Exploring Real-Time Collaborative Heart Rate Displays for Cycling Partners

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ABSTRACT

Training with a partner is beneficial for promoting enjoyment and persistence. However, there has been little research on real-time collaborative displays that enable co-located training partners to share data, such as heart rate (HR). We developed a prototype interface that enables cycling partners to view each others' HRs both as beats per minute and as percentage of each user's maximum HR. In a pilot study with six participants, we found that the real-time display may be particularly helpful for less experienced recreational cyclists, and highly experienced cyclists find it useful when road conditions are dynamic. We also observed that real-time collaborative data may facilitate more social dialogue. All participants indicated that they would use this app in the future. This study highlights the importance of future research on real-time interfaces for exercise, with the goal of enabling more users to integrate physical activity into their lives through successful collaboration.

CCS CONCEPTS

• **Human-centered computing → Collaborative and social computing devices**.

KEYWORDS

Collaborative Physical Activity, Exercise, Real-time Data Sharing, Cycling, Heart Rate, Fitness Tracker

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1 INTRODUCTION

Physical activity can have a positive impact on mental and physical well-being [5, 19]. It can also prevent disease, including type 2 diabetes, hypertension, and cancer [12]. Despite these benefits, many individuals worldwide fail to meet the minimum daily physical activity recommendations suggested by health organizations [6, 12]. Hence, one promising avenue for contemporary HCI research is to empower users to increase their physical activity.

Social support and having a partner can significantly enhance exercise across all age groups, leading to better outcomes [2, 4, 15, 17]. While there is evidence supporting the benefits of collaboration in exercise, current platforms for exercise are lacking in collaborative features. Despite offering a highly customizable display of an *individual's* data, none of the current technologies provide a real-time view of *collaborators*' data during co-located exercise. Some commercial and research projects, such as Zwift, Peloton, and "Jogging over a Distance" [11], do provide real-time data but for *remote* exercise collaboration. Collaborative support for co-located exercise is still underexplored. To the best of our knowledge, the only study of real-time data sharing for co-located exercise was conducted by Walmink et al. [18]. However, their intervention only delivered feedback to one of the cyclists. Therefore, there is a need for further research on supporting collaborative exercise by facilitating real-time data sharing among individuals engaged in co-located exercise.

To address this gap, this paper presents an initial investigation into the design space of real-time displays for co-located, collaborative exercise, specifically cycling. To investigate the potential of real-time heart rate (HR) sharing during a collaborative ride, we developed and investigated a prototype smartphone application that allows two cyclists to share HR data in real-time. We investigate the research question, *How do riders adapt their cycling behavior when they can see their own and their partner's HR data in real-time?* To answer this question, we present a case study analysis of pilot sessions with six participants, through which we examine how participants used the data and interacted with each other. This study points to the importance of further research on real-time interfaces for exercise and sport, which can enable more individuals to integrate physical activity into their daily lives through successful collaboration.

2 BACKGROUND AND RELATED WORK

In collaborative or competitive group cycling, many of the actions cyclists take affect those behind them. These effects are primarily due to the influence of the *draft*, which refers to the lower air resistance experienced by trailing cyclists. Research shows that a rider positioned well in the draft can travel the same speed as the leading cyclist for only a fraction of the effort [10].

Heart rate is one of the most widely used measures of effort or exertion. Many endurance athletes, including cyclists, follow structured training plans that leverage HR; for example, a workout may require an athlete to ride a 30-minute warmup at an easy exertion level (50-60% of their max HR), and then they may ride

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for a 20-minute interval at a "tempo" exertion level (80-85% of max HR). For casual cyclists, HR is valuable to ensure they exert enough effort to gain cardiovascular benefit while not riding so hard as to become exhausted prematurely.

Because HRs differ among individuals, when two people are discussing their exertion in terms of HR, they often provide their max HR for context (e.g.,*"That was a hard ride! I was at 156 bpm and my max is 165!"*); therefore, we assume that successful collaborative exercise apps should also provide users with the option to view HR as a percent of max. Our prototype used a toggle button to view HR as beats per minute or as a percentage of max.

Facilitating Collaboration in Exercise Endeavors. Social support plays a crucial role in motivating individuals to engage in physical activity[8, 17]. A study on a social game named Fish'n'Steps, which is designed for promoting exercise, shows competition and collaboration can increase motivation and foster healthier routines [9]. Sharing physical activity data in low socio-economic status families has been found to increase engagement in physical activity [14]. Similarly, Pina et al. [13] discovered that being able to share data via self-tracking technologies helped families highlight their successes in physical activity.

Some technologies currently exist to facilitate real-time collaborative exercise in remote settings. The Jogging Over a Distance project [11] used spatial audio to convey real-time HR data for jogging partners running in different locations. The joggers communicated with each other over a headset, and their voices were spatialized over a 2D plane based on their relative exertion and target HR. The study found that joggers were able to use the spatialized audio to adjust their levels of exertion and found the experience enjoyable and engaging.

Real-time Collaborative Cycling. Cycling computers are popular among cyclists[1] and provide real-time data such as HR, power, cadence, and distance to cyclists by connecting to available sensors. However, these existing technologies do not display real-time collaborative data. To our knowledge there is only one study, conducted by Walmink and colleagues in 2014 [18], that investigated the usability of a prototype which supports co-located collaborative exercise. In the study, a pair of cyclists rode together while an app displayed the lead cyclist's HR on a screen on the back of their helmet. This allowed the trailing cyclist to monitor their partner's exertion, but not vice versa. The lead cyclist did not have access to any data for themself nor their partner. To the best of our knowledge, our work is the first to investigate real-time collaborative HR displays for co-located exercise, specifically cycling.

3 METHODS

Prototype Design. The prototype was developed on Android 8 and supports connection of any Bluetooth Low Energy (BLE) HR sensor, including chest, wrist, and arm-worn sensors. Each participant pairs their HR sensor with the prototype app, and then the two smartphones are connected with each other through classic Bluetooth to transmit each partner's data in real-time. Apart from the ubiquity of smartphones, we chose this platform primarily for its ease of development compared to smartwatches and cycling computers. The interface design was derived in collaboration with experienced cyclists (R1 and R2, please see Section 3) and includes large HR displays designed to support quick and safe viewing of their own and each other's HR. The workout screen (Figure 1) includes a toggle button to display HRs as either actual values (e.g., 133 bpm) or relative to the user's max HR (e.g., 33%). The HRs are shown within adaptive circles that indicate the user's exertion relative to max HR. When the HR is within the target interval, it is shown in bold, blue font and when the HR is outside of the interval, it is shown in thinner, black font (see Tom's HR vs. Anne's on the screen, Figure 1).

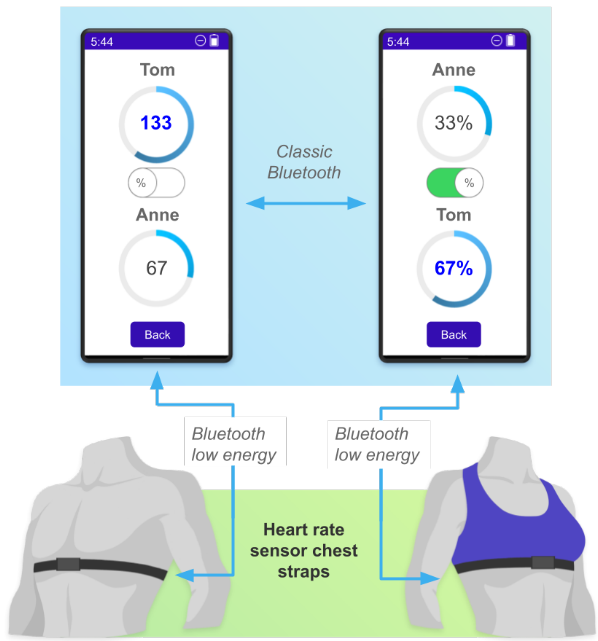

Figure 1: Each participant's HR sensor was connected to their smartphone through BLE, and the participants' smartphones were paired through the app using classic Bluetooth to support real-time data transfer. In this figure, Tom has opted to display HRs as actual values, while Anne has chosen to see the percent of each participant's max HR. Each user's view shows their name at the top of their screen.

Participants. Six participants were recruited through word of mouth within the local cycling community. The recruiting process and study procedures were IRB approved. Participants were not compensated for their participation (Table 1).

Procedures. When participants arrived for the study, the two participants discussed amongst themselves and with the researchers what HR intensity they would target for two ten-minute cycling intervals. For those participants who were not experienced cycling with HR data, the researchers assisted them in calculating a target zone based on estimated max HR according to the "220-age" formula [16]. Most participants used a chest-worn sensor and one participant opted to use his arm-worn sensor. Participants without their own HR sensor were provided one. Researchers provided

Table 1: Participant demographics and cycling experience.

Case #	ID	Gender	Age	Race	Experience level
Case 1	R1	Female	43	White/Caucasian	Competitive (4 years experience)
	P1	Female	39	White/Caucasian	Competitive (10+ years experience)
Case 2	R1	Female	43	White/Caucasian	Competitive (4 years experience)
	P2	Male	32	White/Caucasian	Competitive (5 years experience)
Case 3	P3	Female	N/A	White/Caucasian	Recreational
	P4	Female	N/A	White/Caucasian	Recreational
Case 4	P5	Male	49	Asian-American	Competitive; former professional (10+ years experience)
	P6	Male	19	Asian	Competitive (4 years experience)

smartphones for use during the study, mounted on each cyclist's handlebars.

After consent and hardware setup were complete, the pair of cyclists started their ride. The study was conducted on a paved bike path set apart from motor vehicle traffic. Each pair of participants was trailed by one of the researchers, R2, who is an experienced competitive cyclist. He wore a GoPro Hero 10 on a helmet mount. R2 positioned himself behind or slightly beside the riders to capture their bike positions relative to each other, and also their head positions (to indicate when they looked down at the smartphone). Audio was collected with a RODE Wireless Go2 system. In the cycling portion of the study, the two partners were asked to ride for two ten-minute intervals with a break between the intervals. During the first ten-minute interval, the only way the two partners knew each other's HR was through verbal communication. During the break between the intervals, R2 enabled the collaborative real-time HR display and the cyclists began a second interval in which they were able to view each other's HRs in real-time.

After the ride was complete, participants joined R3 at the trailhead for a post-ride interview. This interview asked participants about their general training habits, feedback on the functionality and visual displays in the prototype app, and addressed usability strengths and challenges the riders faced.

Data Collection and Analysis. In order to investigate our research question, we analyzed audiovisual data collected from the cycling sessions. The four videos totaled 4 hours and 17 minutes, with individual video duration ranging from 47 minutes to one hour and 34 minutes, depending on how much time the participants spent answering the interview questions. We analyzed the audiovisual data from the cycling sessions in concert with the responses to the post-ride interview questions, to deeply examine the four pairs within a case study methodology [3, 21]. R2 analyzed the ride videos, which included visual indications of how the participants were riding in relation to each other (drafting), their hand and body positions, their cadence (indicating their likely effort level), as well as an estimate of their general gaze direction (e.g., observing data on their displays). These visual cues provided one axis of coding, the other axis being dialogue between participants. For analysis of the interviews, R3 transcribed the interview videos and took note of similarities and differences in the participants' responses.

4 FINDINGS

We analyzed the audio-visual recordings of the cycling sessions and coded for dialogue between participants regarding HR, effort, or the use of the novel technology, as well as visual indicators of participants' body language and positioning.

Case 1: R1 and P1

R1 and P1 were targeting a HR range between 150 and 160 bpm. One minute into their first interval, R1 reported her HR as *"154"* and P1 responded, *"mine's 148,"* indicating that P1 was still below their target HR. R1 stated that *"as [she] anticipated, I'm gonna get in your draft; just a little bit, not all the way,"* responding to her HR already being 6 bpm higher than P1. R1 proceeded to position herself behind P1 (see Figure 2, left) in order to gain some aerodynamic benefit, but not fully behind P1 in an attempt to ride at the same relative effort (as reflected in their HR). R1 later noticed that her HR was down to 140 bpm, having done *"too good a job"* getting into P1's draft, thus lowering her HR below the desired target. P1 noted that her HR was slightly too low, and pedaled harder but noted that the downhill slope of the road was making it difficult to pedal hard enough to bring her HR above 148 bpm. P1 and R1 checked in with each other two more times as they negotiated various environmental factors that impacted their relative effort and HR. Towards the end of the first interval, R1 checked in again, asking P1 *"what's your heart rate now?"* P1 responded *"152. What's yours?"*, with R1 replying *"153."*

In the second interval session, R1 and P1 were able to see each other's HRs displayed on their devices. In this interval, R1 positioned herself much closer behind P1 as they were now going into the wind, rather than having a tailwind behind them. Two minutes into the second interval, P1 remarked *"Hey, there it is,"* signaling that she had now entered the targeted HR zone. After five minutes, R1 pulled alongside P1 in order to ride next to her: *"if I really wanted to stay beside you, maybe I can just get really aero..."* (Figure 2, right.) Now riding side-by-side, the participants engaged in more social conversations, and P1 stated, *"it's fun having another number to look at."* Entering the second half of the second interval, R1 declared *"alright, I'm gonna get in your draft a little."* Movement of R1's head indicated that she likely saw her HR increasing relative to P1, indicating that she would need to be in a more aerodynamically advantageous position in order to maintain her target HR zone. After returning to a drafting position behind P1, R1 looked down multiple times to check her HR. P1, in the leading position, looked down less frequently.

Figure 2: Case 1. Left: P1 (leading) and R1 (trailing), with R1 laterally offset in submaximal draft. Right: R1 and P1 riding side-by-side. R1 has lowered her body position by placing her hands on the drops of her handlebars to reduce exertion while not riding in P1's draft. P1 is in a neutral body position.

Case 2: R1 and P2

R1 and P2 were targeting a HR zone of 140 to 150 bpm. Initially, R1 asked P2 if he would like to *"start out side-by-side to see where our heart rates get?"* since the start of this interval was uphill. In response, P2 asked R1 if she wanted to *"...set yours at 145 and let me know when you're there."*

R1 responded, *"Ok, we're going uphill right now so we'll get there pretty quick."* For the first few minutes, as R1 and P2 rode uphill and their HRs increased, they both looked down at their HR frequently. Two minutes into the first interval, P2 announced that his HR had reached 145, in the target HR zone for this interval session. As they continued to ride, P2 continued to verbally update R1 on his HR. Shortly after, P2 was noticeably breathing harder, and began to drift back from his previous side-by-side position with R1. P2 took up an aerodynamically beneficial position drafting behind R1 (Figure 3).

Over the next several minutes, the two participants negotiated their effort verbally, reporting their HRs, and P2 moved into and out of maximal draft positions. Just before ending their first interval, R1 led P2 past several other cyclists (not connected with the study) on the paved trail. R1 stated, *"got my HR a little high,"* and a brief moment later, *"Alright I'm back to 150 now."* P2, who had been in R1's draft the whole time, stated his HR remained consistent at 144. However, passing a second group of cyclists increased P2's HR: *"I'm at 150."*

A brief rest period preceded the second interval, in which R2 enabled the collaborative display. Then, with the ability to see each other's HRs on display, R1 and P2 began their second interval. R1 commented, *"nice, yours (P2's HR) is in zone."* R1 moved to the lead position, in front of P2, as her HR *"was still a little low. "* With P2 riding in her draft, R1 said *"we're both in the zone, now."* For the second half of this interval, R1 and P2 rode through dynamic road conditions presented by sand and vegetation intruding into their path. P2 noted that his HR was *"way over."* R1 noted the presence of *"a little headwind,"* and implied that she would provide more draft for P2 by *"hopping in front of [him]"* in position, as her HR *"was still a little low."* With P2 riding in R1's draft, R1 said *"we're both in the zone, now."*

Figure 3: Case 2. P2 positioned in maximal draft behind R1.

Case 3: P3 and P4

Case 3 consisted of P3 and P4, both of whom are female recreational cyclists who typically ride together. They do not normally view their HR information while riding, but had viewed it as a summative metric after a ride. They set a HR target of 120 to 130 bpm for their intervals. Throughout the warm-up interval, P3 and P4 were actively engaged in observing their own HR, as viewing HR in real-time was novel to them. P3 asked P4 multiple variations of *"what's your HR right now?"*. P4 would respond with her HR and P3 would offer hers in return. At one point, hearing that P4's HR was 120 bpm, P3 noticed that her HR was higher than P4's: *"Oh, mine's high. I'm at 126!"* P4 then noted that P3 would have to address the disparity, suggesting that *"you'll have to slow down."* P3 noted that she could also change her gearing in an attempt to moderate her effort and HR. Through continued comparisons of their HRs, P3 noticed that she had a consistently higher HR than P4. About three minutes into their first interval, P3 said her HR had reached *"130, so I'm gonna slow down. Yeah, I'm gonna slow down just a tad."* As P4 continued to pull away from P3, P3 called out to P4 that she *"can't keep up with you, you're too fast, woman."* P4 said *"[her HR was] only at 122."* P4 had opened up a significant gap on P3 (see Figure 4, left), prompting P3 to comment, *"alright, I'm gonna catch you."* At a particularly steep section, P3 said that her HR is *"high, I'm like 145."* P3 then called out to P4 *"alright, you need to wait for*

Figure 4: Case 3. Left: P3 and P4 riding with a very large gap between them. Right: P3 in submaximal draft behind P4. Crosswind is coming from the riders' left, so maximal draft would be behind and to the right of the leading rider.

me!" After the end of their first interval, P3 noted that *"I don't think we were very good, trying to stay in the HR together, even though we were communicating together."*

At the start of their second interval, P4 announced that she was going to get in front of P3, returning to the positions they occupied for the majority of the first interval (see Figure 4, right). P4 noted keeping their HRs in the same zone was *"way easier when you can see it!"* P3 agreed that *"it's way easier when I can see yours, yes."* Unlike the warm-up period and the first interval, P3 and P4 rarely engaged in verbal communication regarding their HRs, now that they could see each other's HR. P3 talked about how different features of the road will impact their HR, and P4 responded by *"this tells me we don't work hard enough on our bikes, huh?"* As P3 pulled ahead of P4 about halfway through their second interval, P4 warned P3 that *"you're still too high,"* referring to her HR being above their target. As she rode in front, P3 observed, *"we're gonna be going up an incline, mine will probably go up some,"* referring to her HR. As they continued up the incline, P3 said *"I'm a little high,"* and P4 responded that, *"we're both high."* P4 again stated that *"it's a ton easier when you can see them both,"* and P3 agreed. As they ended their second interval, P3 said that seeing each other's HR was *"... kinda fun"* to which P4 agreed, *"it's kinda cool."*

Case 4: P5 and P6

P5 and P6 had very different HR zones. They decided to ride in their own HR zone 2, which is an endurance HR zone. For P5, this corresponds to 117-134 bpm, and for P6, this corresponds to 120-145 bpm. As P5 and P6 approached their first interval, P5 said that he was *"actually under zone 2 right now, I'm actually in zone 1,"* meaning that his HR was below the target HR they had set out before the ride. P6 responded, *"I'm almost at zone 2, almost."* Shortly after beginning the first interval, P6 said that he was *"right in the middle of zone 2 now"* (their target HR zone). P5 responded that he was also in the middle of zone 2. At the end of the incline section, P6 pulled ahead of P5, and P5 announced at this point that he was *"on [his] upper limit,"* while P6 was at his *"lower limit."* P5 then moved into P6's draft, seeking greater aerodynamic benefit in order to maintain an endurance HR zone. Halfway through the first interval, P6 looked back to ask *"this pace OK for you?"* and hearing an affirmative from P5, P6 announced that *"I'll keep it."*

Figure 5: Case 4. P5 in maximal draft behind P6.

Before beginning the second interval, P6 told P5 that he *"was doing around 135."* P5 responded, *"oh really? I was between 124 and 129, But my zone 2 is lower than yours."* Within a minute of beginning the second interval, P5 had returned to a position in P6's draft (Figure 5). As P5 and P6 rode uphill, P5 said that he was *"hitting the bottom of my zone 3, 134 is my upper zone 2."* P6 responded that he will go slower. P5 noted that his HR was higher than P6's when riding uphill.

Post-Ride Interview Results. In the post-ride interview, we asked participants, *"If your training partner's data was an option to be displayed during your collaborative training sessions, is this something you would use?"* All participants responded positively. P1 said it was fun to have both numbers. P3 stated that having real-time data from peers made it easier for them to stay in the same HR zone. P5 also mentioned, *"This would be something helpful, especially for me and my friend."* Other participants said that they would like to use a similar option during collaborative rides in the future.

P6 said: *"It's pretty simple. Like, you can just... I don't even look at the numbers, I just look at the circle. It's pretty representative, and I like that, because when you're really riding, you don't want to pay too much attention to too many things. So, this kinda like circle stuff,* *yeah, I like that."* P5 also stated that he liked the simplicity of the app design.

Then, we asked participants what needs to be changed in the app. P1 suggested greater visual contrast when the HR is out of the zone, as well as displaying a timer for interval duration. P2, P3, and P4 suggested changing the background color based on HR changes. Also, P3 suggested the option to see both HR absolute value and its percentage shown on the screen at the same time. P5 recommended displaying additional metrics, such as power output.

5 DISCUSSION

The prototype described in this paper provides a collaborative data display designed to enable workout partners to maintain awareness of each other's exertion and cooperate to achieve their target intensities. It responds to a long-standing demand for technologies that support collaboration [7] and enable joint aerobic exercise between partners at potentially different fitness levels [20]. In contrast to prior systems that focus on non-co-located partners or post-session HR sharing, our prototype aims to cultivate a more collaborative environment between partners. Our findings, consistent with [18], demonstrate that access to both partners' HRs may enhance the social experience during exercise, fostering empathy and a sense of teamwork, as exemplified in Case 2 when R1 decided to "hop in front of" P2. Furthermore, the use of this technology may foster increased social dialogue, as participants engage in fewer discussions about HR when they can view their partner's data. This heightened social interaction may enhance the overall exercise experience and boost motivation. Moreover, the results suggest that the prototype supported cyclists in making the conceptual connection between their own HR and their position in the draft, as evidenced by R1's adjusted body position when outside of the draft, and P5's discussion of using the draft to keep up with P6. Further studies on this phenomenon are an important direction for future work.

Design Considerations. Our design of this prototype app has brought to light several design considerations. First, privacy of HR data is an important concern: our prototype did not provide the ability to pause sending one's data to the partner other than by exiting the app, but in the future, users should be able to control what data they send to collaborators at any point. Second, future apps should support a more extensive suite of collaborative data, including metrics such as power and cadence. Finally, continued work is needed to refine the usability of the visual interface, which must enable cyclists to make sense of collaborative data at a glance. One limitation of the study design is that the order of conditions was fixed in this exploratory study, and future studies should investigate the impact of condition order as well as riders' fatigue on the benefits of novel technologies to support collaboration.

6 CONCLUSION AND FUTURE WORK

This work has investigated the ways in which cyclists adapt to collaborate with each other in the presence of a novel display with real-time collaborative HR. We found that without the prototype, cyclists frequently conveyed their HR to each other verbally and engaged in less social dialogue, whereas with the prototype, they were able to focus on moving their bodies and bikes in ways that moderated their collaborative effort. We noticed a corresponding increase in social dialogue in three of the four cases when the prototype was enabled. These results suggest that real-time collaborative display may be helpful not only for fidelity to training zones and facilitating a more positive workout experience, but also fostering more social dialogue, which is a large part of why many cyclists choose to workout collaboratively in the first place.

This early exploratory work points to several important directions for future work. First, it seems clear that collaborating cyclists are able to utilize real-time collaborative displays to successfully moderate their effort. Further work is needed to examine collaborative workouts in other sports. Additionally, future work should investigate display formats including purpose-built cycling computers for experienced athletes, and smartwatch displays for those who prefer to walk or run together. In sports such as walking or running, where drafting is much less a factor, fundamental questions of how participants can use and adapt to the real-time collaborative displays should be investigated. It is hoped that this broad line of investigation could lead to a new generation of technologies that foster collaborative exercise and physical activity to empower people to achieve their goals.

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