.1 Feedback Presentations

1. Non-Distracting Feedback: Participants expressed a preference for feedback designs that are non-distracting while pulling their attention to allow them to maintain their flow during runs [P25]. While some participants found feedback through drone screens or motions to be distracting [P9], there were still ideas for feedback through these modalities (Figure 3) at least by some of the participants [P8, P21].However, there was a consensus on less distracting feedback designs, such as alerts on distance, pace, time, heart rate, cadence, and energy presented through earphones or haptic sleeves. These simple forms of feedback could be conveyed using numbers, percentages, or beeps/vibrations [P4, P6, P7, P14]. Additionally, there were ideas about integrating feedback on heart rate with the runners' music [P3] and using laser pointers/projections to indicate stepping locations on the ground [P1]. While favorable ideas for

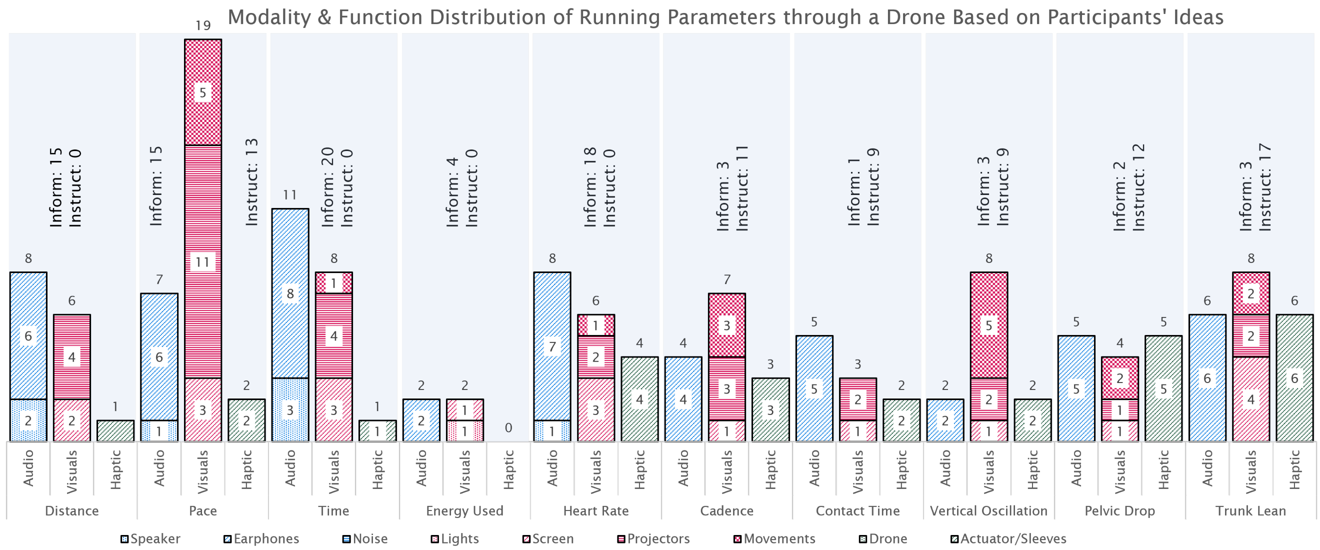

Figure 3: Modality & Function Distribution of Running Parameters through a Drone Based on Participants' Ideas

feedback through projectors/haptics were generated, there were runners who also stated feedback presented through these mediums, could also either distract them or disrupt their rhythm [P12, P14-2]. While these are opposing viewpoints to what could be considered non-distracting feedback, it should be noted that these differences may stem from differing runner characteristics, motivations, and focus of run. However, this doesn't mean other modalities cannot be utilized, as long as the design is simple, motion is minimized, and it serves the purpose of providing interpretable feedback.

> [P25]: *"I like to be in my running experience without getting too distracted."*
> [P9]: *"It'll be hard to both see that (drone motion) and focus on running."*
> [P8]: *"I want drone to show a visual of clock with time elapsed & visuals for speed on screen."*
> [P21]: *"Images, (on screen) can convey more than words."*
> [P4]: *"Not necessarily advice, but alert if heart rate is high for long I want information quickly and not look at the screen so then I would need haptic alert."*
> [P6]: *"Generate haptic feedback for the pace at which I must go."*
> [P7]: *"Reminder through earphone like you have one kilometer left."*
> [P14]: *"Like my app I would like a beep about my speed every quarter. I don't need to know more than that."*
> [P3]: *"[...] heart rate could be added to music."*
> [P1]: *"[...] projecting a line to indicate a pace would be really useful."*
> [P12]: *"If I have something like this (projections) you can get distracted and look down all the time."*
> [P14-2]: *"I don't think haptic works for me, because it would keep me out of the rhythm."*

2. Interpretable Feedback: Feedback should be designed in a way that allows runners to easily interpret the presented details. The level of detail and simplicity of the feedback can vary depending on the type of run and the runner's characteristics. Some participants expressed a preference for detailed instructions on bio-mechanical parameters, such as trunk lean, pelvic drop, contact time, vertical oscillation, and cadence. They preferred receiving these instructions feedback through audio (earphones or speakers) [P13] or visual means (screens or projections) [P7]. One participant was particular about receiving instructions in a conversational form rather than monotone robotic statements [P25]. On the other hand, some participants preferred simpler and less intrusive feedback for both activity and bio-mechanical parameters. They favored visual ground projections, such as footprints, dots, or lines, to indicate where to step [P11] or graphs/numbers on screens to display distance, pace, time, and heart rate [P23]. They also mentioned using earphones to receive alerts for non-optimal cadence [P12] or simple color-coded lights to indicate energy burn levels [P10]. Simple haptic vibrations on specific body locations were also appreciated to indicate the direction of change in targeted bio-mechanical parameters or provide alerts on activity parameters [P9]. As the feedback design becomes simpler, it becomes essential to incorporate context and intuitiveness to ensure the interpretability of the feedback.

> [P13]: *"I want something simple and if something is wrong I want verbal instructions to correct it."*
> [P7]: *"I am usually more of a visual learner, and would like an animation on what you're supposed to be doing."*
> [P25]: *"I prefer having conversations with drone, as opposed to receiving robotic instructions."*
> [P11]: *"If I want to go at 15 min/km, but don't actually know how fast I need to go, indicating the steps I should follow could be nice."*
> [P23]: *"I would like it to fly next to me and on the screen, display the distance."*
> [P12]: *"If I take longer step/have less cadence, then I get injured, so I would like to be just informed that it is not optimal [...] I know my optimal cadence."*

> [P10]: *"I would like to my energy the difference (transition) and it would be nice to watch it using lights on drone. The change of colour shows the difference."*
> [P9]: *"You get some sort of haptic feedback for trunk lean, like, move, backwards or move forwards. And this stops the moment you're correct."*

3. Intuitive Feedback: The intuitiveness of feedback presentation should be considered to ensure that runners can sense, understand, and act on the feedback within the minimal attention span they can afford during their run [P14]. Some ideas of participants took advantage of certain qualities of modalities and mapped them to certain parameters. For example, using haptic feedback to accentuate sensations for parameters felt by the body, such as heart rate or bio-mechanical parameters, were considered more natural and could lead to quicker reactions from runners [P6, P10]. The drone's relative motion and position were mentioned as intuitive representations for feedback on bodily movements/sensations. Ideas included the drone acting as a pace setter, bouncing to highlight non-optimal vertical oscillation, tilting to indicated non-optimal trunk lean/pelvic drop, and using its motion to mimic heart rate levels [P3, P16, P18]. Intuitive ground visual projections ideas, such as lines, footsteps, or simple dots, to indicate where to step were also generated to suggest target pace, cadence, or vertical oscillation [P19]. Intuitiveness plays a crucial role in designing feedback that quickly informs runners without requiring extensive cognitive processing.

> [P14]: *When I'm running, I wouldn't want to be interrupted, but the drone could add value [...], to my running, make it more efficient."*
> [P6]: *"I found haptic feedback the clearest as it requires less attention, second I can react faster and I felt it was the most natural way of of communicating information about movement."*
> [P10]: *"With watch I have to check each time. If I feel the heart rate through haptics like dub dub dub I will sense it better."*
> [P3]: *"[...] prefer drone movements for speed where it speeds up or slows down."*
> [P16]: *"For pelvic drop it's [...] very simple, the drone will be [...] slanted."*
> [P18]: *"I think that vertical oscillation is one that would be very natural to indicate with drone motions."*
> [P19]: *"I would want (drone) to like, put lights on the ground to tell me where I should step, to indicate the pace I want to get to."*

4. Privacy-Conscious Feedback: During the discussions and idea formulation, it became apparent that runners value their privacy. Many participants expressed concerns about their data being displayed on a drone's screen for everyone to see or receiving instructions through a speaker that could potentially disturb them and others, leading to self-consciousness [P13, P16]. Consequently, most participants preferred feedback on parameters like heart rate, pace, distance, time, and motion to be presented privately, solely for their own experience. This preference resulted in the emergence of ideas centered around earphones and haptic feedback. However, a few participants were open to public display of information as long as it was coded and contextually understood only by the runner [P17]. This particularly concerned ideas involving feedback for encouragement or indicating the amount of distance, time, or energy burned or remaining, striking a good balance between privacy and public feedback [P14].

> [P13]: *"I don't like the idea of drone having a speaker because it's gonna be loud and everyone is gonna hear."*
> [P16]: *"I definitely do not want screen, because one concern I have with that is that it will make my heart rate public. Heart rate is more like private data to me, and I want to keep that close to my body."*
> [P17]: *"As long as the visual is colour coded as per zones, then I don't have to look at a number. I can see the colour & I know I'm here."*
> [P14]: *"A drone with a speaker that talks to me, for example the last quarter I get feedback every few second to help me get motivated."*

5. Environment-Aware Feedback: The delivery of feedback via drones can pose challenges that are contingent on the environment. Bright conditions or uneven surfaces may hinder the generation of clear projections [P4]. Haptic feedback might be difficult to discern on uneven terrains due to the vibrations already experienced during running [P18]. If feedback is conveyed via speakers, they must be sufficiently loud to overcome drone noise, potentially disturbing quiet areas [P18-2]. Moreover, feedback through drone movements may be misconstrued without prior alert or contextual information, particularly when navigating obstacles [P9]. Researchers need to be mindful of these considerations while designing feedback through drones for runners.

> [P4]: *"With a laser it will be easy to follow, and easy to see, even in daylight."*
> [P18]: *"There's a lot of haptic noise running in bad weather on varying terrain with a wind suit on."*
> [P18-2]: *"Drones are noisy [...] so the speakers will be problematic, because it will have to compensate the noise and disturb deserted areas."*
> [P9]: *"Drone movements, will be hard to see when you're running, especially if it's flying above you or away from run direction".*

4.2 Timing & Frequency of Feedback

The effectiveness of feedback can be compromised if it is delivered at inappropriate intervals and as a result impact the flow of a run. A notable response from a participant emphasized that receiving feedback or advice at incorrect times can not only be annoying but also erode the trust placed in the feedback system.

> [P4]: *"If the drone were to give me advice to act upon at the wrong time, that would irritate me & my confidence in the capabilities of the system would be reduced."*

This insight underscores the importance of carefully considering the timing and frequency of feedback during the design process. From our analysis it is evident that the concept of 'correct timing' is subjective, and it may vary among runners. In essence, personalized timing and frequency of feedback are essential to cater to individual needs and preferences. By understanding the significance of when and how often feedback is provided, researchers can optimize its impact, ensuring that it is delivered in a manner that enhances its value and maintains user engagement. The design considerations that were conceptualized are provided below with the brief reasoning that originated from the ideas they generated.

1. Triggered by Moving Body & Expectations: Incorrect Motion: Some participants expressed a unanimous preference for receiving feedback on specific parameters when their body movement deviated from optimal levels or pre-set values. These parameters included trunk lean, pelvic drop, vertical oscillation, cadence, contact time, and pace [P2].

> [P2]: *"[...] with step frequency if the drone can see it's incorrect then it display the steps in front of you."*

2. Triggered by Moving Body & Expectations: To Achieve Desired/Target Motion: Some participants indicated a preference for continuous feedback on pace and cadence to help them maintain their desired or optimal levels of motion throughout their run, ensuring a smooth and uninterrupted flow [P5, P8].

> [P5]: *"The drone can be a pacesetter, reminding me the pace to maintain."*
> [P8]: *"[...] would like drone to be with me most of the time, like, a co-runner. Showing the speeds that I would like to run."*

3. Triggered by Moving Body & Expectations: Signalling (Gestures) During Run: Some participants expressed a preference for having the autonomy to receive feedback on parameters such as pace, heart rate, distance, vertical oscillation, time, and cadence only when they made specific gestures, allowing them to control the timing and frequency of the feedback [P15].

> [P15]: *"I don't want to ask if I've run 20 minutes. I'd like doing a gesture, or heads up and the drone sees that and provides feedback."*

4. Triggered by Time: Some participants expressed a preference for receiving feedback on specific parameters at set time intervals, allowing them to track their progress and performance over time. These parameters included time, heart rate, pace, distance, and energy burned [P24].

> [P24]: *"I would not prefer feedback on this (energy burned) every second but maybe every third minute."*

5. Triggered by Distance: Some participants expressed a preference for receiving feedback on specific parameters at set distance markers, allowing them to monitor their performance and progress as they reach specific milestones. These parameters included distance, time, pace, and heart rate [P20].

> [P20]: *"I would like feedback (heart rate) through audio for every kilometre."*

6. Triggered by Physiological Changes: Some participants expressed a preference for receiving feedback on certain parameters based on changes in their exhaustion levels. They wanted feedback on heart rate when it became irregular, reached a specific level, or during periods of sustained irregularity [P22]. Additionally, participants desired feedback on distance, pace, time, and energy burned at the end of their run when they were most exhausted or at regular intervals during the cooling down phase to provide an extra motivation to meet their goals [P21].

> [P22]: *"I would probably prefer just high and low (heart rate) alerts for the warm-up stage. So I know I'm ready for next stage."*
> [P21]: *"If the drone could offer encouragement when it notices that I'm struggling, like you have already expended 300kcal or 50% of target or 12 grams of body fat. This will motivate me to continue."*

7. Frequency of Feedback: Self Selected: Participants had varying preferences for the frequency of feedback. Some participants found constant feedback annoying and preferred self-selected intervals, allowing them to control when they receive feedback. Moreover, some indicated a buffer time is necessary between receiving feedback on different parameters to avoid an overwhelming amount of information and to maintain the flow of their run [P15, P17].

> [P15]: *"[...] if I get information every 2 seconds it would be a lot, so it would be good if I can select the time between feedback."*
> [P17]: *"[...] it (drone) can wait a time/distance to remind you because it would be really annoying it it constantly reminds you that you're doing various things wrong."*

8. Frequency of Feedback: Triggered Always: While there were a few ideas suggesting continuous feedback for parameters like speed, heart rate, and time presented through visual projections at all times [P7], one participant noted that receiving continuous feedback might eventually blend into the background and go unnoticed, diminishing its effectiveness [P14].

> [P7]: *"It would be nice to get continuous projection feedback (pace/cadence)."*
> [P14]: *"If drone motion feedback is constant you are not really going to pay attention to the drone anymore because it does the same thing over and over again."*

5 DISCUSSIONS AND CONCLUSION

We conducted this study to understand how runners prefer feedback on their desired running parameters to be presented through a drone. Our findings revealed that some preferred feedback presentations aligned with their established running habits, while others found newer approaches more appealing. Notably, a significant number of runners preferred to be informed about their current state for activity-related parameters rather than receiving instructions to reach specific levels. These observations are consistent with previous research [31] on runners relying on trackers for notifications about running-related parameter deviations, as familiar feedback presentations help maintain their cognitive flow during running. However, when it came to pace, some runners desired actionable feedback to help them achieve target or optimal levels, similar to bio-mechanical parameters. This inclination toward instructional feedback likely stems from their goals of performance improvement and injury prevention. Running-related injuries can demotivate runners and lead to discontinuation of the activity [60], which most runners engage in for relaxation and enjoyment of nature. The runners' ability to articulate the reasoning behind their feedback preferences indicates that our study successfully fostered experiential awareness and meaningful reflection grounded in individual preferences, rather than exploring all possible approaches.

The feedback design considerations we conceptualized also influence the hardware and software design consideration for drones that would accompany runners. Some of these considerations include configurability, operability, programmability, tracking, and payload, computing and battery capacities. The variability of the participants preferences highlights the need for flexible feedback presentation, necessitating drones with different configurations or easy configurability to meet diverse runner motivations and requirements. Runners should have the option to easily operate or program the drone, allowing them to modify its function with changes in configuration. Furthermore, the drone's design should support carrying the necessary devices that deliver feedback and the computing devices that would process and output the data to the various feedback devices. Sufficient battery capacity is essential to power these devices and maintain adequate flight duration for outdoor running sessions. Additionally, the drone should possess robust computing power to handle tracking and running parameter estimation tasks while maintaining reliable flight performance for feedback through drone motions and foster trust with runners. Technological advancements hold promise for designing drones that adhere to the various requirements of runners while enhancing safety and minimizing disruption [40, 59] but designers should be critical about the limitations and prioritize responsible practices in drone development for running activities.

While our study yielded noteworthy results, it had limitations that may have impacted the collected data. The space available for the study was limited, and as indicated by some participants (7/25 participants), it presented some challenges with respect to their running. Future work can benefit from a larger running space, and one could study the impact of the running space on the results. Some participants (4/25 participants) felt overwhelmed with the presentation of feedback during step two of the study. One participant adapted over time however the others indicated it might have negatively impacted their responses and focus during the activity. The way haptic feedback for cadence was provided could have introduced a limitation. For safety, the feedback was delivered on the ground near the foot, requiring participants to imagine the sensation on their foot. Although the extent of the felt difference was not evaluated, this modification could have influenced participants' preferences, since a significant number of participants expressed a preference for haptic feedback on other parameters, finding it more understandable. Future work could take this into account, and investigate the impact of various ways haptic feedback could be presented for studies that investigate fast interactions. Additionally, participants' prior knowledge and experience with feedback presentation through coaches or smart devices may have influenced their feedback preferences. It is possible, as participants become more acquainted with feedback presentation, their requirements and preferences may evolve, particularly in terms of posture and technique correction. We believe these warrants further analysis through a longitudinal study.

While we made efforts to group ideas systematically and identify themes, we recognize the potential for further analysis to explore preferences among runners with different characteristics and motivations. Building upon the approach taken by Janssen et al. [28], as a future direction, we aim to cluster our participants and examine differences or similarities within and between clusters. This analysis can provide valuable insights for participant selection, identifying outliers, and conducting more extensive investigations in the realm of runner-drone interaction studies.

In conclusion, we devised a novel methodology to explore runners' preferences for drone feedback presentation of various running parameters. We engaged runners in an activity that replicated the transition of their running exertion levels while providing context on the various feedback presentation methods. By reflecting on this activity, runners expressed their feedback preferences, influencing their ideas on drone feedback presentations. Through analyzing the responses from 25 participants, we have identified design considerations for feedback presented using drones on different running parameters. Additionally, our work also presented a methodology that could help researchers in immersing participants in contextual experiences to uncover their latent preferences. We believe that similar approaches will facilitate more meaningful discussions on designing technology and data presentations that align with the preferences of participants.

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