Jogging with a Quadcopter

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ABSTRACT
Jogging is a popular exertion activity. The abundance of jogging apps suggests to us that joggers can appreciate the opportunity for technology to support the jogging experience. We want to take this investigation a step further by exploring if, and how, robotic systems can support the jogging experience. We designed and built a flying robotic system, a quadcopter, as a jogging companion and studied its use with 13 individual joggers. By analyzing their experiences, we derived three design dimensions that describe a design space for flying robotic jogging companions: Perceived Control, Focus and Bodily Interaction. Additionally, we articulate a series of design tactics, described by these dimensions, to guide the design of future systems. With this work we hope to inspire and guide designers interested in creating robotic systems to support exertion experiences.

Author Keywords
Jogging; running; movement-based play; whole-body interaction; sports; quadcopter; robot; exertion

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]: User Interfaces - Miscellaneous.

INTRODUCTION

Understanding the role of interactive technology to support physical exertion is a thriving field in HCI. By exertion interactions we mean interactions with technology that require intense physical effort from the user [20]. Supporting exertion is important, as exertion activity can facilitate social, mental and physical health benefits.

One popular exertion activity is jogging, i.e. running at a leisurely pace. The abundance of jogging apps, sports watches and wearable sensors (for example embedded in shirts and socks [3]) suggests to us that joggers appreciate the opportunity for technology to support their jogging experience. This trend has been recognized and investigated by research [39] while special interest groups (SIGs) at CHI have also been formed to encourage further developments in this area [23, 24].

Figure 1. What is it like to jog with a quadcopter?

We believe that the current range of systems to support jogging is only the beginning of a trend. With sensor advancements, improvement in battery performance and miniaturization, more opportunities will emerge for designers to support people's exertion experiences. Along with technology advancements, there have also been advances in our understanding of the role of bodily aspects from a system's design perspective, most often under the name of embodiment [10, 36]. We take this investigation a step further and wonder if exertion activities like jogging that are so embodiment-focused might benefit from designs with a similar embodiment focus. We see robots as having the potential for such an embodiment focus, and therefore begin by exploring if, and how, robotic systems can support

CHI 2015, April 18 - 23 2015, Seoul, Republic of Korea.

ACM 978-1-4503-3145-6/15/04…$15.00
http://dx.doi.org/10.1145/2702123.2702472

the jogging experience. We therefore designed and built a flying robotic system, a quadcopter, and ask the question: "What is it like to jog with a quadcopter?"

Our quadcopter is an autonomous unmanned vehicle (UAV or drone) that flies around a predetermined jogging path at a fixed speed in order to accompany a jogger. Although more advanced systems that support richer interactions with the jogger have been implemented inside laboratories [14], we believe our quadcopter is the first system that has been successfully deployed in an outdoor setting generating data for an HCI study. We can therefore present the first conceptual understanding of flying robots in relation to outdoor jogging. However, as we studied only one flying robot, our results are naturally limited and incomplete. Nevertheless, our work is grounded in our first-hand experience of designing such a system, including six flying robot design iterations (and associated informal jogging experiences), as such, we believe we can offer first insights into the design of future flying systems supporting jogging. We focus on various flying robots such as quadcopters, helicopters, wing-based robots and augmented blimps as we are interested in supporting joggers outdoors, avoiding trips or falls by floor-based robots. We note that such flying robots are becoming more affordable and hence more accessible, and they seem to be increasingly targeted at supporting sportspeople, for example see [1] (however, so far focus has been on capturing video of the sportsperson rather than directly supporting the sports action). Yet none of them appear to be designed according to HCI principles, as so far no such guidance exists. CHI work has previously highlighted the importance for HCI researchers to study novel technology in its early stages, to guide advances through HCI knowledge [19], as such, our work aims to serve as such early guidance for this emerging field.

We used interview data, video footage and system logs from 13 joggers who jogged with our quadcopter outdoors. With these results, we derived three dimensions that describe a design space for flying robotic jogging companions: Perceived Control, Focus and Bodily Interaction. Additionally, we articulate a series of design tactics, described by these dimensions, to guide the design of future systems. Together with the quadcopter design, they form the central contribution of this paper.

TECHNOLOGY SUPPORTING JOGGING

The use of interactive technology to support jogging experiences is a recent trend, exemplified by popular mobile phone apps like Nike+, Endomondo, Runtastic, TrackMyRun and Runkeeper. They appear to support the jogging experience, however, most of the apps focus on the data analysis *after* the jog, such as how many kilometers have been run. Sports and smart watches such as those offered by Polar, LG and Suunto offer similar functionality, however, their strength is real-time feedback glances at the wrist to gather information about the jog, such as current speed. These devices offer support *during* the jog, however only when the jogger decides to look at the watch.

A few systems support the jogging experience *throughout*; for example, the mobile phone app "Zombies, Run!" [39] delivers a narrative-focused game experience using headphones. This suggests to us that technology can support the jogging experience while it occurs, and recent research has built on this: for example, Curmi et al. have developed a system that allows joggers to share their heart rate during a run with other joggers but also with friends at home, highlighting how technology can support companionship as part of the jogging experience [9]. Another example of a system that draws on jogging companions via means of technology is Jogging over a Distance [28]. It used relative heart rate data to balance participants of different physical abilities, allowing people who would not be able to do so without the technology to jog together [26]. This highlights that technology provides an opportunity to facilitate novel jogging companion experiences.

All systems described above focus on supporting the jogging experience through a screen- or audio-based interface. We want to explore alternative technologies to support the jogging experience. In particular, we are inspired by prior work on human-robot interaction that highlights their potential for companionship [6, 12] and recent developments in our understanding of designing technologies to support exertion activities [31, 38]. Furthermore, prior work has investigated the use of technology for joggers indoors (on treadmills) [30], in contrast we are interested in supporting the outdoor jogging experience [28, 29].

Prior work on the convergence of robotics and sports exists, however, it often focuses on either trying to create robots that "do" the sport (like in the Robocup initiative or attempts to create jogging robots [4]) or utilizing robots to train specific actions, e.g. with ball machines (e.g. [5]) and does therefore not examine the interaction between the human and the robot.

Prior research has demonstrated a quadcopter aimed to support athletes, however the objective with this prior system was to capture athletes' actions via an attached camera [16] for subsequent analysis. The idea to focus on joggers with a quadcopter is also not new: an AR.Drone has been previously used to demonstrate the idea as a design concept [22]. The demo used the in-built camera to read a visual marker on the jogger's T-shirt in order to fly at a fixed distance in front of the jogger, adapting the speed to match the jogger. Due to the light-sensitive technology used, it was targeted at indoor use. Furthermore, no formal user study was conducted, so we do not know much about the quadcopter-jogger interaction.

A QUADCOPTER AS JOGGING COMPANION

Based on our review of existing work and understanding of existing technologies, we set out the following criteria for our quadcopter: a) being autonomous yet manually controllable, b) suitable to be used near people, c) large enough to be seen by joggers, d) open platform, e) long battery life, f) works outdoors and g) could fly as fast as common jogging speeds. In particular, our system needed to be different to the prior work's commercial platform [22] as we wanted our quadcopter to know its absolute speed and position (that required combining high-accuracy GPS with inertial sensors), feature a protective guard system (that we needed to balance against performance requirements) to ensure the safety of the joggers and bystanders, and include a manual override-function in case of any emergency. We quickly realized we needed to build our own system.

Figure 2. The final design of our quadcopter.

We built six different quadcopters guided by our experiences working with joggers [29], designing jogging systems [28], and following related works as well as our personal experiences using commercial jogging systems. Having personally designed and developed these quadcopters resulted in an annotated portfolio [13], with the associated craft knowledge providing insights on the best size for the quadcopter (we experimented between 10-60cm), the preferred speed (maximum speed vs. flying time), optimal propeller orientation being up- or downwards (safety implications) and different protective guards (affecting flying behavior in wind). We found the design in Fig. 2 the best compromise between performance, safety, stability and outdoor flight characteristics suitable for jogging [25]. It consists of four 10-inch propellers, 980kv brushless motors, a 3DR Pixhawk/PX4 controller with Invensense MPU6050 accelerometer/gyroscope and MS5611 barometer, and an off-board uBlox GPS and HMC5883 magnetometer. Our quadcopter measures approximately 55 x 55 x 10 cm while the flight time is approximately 16 minutes depending on wind. We designed the quadcopter to fly approx. 4 meters in front of the jogger at an altitude of 3 meters; however, altitude depends on sensor accuracy and environmental factors.

The quadcopter is able to follow a predetermined path through a set of waypoints that we laid out on a satellite photo. After taking off, the quadcopter will fly to each waypoint using assisted GPS. It should be noted that a quadcopter travelling along waypoints exhibits unique movement characteristics, quite different to, for example, a plane. First, the quadcopter is never completely horizontal in the air, slightly "wobbles" and tilts due to wind and sensor inaccuracies. We call these secondary movements to contrast them with the primary movement along its path. The quadcopter's controller compares GPS data at 5Hz with the next waypoint, and once within its hit zone (qualifying as having arrived at the waypoint), it orients itself towards the next waypoint. We learned that we needed to carefully manage the size of the hit zone, as a too large hit zone can mean the quadcopter's path does not match the jogging path, and a too small hit zone can mean the quadcopter might overshoot the waypoint. Furthermore, we also needed to consider the waypoint density, as adding a waypoint meant that the quadcopter spends some time reorienting itself at the waypoint, which affects overall speed. However, too few waypoints restrict the shape of the terrain that can be covered. A typical flight path for one jogging lap can be seen in Fig. 3, with a high waypoint density at the corners to smooth the turning angles.

Figure 3. The waypoints and quadcopter flight path for a single jogging lap.

STUDY

We conducted a study in order to understand the experience of jogging with a quadcopter. We recruited 13 casual joggers (10 male, 3 female) aged between 24 and 44 years old (average 32.8 years). Our joggers jog on average 7 times per month, 44% of these runs are with other people and their average jogging distance is 6 kilometres for a duration of 34 minutes. The participants were all volunteers and they were not monetarily compensated.

Procedure

Our study took place outside in a park with even terrain; it is often used for sports activities (with suitably short grass) and jogging. Three of the 13 participants jogged with a different quadcopter model due to technical difficulties or varying wind conditions, which we considered in the analysis. We asked participants beforehand at which pace they would like to jog. Most participants knew their jogging pace from the use of jogging apps, if not, we organized a test run to ascertain pace. We also gave participants the opportunity to jog with our system for a couple of minutes. We equipped participants with a GoPro action cam that we attached to their head with the supplied GoPro headstrap in order to record their experience. We then started the quadcopter, which followed a predefined flight path, similar to the circumference of a football field. Participants were free to cut corners or jog on the outside of the circumference. We were positioned at the starting point in order to be able to take manual control of the quadcopter at any time for safety reasons. Participants were free to stop at any time. If participants wanted to jog longer than our batteries lasted, the quadcopter, upon running out of power, was programmed to fly back to the starting point where we exchanged the batteries. Each run was between 15 and 40 minutes long, with an average of 26 minutes.

Data Collection and Analysis

At the end of the jog, we interviewed participants while they were still exhausted. Our interviews were audio-recorded and semi-structured; we focused on the participants' experience, asking questions such as: "what was it like to jog with a quadcopter?" and "did the quadcopter affect your jogging experience and if so, how?" Most interviews lasted around 30 minutes. We then watched the action cam recording together, asking the joggers to comment on their relived experience.

We included our participants in the data analysis process as we wanted to have a rich account of how the experience unfolded throughout the run from their perspective. We found interviews during the run not to be feasible, hence we opted for the approach of interviewing straight afterwards, while still exhausted, complemented with watching a video from a first person perspective. We imported the data into qualitative data analysis software (NVivo). We transcribed both, the initial interview and action cam comments. Coding was done by the first author who has extensive experience in open-coding interview data; the goal was to derive key themes that were further distilled through affinity diagrams into the results below.

JOGGING WITH A QUADCOPTER

Participants expressed that they enjoyed taking part in the study. They described it as a *"very interesting"* experience and enquired if they could use the quadcopter in their future jogs. We now describe the different elements that came together for our participants in making jogging with our quadcopter an engaging experience, and also highlight elements that did not work for our joggers.

Quadcopter as a pace keeper: Pace keeping

As the quadcopter's speed was determined by the jogger, it was not surprising that all participants engaged with the quadcopter at some point by using it for pace keeping. This was particularly prevalent along the straight parts of the path: *"…and then it started to feel like a pace keeper. […] I think there is something great in [the quadcopter] that it forces you to go a certain pace, pushes you a bit further." [P10]*

Pace keeping was appreciated by our joggers who found it difficult to keep a constant pace without technology: *"If I was running by myself, I think my pace would vary a bit more, this is a more set pace." [P7]*

One participant explained how he used his watch's pace keeper previously: it requires a deliberate look at the display, whereas the quadcopter allowed for a more continuous way of being aware of his pace: *"You start to take this [pace keeping] in quite passively, as your pace, cause it's in front of you and you sort of, you get in tune with it, so your pace is almost subconsciously controlled." [P5]*

Quadcopter as a pace keeper: Peer pressure from the quadcopter

The joggers also felt they needed to keep jogging if the quadcopter keeps on flying, and compared this form of pressure to their positive experiences when jogging with peers: *"If you jog with someone, you have the motivation to keep running, because the other person is still running, and its similar to that because you know it keeps going a certain pace, and you have to keep your pace up all the way around, so it's a good way to stay motivated." [P7]*
"I think ultimately there was a level of engagement. You felt you had to be responsible for its actions, because in theory you had programmed it go along a certain route, so you had to keep with it, so you felt responsible for it."[P2]

Quadcopter as a pace keeper: Finding a way to jog together

Inducing joggers to change the way they jogged was perceived as detrimental to their experience as it did not match their expectations. However, our joggers noted how, over time, they *"figured out"* how to jog with the quadcopter: *"…started to find a jogging pattern with it, started to arc around it when it hit a hard corner, or arc inside of it […] after maybe the 3rd lap or so, started to find my rhythm with it, started working with it a bit better…" [P10]*

Quadcopter as a pace keeper: The quadcopter dictating the path

Our participants said they were disappointed that they did not have more control over the path, lamenting a lack of autonomy [32]: *"I felt the experience was more of a training exercise, we are running a track, a circuit, I didn't get to run wherever I like. […] I had to maintain a circuit, so I didn't get as much control over my path." [P10]*

Quadcopter as a pace keeper: Perceived performance improvement

Participants applauded that the system resulted in a perception of an improved jogging performance, meaning participants thought the quadcopter *"made"* them jog longer and faster than they would have without: *"The best thing was it did make me exercise more!" [P5]*

"[…] without the [quadcopter], I would have slowed down more, but the [quadcopter] perhaps motivated me to keep a faster pace as my jog continued." [P10]

Safety

The quadcopter was designed with the safety of the jogger in mind. We also instructed our participants to not touch it to reduce risk and explained the dangers that come with any flying object, borrowing language from quadcopter safety manuals and legislations. This focus on safety made it into the interview statements, where participants expressed that the safety aspects affected their jogging experience: *"So safety was one thing that felt a bit weird, but once overcoming that, then it became interesting." [P10]*

Participants sometimes experienced the quadcopter being seemingly *"out of control"*, for example when the quadcopter diverted from its path when caught by wind or through sensor inaccuracies. Although slight path variations do not necessarily have to be safety issues, any perception of compromised safety affected the participants' experiences negatively: *"The worst [was] when it nearly rotated 90 degrees and I wasn't sure what is going to happen with it, thought it might run into me." [P10]*

"[Pointing at an instance where the quadcopter diverted from its path] At that point I don't trust it." [P10, action cam interview]

Safety: Safety concerns drawing attention

The safety concerns drew the jogger's attention to the quadcopter, which affected their jogging experience: *"But it definitely did take some of my attention away from the experience as I was worried about focusing on [the quadcopter], so for safety and pace, keep an eye on it I guess." [P3]*

The quadcopter as a companion: Movements caused by wind

Our participants experienced secondary movements, often in the form of little jiggles and slight variations from the flight path that were the result of wind and sensor inaccuracies. Our joggers perceived some of these secondary movements as means of communication, i.e. they thought the quadcopter wanted to tell them something: *"Also the movements of the robot, I think it did this motion, I think it was the wind […] it was trying to tell me some message, it felt a bit like there was some communication […] I wouldn't say I did feel a human touch thing going on, but I had a slight feeling of, well it could have communicated to me, well those actions felt like 'slow down!' [laughs]." [P5]*

In response, they thought of the quadcopter as a companion: *"I am not sure of wind or whatever, but it started to wobble, and it started to crisscross in front of me, and I quite liked it, because it reminded me that I am running with something, I like running with a buddy, […] it gave it a bit of personality, a bit of character, I think what was cool about it, in that moment, cause it was like 'Hey, follow me!' [laughs][…] It was playful, I liked that! […] That kinda injected some character into it, cause I am thinking if I am following it, […] and it was completely static, it would feel really sterile, completely like a training tool. Whereas at least like that it was like, I don't know, like having a buddy." [P3]*

The quadcopter as a companion: The quadcopter being in the way

The quadcopter's actions also affected how our joggers jogged: sometimes by simply being in the way when it diverted from its path due to wind and sensor inaccuracies. As a result, the joggers had to slow down in order not to run into it or be underneath it (we told them not to be underneath it due to safety): *"My pace was a bit slower here because I felt I needed to slow down because [the quadcopter] felt like it was slower, to not be underneath it." [P1, action cam interview]*

"Sometimes it stops a bit, and then you have to stop a bit until it corrects course." [P7]

Desire for control: Joggers seeking more, but not complete control over the quadcopter

A desire to be more in control of the quadcopter was another dominant theme that came out of the data: *"It's more than a coach than my peer, because it's not negotiating a pace with me, we are not communicating, it has some kind of authority combined with sort of a removedness, I can't communicate with it." [P10]*

"The worst thing is just that it was not adapting to any of my actions, it was just a robot doing it's thing, and I felt that I wanted it to react more to what I was doing." [P5]

One reason why the joggers wanted to be more in control is for safety reasons: *"I didn't mind I can't manipulate it like some subservient robot, but was bothered I couldn't at least communicate like 'watch out!'" [P10]*

Our joggers also expressed that they did not want complete control, but rather some control over the quadcopter: *"Even if I could not set the speed, like it was treating more of a negotiation, like 'No, [jogger's name], we are going 12k's', I'd like that if it were encouraging me, so if I at least,* *maybe it says 'Come on, let's try 12' 'Yeah, alright', and I'd say 'No, no, I definitely can't', and then 'Alright, we do 8' that would be cool, I'd feel like it was working with me, maybe negotiating […] the speed." [P3]*

"[…] having some kinda discussion about [the pace] would be good. Not completely control it, or set the speed, that would kinda devalue it." [P10]

Quadcopter draws attention: Attention pull of quadcopter affecting the ability to unwind

Participants expressed that the attention the quadcopter demanded reduced the opportunity to use the jog to unwind: *"[…] it definitely did take some of my attention away from the experience as I was worried about focusing on [the quadcopter] I didn't get to look around or think to myself, being very mindful of [the quadcopter], but again, as I got more acquainted with [the quadcopter], that came down a bit, I was less distracted by it, or less preoccupied, I wouldn't say it was distracting, but it was engaging maybe. […] I feel [by] more practicing with [the quadcopter], I would get more familiar with it and pay less attention to it." [P10]*

Quadcopter draws attention: Spectators

As our participants were jogging in a public park, there were opportunities where other park users could observe them jogging with the quadcopter: *"And the best experience, […] I come around that corner, a woman or young lady noticed, she was in awe, that was kinda cool I'm jogging with a robot, and people think it's rad." [P10]*

However, the same jogger noted: *"[…] I felt a bit awkward with a camera on my head and jogging with a robot." [P10]*

Quadcopter draws attention: Distraction from the discomfort of exercise

Participants applauded that the system changed their focus away from the discomfort of exercise, distracting them from associated fatigue: *"It distracted me from getting tired." [P5, action cam interview]*

"You have something in front of you floating in front of you, distracts you, so it's easier to get through the workout. Distracting in a good way, made the run a bit easier […] similar to having someone running along side you, chatting, similar sort of, taking your mind of the physical activity, and sort of focusing somewhere else." [P7]

Quadcopter draws attention: Altitude directing focus

The quadcopter attracted the jogger's attention, in particular, the altitude of the quadcopter influenced what joggers focused on and that in turn affected how they perceived their jog: *"I preferred it when it was higher up, the distraction, taking your mind of your tired legs, if you are looking up, at the sky, you forget you have all this distance to run, whereas when it drops you see how far you have left to run, when you look down you don't close your head when you are tired, if you look up, and there is the sky and everything and you are not thinking about the distance in front of you." [P7]*

DESIGNING ROBOTS FOR JOGGING

Based on our analysis, we found that the key to facilitating an engaging robot-supported jogging experience is to find the right balance between supporting the jogger towards a satisfying athletic performance and considering the jogger's abilities and intentions. In this sense, the designer helps participants enter the "flow zone", in which skill and challenge levels are aligned [8]. We begin by articulating the design of flying robots for jogging through a set of dimensions: Perceived Control, Focus and Bodily Interaction. Based on our study, we present broad aspects of these dimensions, describing a design space. To aid designers in navigating this space, we also use these dimensions to articulate a set of design tactics. These are based on our craft knowledge of designing our quadcopter and our study. We note that the design dimensions are to be understood as a proposal based on this initial study, while future investigations, such as longitudinal studies, may provide further insights that might lead to revising these design dimensions. In fact, this first study can provide the grounding for future studies and help to design these.

Dimension 1: Perceived Control

Every robot needs some kind of control. Our study suggests that a careful balance of who is in control of the robot and how is it perceived is a key aspect of a system's design. "Perceived Control" is therefore our first dimension and deals with who is in control of the robot. We identified three broad aspects of how a robot could be controlled and how this is perceived, and in turn, how it affects the jogging experience:

Robot in Perceived Control: The robot being in perceived control means that the jogger perceives an autonomous system with no sensed input from the jogger. Technically, our robot was in control, as it did not sense the jogger, however, our participants perceived some sense of control coming not from the robot, which we explain next.

Jogger in Perceived Control: Our joggers perceived some of the movements of the quadcopter in response to wind and sensor inaccuracies as the quadcopter trying to communicate in response to their jogging movements. As the joggers set the initial pace at the beginning of the study, they perceived to be in control of the quadcopter at least to some extent themselves.

Third-Person in Perceived Control: We as designers were also partially in control by having laid out the course for the robot to follow. Furthermore, we had one instance where a jogger perceived that we temporarily took over manual control with our remote controller, which suggests to us that designers should also consider having a third-person take control of the robot. In our case, we were ready to do so for safety reasons, but our interviews suggest that participants can also see value in a coach having control over the robot, for example to offer remote guidance in a tele-training scenario [35].

This dimension also highlights that perceived control facilitated our joggers' experience with the quadcopter in three key ways: firstly as a tool, when they used it for pace keeping; secondly as a safety issue when it was seemingly out of control; and thirdly as a companion during their jogging activity. The first two aspects remind us of the ready-to-hand and present-at-hand concepts previously appropriated by HCI [10] to describe how the same technology can be experienced as invisible when the focus is on the task, but also quite disruptive when a breakdown occurs. Our work shows that in an exertion context, technology can additionally be experienced as companion, in particular, our joggers perceived the quadcopter both as a companion and as a tool within the same exertion activity.

To facilitate this experience of a companion, designers do not necessarily need to design specific control aspects, as the perception of control might suffice: our quadcopter showed that robots do not necessarily need to sense the jogger to be considered a companion, utilizing simple wind movements can already contribute to a sense that the robot is a "buddy". This aligns with prior work on social robots that highlights that people can experience a social connectedness with them [6, 12], here we extend this work by highlighting that perceived control matters in contributing to a social exertion experience.

Dimension 2: Focus

A jogger's attention can be on the jog, trying to focus on the path ahead or paying attention to how the body responds to the physical activity. A jogger's attention can also be away from the jog, used to unwind and distract oneself from the discomfort of exercise. With the addition of a robot, a jogger now has another opportunity to shift focus elsewhere. Our study suggests that designers need to carefully consider the jogger's attention in regards to the robot and the jog. "Focus" is concerned with the extent to which the robot is designed to demand focus. We identified the following key ways how designers can direct focus to and away from the robot:

Size: The size of the robot affects the attention it can draw; in our study, the jogger needed to see the robot, therefore fist-size quadcopters, which we also experimented with, we deemed not suitable as they are much more difficult to locate and track at a distance. A larger quadcopter can draw more attention, however, designers need to consider size in relation to battery performance and therefore flight time.

Altitude: Another way designers can direct attention is by considering the altitude of the flying robot. On the one hand, a high altitude directs the jogger's attention away from the path and tired legs (but might invite tripping), distracting from the discomfort of exercise, on the other hand if the altitude is lower, joggers can focus on the path but might also pay more attention to any fatigue.

Proxemics: Considering the distance between the jogger and the robot is another way designers can direct focus. This draws on the notion of proxemics, the interpersonal distance between people [15], but has also been shown to apply between people and robots [11]. Our study demonstrated that if the quadcopter gets too close to the jogger, it immediately shifts any focus, even if it is just from a safety perspective. Designers should therefore consider how they could use this interpersonal distance to direct any focus between the robot and the jog.

Dimension 3: Bodily Interaction

Our study highlighted the potential of the robot's actions to affect the jogger's actions. This dimension is therefore concerned with the bodily interaction between the robot and the jogger: it describes the extent to which the robot's actions affect the jogger's actions.

One pole of the dimension is where the designer minimizes the effect the robot's actions have on the jogger's actions (where the robot becomes a spectator), the other pole is where the designer tries to actively affect the jogger's actions through the robot's actions (for example if the quadcopter would use its propellers to create a draft that propels the jogger forward). We see a unique potential for robots to affect the jogger's bodily actions but also note that this dimension could be complemented with other, more cognitive-focused approaches (such as robots that cheer the jogger on). We identified the following key ways designers can use the robot's actions to affect the jogger's actions:

Contending for Space: Both the jogger and the robot have a physical body that share the same physical space, and unlike virtual avatars, they cannot occupy the same location at the same time. So when our quadcopter flew into the way of the jogger, the jogger had to yield. As the quadcopter was contending for space, participants had to sometimes slow down and step to the side, changing the way they ran. So one way to affect the jogging action is by utilizing the robot's actions to contend for space.

Bodily Directing Jogger's Actions: Designers can use the robot's actions to guide a person's actions, in our case the quadcopter directed where the joggers jogged through the path it set. Robots can either subtly direct a person's actions, such as the pace setting in our study, or they can direct a person's actions to a more physical extent, for example we can envision a physiotherapy application in which a robot physically directs a person's limbs.

Robot Exerts: Another way the robot's actions affected the jogger's actions was through the quadcopter "exerting": flying requires a significant amount of energy (just like jogging), which was visible to the jogger through the propellers turning very fast, the amount of noise and the fact that we needed to change batteries from time to time. As the robot as well as the jogger was exerting, a shared exertion experience [28] emerged, which motivated our joggers to jog for longer.

Tactics for Designing Robots for Jogging

We now present 5 design tactics we derived from our craft knowledge of designing, building and studying the use of our quadcopter system. These design tactics are aimed at guiding designers navigate the design space in order to make good choices when designing flying robots for jogging. We describe them using the dimensions.

Tactic 1: Support "Contending for Space" to facilitate movement variety

If joggers are not completely in control of the robot (Dimension 1), designers have the opportunity to design the robot's movements so that there are opportunities to contend for space (Dimension 3) with the jogger. Usually if a robot contends for space with a human it is seen as undesirable, however, our study suggests that in the context of jogging, this can be exploited to facilitate movement variety.

In "Run, Zombies!" a narrative and contending for virtual space turns the jog into interval training [39]. It highlights for us the power of technology to change the character of jogging experiences. Our work extends this by pointing out that designers can use robots to support contending for physical space, facilitating movement variety.

Tactic 2: Use robot to direct focus away from discomfort of exercise

Exertion activities often involve some moments where the participant experiences discomfort as a result of the exercise. Prior work showed that designers can employ technology to distract from this discomfort of exercise, contributing positively to the experience [28]. Here we point to the robot as design opportunity to direct focus away from the body (Dimension 2), which could result in a distraction away from discomfort. However, designers should consider the right time when to direct focus away from discomfort: we believe designers could benefit from knowing when these discomforts occur (informed by, for example, biosensors), as they could then aim to alter the focus of attention, for example by changing the altitude of the quadcopter.

Tactic 3: Utilize, not fight the robot's secondary movements

Most robots exhibit some sort of secondary movements when they are moving. Secondary movements [21] are movements that do not directly relate to the robot's goal [17], in our case secondary movements were those movements caused by wind and sensor inaccuracies. Engineers usually try to minimize these secondary movements (for example by creating better sensors), in contrast, our study suggests that these secondary movements have the potential to contribute positively to the jogging experience: our joggers reported that they draw focus (Dimension 2), which some of them perceived as entertaining and can even read as communication attempts, resulting in the quadcopter being described as having some "character".

Prior work on secondary movements highlight their expressive and performative potential to support movement-based interactions by humans [18, 34], here we extend this work by suggesting that these secondary movements can also be exploited in robots to support joggers.

Tactic 4: Utilize the shared space to support movement

We also recommend to designers to utilize the shared space that hosts both the robot's actions and the jogger's actions (Dimension 3) to support movement. In our study, the use of the quadcopter as physical pace keeper acting within the same space worked very well for our participants: it provided them with a continuous awareness of their target pace that was easy to comprehend because both the robot and jogger were moving in the same physical space.

This contrasts with screen-based pace keeping watches: our robot was situated in the same physical space and therefore always available (Dimension 2) and therefore did not require a deliberate interaction such as looking at the watch. Furthermore, the robot communicated the desired pace by moving through the same space (in contrast to a mapped virtual space or a number that demands cognitive load), as such it was much easier to understand how much the jogger needs to speed up (in contrast to a numerical display asking for a 0.4 min/km increase for example).

Using embodied systems to support movement in the same space has been previously discussed in embodied interaction research [36] and human-robot interaction [37]. Our work extends this by highlighting the opportunity of autonomous robots to support exertion actions by utilizing the shared space.

Tactic 5: Exploit mutual exertion investment

Sports science found that investing exertion with others changes one's pain threshold and can therefore lead to working out harder [7]. Although we did not measure athletic performance in our study, our joggers appreciated that the quadcopter was also "working out", resulting in a perceived performance enhancement. We noticed our joggers perceived the quadcopter to also be exerting mainly through what we initially thought were "shortcomings" in our design: the motors were quite loud, the quadcopter does not maintain hovering stability, and the battery needs to be changed from time to time. At the beginning, we thought we needed to "fix" these shortcomings through an engineering approach, however, we became quickly aware that our participants appreciated them as they attracted attention (Dimension 2) to the fact that the quadcopter also exerted during the activity, which contributed to the emergence of a shared exertion experience that our joggers appreciated.

In consequence, we suggest that designers exploit the fact that robots invest physical effort – that they "exert" to operate. In other words, if designers design for exertion, a suitable approach might be considering an exerting technology, as it can offer an opportunity to complement the exertion character of the human's experience with the potential result of facilitating a shared exertion experience.

LIMITATIONS

One limitation of our work is the fact that we were always in eyesight in order to be able to manually take control of the quadcopter if safety needs had arisen. The presence of researchers is quite different to our joggers' usual jogging experiences. Furthermore, our joggers only jogged once with the system. Nevertheless, we believe our in-the-wild [33] insights can serve as valuable starting points towards future investigations when participants can be outfitted with quadcopters without supervision.

Another limitation is that our quadcopter did not sense the jogger nor the terrain, i.e. we had to lay out a path that did not involve trees or other obstacles and the jogger did not have the opportunity to change the path or alter the jog in any other way. Our participants lamented this lack of autonomy. However, we showed that even a restricted quadcopter system can support the jogging experience. With advancements in technology, future studies that consider these additional aspects will provide further insights.

CONCLUSION

We have presented the first study of a flying robot as jogging companion. We analyzed the participants' experiences and found key elements that made jogging with a flying robot an engaging experience. With these key elements, we derived a set of dimensions that create a design space for flying robots supporting jogging experiences. We then used these dimensions to articulate tactics for the design of future systems. As this work is the first investigation around quadcopter-jogger interactions, we see our dimensions as a starting point towards future studies. In particular, we think studies where people jog with a quadcopter multiple times might provide further insights. Nevertheless, we believe our dimensions and associated tactics could also be beneficial for the design of robots in other sports, in particular parallel [27] exertion activities, i.e. exertion activities in which participants are not physically interfering with one another, such as cycling, cross-country skiing and rowing. For example, designers could use Tactic 1 in a cycling scenario, where a flying robot is moving close to the cyclist, "occupying" the space while using its propellers to create a draft, providing a psychological and maybe even physical boost. Similarly, Tactic 2 could be applied to long-distance cross-country skiing, where a flying robot with an embedded display could show motivating messages when participants get tired, directing focus away from the discomfort of exercise. In a rowing scenario, Tactic 3 could be used to design a flying robot that would hover just above the water's surface, utilizing secondary movements caused by water movement, adding a performative element to the experience.

We believe our dimensions and associated tactics could also support coaching, for example we can envision future quadcopters supporting "fun runs" as pace keepers and coaches utilizing them to support their training targets. This is not that far in the future, as some sports clubs already utilize quadcopters (however, up to now only for birds-eye video analysis afterwards [2]). Our dimensions might also contribute insights to the design of sports technologies such as watches and jogging apps from an embodiment perspective, highlighting opportunities for designers. Our work might also inform the design of other exertion-focused systems such as the Wii, Sony Move and Kinect that in the future might incorporate small robotic toys as part of the game experience (this is not that far off as flying robotic toys are already popular with children). Lastly, our work might be beneficial to support the design of a range of actuator-based systems that aim to support bodily activity, for example clinical programs that use interactive moving parts to support movement rehabilitation.

Overall, our work aims to inspire other designers to utilize robotic systems to support exertion activities. By doing so, we believe we can not only enhance our understanding of the design of engaging sports activities, but also our knowledge of the coming together of exertion activities with exerting systems, and how they can draw from each other to further the field of embodied interactions.

Our results also highlight the potential of robots to *support* human action (contrasting the approach of *replacing* human action as popularized by robotic vacuum cleaners) that humans like to engage in, such as jogging. In other words, our work contributes to a trend of using robots to support playful human activities. In particular, we believe our work can sensitize designers to the fact that exertion activity can benefit from exerting systems and vice versa, and we see the current research as the first step in this promising direction.

In summary, we hope our work is able to inspire and guide designers interested in creating robotic systems to support exertion experiences and hence ultimately contribute to further participation in physical activity, supporting more people to profit from the many benefits of exertion.

ACKNOWLEDGEMENTS

We thank all joggers and everyone who helped with this project. Florian 'Floyd' Mueller thanks the Australian Research Council Fellowship DP110101304.

REFERENCES

1. Airdog. http://www.airdog.com/.
2. Drone flying takes off as a popular hobby. http://www.theage.com.au/digital-life/digital-life-news/drone-flying-takes-off-as-a-popular-hobby-20140709-zst12.html.
3. Sensoria Fitness. http://www.sensoriafitness.com/.

4. U-M researcher honored for MABEL, the jogging robot. http://ns.umich.edu/new/multimedia/videos/20819-u-m-researcher-honored-for-mabel-the-jogging-robot.
5. Baca, A. and Kornfeind, P. Rapid feedback systems for elite sports training. *Pervasive Computing, IEEE*, *5* (4). (2006), 70-76.
6. Breazeal, C. Toward sociable robots. *Robotics and autonomous systems*, *42* (3). (2003), 167-175.
7. Cohen, E.E.A., Ejsmond-Frey, R., Knight, N. and Dunbar, R.I.M. Rowers' high: behavioural synchrony is correlated with elevated pain thresholds. *Biology Letters*, *6* (1). (2010), 106.
8. Csikszentmihalyi, M. *Flow: The psychology of optimal performance*. New York: Harper and Row, 1990.
9. Curmi, F., Ferrario, M.A. and Whittle, J. BioShare: a research tool for analyzing social networks effects when sharing biometric data. In *Companion Proc. DIS 2014*, ACM Press (2014), 101-104.
10. Dourish, P. *Where the Action Is: The Foundations of Embodied Interaction*. Boston, USA: MIT Press, 2001.
11. Eresha, G., Haring, M., Endrass, B., Andre, E. and Obaid, M. Investigating the influence of culture on proxemic behaviors for humanoid robots. In *RO-MAN, 2013 IEEE*, (2013), IEEE, 430-435.
12. Fong, T., Nourbakhsh, I. and Dautenhahn, K. A survey of socially interactive robots. *Robotics and autonomous systems*, *42* (3). (2003), 143-166.
13. Gaver, W. What should we expect from research through design? In *Proc. CHI 2012*, ACM Press, 937-946.
14. Graether, E. and Mueller, F. Joggobot: a flying robot as jogging companion. In *Proc. CHI 2012 Extended Abstracts*, ACM Press (2012), 1063-1066.
15. Greenberg, S., Marquardt, N., Ballendat, T., Diaz-Marino, R. and Wang, M. Proxemic interactions: the new ubicomp? *ACM Interactions*, *18* (1). (2011), 42-50.
16. Higuchi, K., Shimada, T. and Rekimoto, J., Flying sports assistant: external visual imagery representation for sports training. In *Proc. Augmented Human 2011*, ACM Press (2011), 1-4.
17. Hoffman, G. and Ju, W. Designing Robots With Movement in Mind. *Journal of Human-Robot Interaction*, *3* (1). (2014), 89-122.
18. Hornecker, E. and Buur, J. Getting a grip on tangible interaction: a framework on physical space and social interaction. In *Proc. CHI 2006,* ACM Press, 437-446.
19. Lieberman, H. Out of many, one: reliable results from unreliable recognition. In *Proc. CHI 2002 Extended Abstracts*, ACM Press (2002), 728-729.
20. Mueller, F., Agamanolis, S. and Picard, R., Exertion Interfaces: Sports over a Distance for Social Bonding and Fun. In *Proc. CHI 2003,* ACM Press, 561-568.
21. Mueller, F., Edge, D., Vetere, F., Gibbs, M.R., Agamanolis, S., Bongers, B. and Sheridan, J.G. Designing Sports: A Framework for Exertion Games. In *Proc. CHI 2011,* ACM Press (2011), 2651-2660.
22. Mueller, F., Graether, E. and Toprak, C. Joggobot: jogging with a flying robot. In *Proc. CHI 2013 Extended Abstracts*, ACM Press (2013), 2845-2846.
23. Mueller, F., Khot, R.A., Chatham, A.D., Pijnappel, S., Toprak, C.C. and Marshall, J. HCI with sports. In *Proc. CHI 2013 Extended Abstracts*, ACM Press, 2509-2512.
24. Mueller, F., Marshall, J., Khot, R.A., Nylander, S. and Tholander, J. Jogging with technology: interaction design supporting sport activities. In *Proc. CHI 2014 Extended abstracts*, ACM Press (2014), 1131-1134.
25. Mueller, F., Muirhead, M. Understanding the Design of a Flying Jogging Companion. In *Adjunct Proc. UIST 2014*, ACM Press (2014), 81-82.
26. Mueller, F., Vetere, F., Gibbs, M., Edge, D., Agamanolis, S., Sheridan, J. and Heer, J. Balancing exertion experiences. In *Proc. CHI 2012,* ACM Press (2012), 1853-1862.
27. Mueller, F., Vetere, F., Gibbs, M.R., Agamanolis, S. and Sheridan, J. Jogging over a Distance: The Influence of Design in Parallel Exertion Games. In *ACM SIGGRAPH 2010*, 2010, ACM.
28. Mueller, F., Vetere, F., Gibbs, M.R., Edge, D., Agamanolis, S. and Sheridan, J.G. Jogging over a distance between Europe and Australia. In *Proc. UIST 2010*, ACM Press (2010), 189-198.
29. O'Brien, S. and Mueller, F. Jogging the distance. In *Proc. CHI 2007*, ACM Press (2007), 523-526.
30. Park, T., Yoo, C., Choe, S.P., Park, B. and Song, J., Transforming solitary exercises into social exergames. In *Proc. CSCW 2012,* ACM Press (2012), 863-866.
31. Pijnappel, S. and Mueller, F. Designing interactive technology for skateboarding. In *Proc. TEI 2014*, ACM Press (2014), 141-148.
32. Rigby, S. and Ryan, R. *Glued to games*. Praeger, 2011.
33. Rogers, Y. Interaction design gone wild: striving for wild theory. *interactions*, *18* (4). (2011), 58-62.
34. Sheridan, J. and Bryan-Kinns, N. Designing for Performative Tangible Interaction. *Journal of Arts and Technology. 1* (3/4). (2008), 288-308.
35. Sheridan, J. and Mueller, F. Fostering Kinesthetic Literacy Through Exertion Games. In *Workshop on Whole-Body Interactions at CHI 2010.*
36. van Dijk, J., van der Lugt, R. and Hummels, C. Beyond distributed representation: Embodied cognition design supporting socio-sensorimotor couplings. In *Proc. TEI 2014,* ACM Press (2014), 181-188.
37. Wallis, M., Popat, S., McKinney, J., Bryden, J. and Hogg, D.C. Embodied conversations: performance and the design of a robotic dancing partner. *Design Studies*, *31* (2). (2010), 99-117.
38. Walmink, W., Wilde, D. and Mueller, F. Displaying heart rate data on a bicycle helmet to support social exertion experiences. In *Proc. TEI 2014,* ACM Press (2014), 97-104.
39. Witkowski, E. Running from zombies. In *Proc. Interactive Entertainment 2013,* ACM Press (2013), 1-8.