

Social Fabric Fitness: The Design and Evaluation of Wearable E-Textile Displays to Support Group Running

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ABSTRACT

Group exercise has multiple benefits including greater adherence to fitness regimens, increased enjoyment among participants, and enhanced workout intensity. While a large number of technology tools have emerged to support real-time feedback of *individual* performance, tools to support group fitness are limited. In this paper, we present a set of wearable e-textile displays for running groups called *Social Fabric Fitness (SFF)*. SFF provides a glanceable, shared screen on the back of the wearer's shirt to increase awareness and motivation of group fitness performance. We discuss parallel prototyping of three designs—one flexible e-ink and two flexible LED-based displays; the selection and refinement of one design; and two evaluations—a field study of 10 running groups and two case studies of running races. Our qualitative findings indicate that SFF improves awareness of individual and group performance, helps groups stay together, and improves in-situ motivation. We close with reflections for future athletic e-textile displays.

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI).

INTRODUCTION

Since the 1990s, running has experienced unprecedented growth in the US [25,27]. Although typically seen as an individual activity, a growing number of runners are choosing to run in groups and/or joining running clubs [2]. Sports psychologists and coaches cite multiple benefits of group exercise, including greater adherence to exercise regimens, increased commitment to reach shared goals, and more intense workouts [13,14,24,33]. While a large number of tools have emerged to support real-time feedback of *individual* performance (e.g., Runkeeper, Nike+), we are unaware of work that investigates real-time tracking and feedback to support collocated group fitness activities.

In this paper, we introduce a set of wearable electronic textile (e-textile) displays—called *Social Fabric Fitness (SFF)*—designed to increase performance awareness and motivation for group fitness (Figure 1). SFF is worn by one



Figure 1: SFF visualize real-time run-tracking information on shared, glanceable wearable displays to increase group awareness and fitness performance. See also the video in our supplementary materials.

or two pace leaders in a running group; the displays wirelessly communicate with the wearer's mobile phone, and present real-time feedback about the group's activity (e.g., average pace, distance, and duration). Based on work in behavioral science related to the motivational effects of goal-setting and public commitment [15,26], SFF also compares recent pace averages to a group-set target pace. While a number of projects in ubiquitous computing and HCI have focused on on-body sports sensing (e.g., [6,18,30]), only a few have provided real-time textile-mediated feedback [16,22]. None have explored a shared, wearable display for runners aimed at enhancing group awareness, cohesiveness, and motivation.

As the first work exploring e-textile information displays for runners, our research questions are largely exploratory, including: what impact, if any, does SFF have on the wearer in terms of comfort, performance, self-awareness, and mental affect? How does SFF impact the group running experience—does it help support group awareness and/or cohesiveness? Finally, how does SFF compare to other tracking sources (e.g., watch, mobile phone)?

To examine these questions, we first designed, iterated on, and informally evaluated three flexible e-textile prototypes: two LED-based and one e-ink-based. During our iterative process, we focused primarily on viewability, comfort, size, weight, and display content. We then selected and refined a final prototype and performed a field study with 10 running groups and two small race case studies. For the field study, we recruited pre-existing running groups with at least 4 members to run with two SFF prototypes along a regular

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run route of their choosing for 30 mins or longer; in total, 19 wearers and 33 non-wearers participated ($N=52$). For the second study, we evaluated SFF in race environments—an 8K trail run and a 10K road race ($N=4$). For both studies, we collected data with pre- and post-study questionnaires, semi-structured post-study interviews, and observations.

We found that both non-wearers and wearers felt that SFF improved their awareness of their group's performance, helped motivate them to run at the group-set target pace, and helped keep the group together. Surprisingly, only a few wearers were concerned with publicly revealing their run data. When asked, 44 of 52 participants (85%) expressed interest in using SFF again (90% of wearers).

In summary, the contributions of this paper are: (i) an exploration of three e-textile designs built to support group fitness activities; (ii) findings from a field study of 10 running groups and two case studies of race events; (iii) design reflections and directions for future athletic jerseys for runners and other sports applications (*e.g.*, bicycling); (iv) the idea of and new directions for the reappropriation of quantified self systems for co-located shared activities.

RELATED WORK

We discuss benefits of group exercise and sports performance feedback before covering technology tools to support running and e-textiles for athletics.

The Benefits of Group Exercise

Sports psychologists and fitness coaches emphasize that exercising in groups: (i) helps participants adhere to training regimens; (ii) provides educational benefits since the community can share knowledge on training approaches and athletic events; (iii) increases enjoyment and engagement in the activity itself; and (iv) aids training intensity as group members push each other beyond preconceived limits [2,5,13,14,24,33].

For point (iv) sports psychologists often refer to social facilitation theories, which posit that the presence of others can increase a person's general drive and focus [5,29]. Bond [3] reframes this phenomena in terms of Goffman's presentation of self [12] where the individual is motivated to project an image of competence in the presence of others, which can have a positive impact on performance. For tasks perceived to be too difficult, however, performance may actually decline as the individual becomes self-conscious. In relation to SFF, there is a potential dichotomy of effects: the wearer could feel motivated to reach fitness goals because their performance is externalized and viewable, but also feel additional pressure or stress impairing them from reaching their potential. We explore both in our paper.

Sports Performance Feedback

Feedback is essential to athletic performance [1]. Sport scientists distinguish between two types [10,23]: (i) *inherent feedback* from an individual's own sensory mechanisms (*e.g.*, awareness of breathing rate) and (ii) *augmented feedback* from outside sources such as a coach,

video, or other technology. Augmented feedback—which is our focus—has multiple benefits that include helping athletes develop performance strategies (*e.g.*, to conserve energy), providing motivation, and increasing workout intensity [1,23]. These effects are moderated by the feedback's frequency, content, and concurrency with the action itself (*i.e.*, real-time). Though research into *shared* feedback systems is limited, Williams *et al.* found that swimmers were faster in relays than individual events but only if individual scores were released for each leg [32]. In our work, we were interested in investigating whether SFF wearers—who provide performance feedback for the entire group via their displays—feel an increased sense of responsibility or drive for their group's performance.

Tools to Support Running

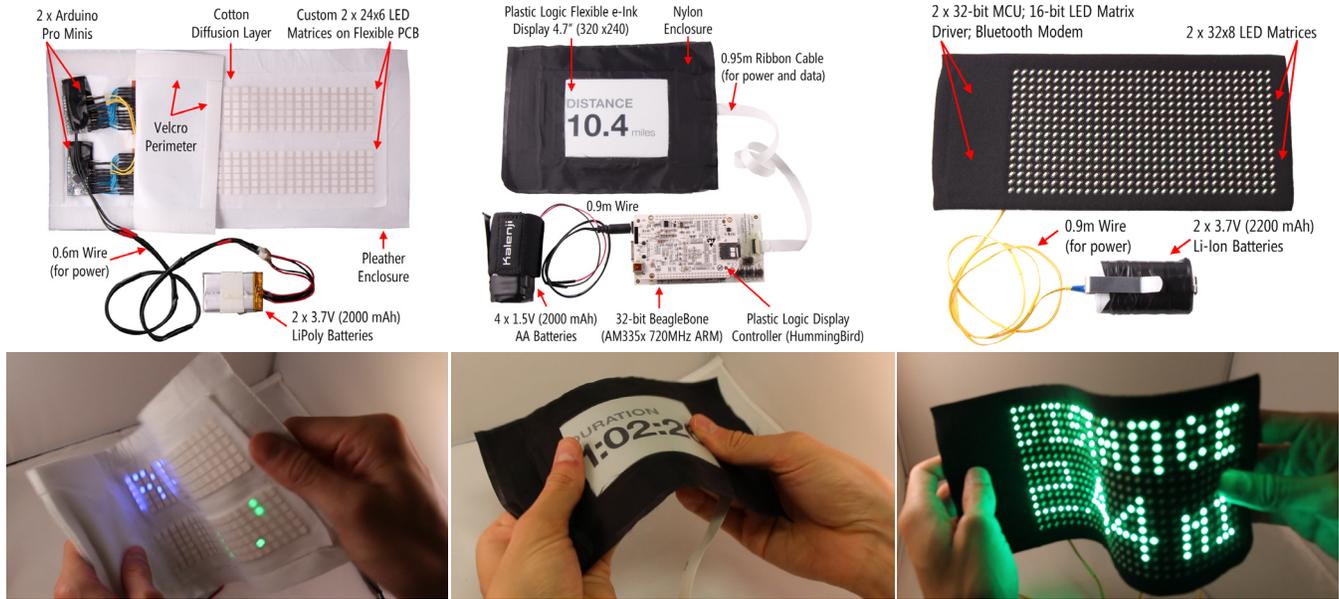
With the emergence of small, sensor-rich devices—including watches and smartphones—there has been huge growth in run-tracking applications (*e.g.*, Nike+, RunKeeper, and MapMyRun). Although some applications support social goals, challenges, and sharing workouts via social media they are not designed for shared, collocated experiences, which is the intent of SFF.

In the HCI research community, there has been similar interest in tools to support runners, including adapting music automatically to support pace goals [21], playing auditory signals to improve running cadence [11], and transforming the run into an adaptive fitness game [4]. However, the focus is on personal tracking and motivation. One exception is from Mueller *et al.*, who explored how mobile technology can support shared jogging experiences between remote partners (*e.g.*, partners are geographically dispersed but running in synchrony) [19,20]. Our work shares the goal of transforming the social experience of running, but, again, we are interested in collocated groups. We also focus on glanceable, visual displays compared to Mueller *et al.*'s auditory modalities.

E-Textiles and Sports

Most e-textile athletic wear has focused on data collection with *post-hoc* analysis by coaches and athletes rather than an integrated sensing and visualization system (*e.g.*, [7]). A few newer systems such as the Adidas miCoach Elite [31] and the Under Armour E39 smart jersey [28] sense and transmit the wearer's physiological and movement data in real-time. Again, however, the visualization is not integrated into the e-textile. In contrast, the recent Reebok CheckList both senses and visualizes potentially concussive hits directly on the helmet [16]. Similarly, SFF senses and visualizes a runner's movement and heart rate on the body within an integrated wearable platform.

As a group-based e-textile information display for fitness, our work is most similar to Page and Vande Moere's *TeamAwear* "smart" basketball jerseys [22]. Both SFF and *TeamAwear* surface otherwise latent information on shared displays directly on the athletes themselves; however, *TeamAwear* was meant to help coordinate action and



(a) Prototype 1: Custom LED matrix on flexible PCB (b) Prototype 2: Flexible e-Ink Display by Plastic Logic (c) Prototype 3: Flexible LED matrix by Erogear

Figure 2: We built and informally evaluated three flexible, e-textile prototype displays. The top row describes the displays, the requisite hardware including microcontroller and power, and the fabric enclosures. The bottom row highlights the flexibility of the prototypes.

improve in-game decisions among athletes in a competitive sport context. In contrast, SFF is designed to improve group awareness, cohesiveness, and motivation. Further, their evaluation consisted of only a 15-minute case study, in contrast to our evaluations of SFF: a field study with 10 pre-existing running groups and two case studies.

DESIGN PROCESS AND GOALS

The construction and design of the SFF display used a three stage human-centered, iterative approach. We first designed and built lo-fidelity mockups using materials such as fabric, foam, and Velcro. Here, we were interested in examining *wearable attributes* such as shape, size, and weight of display. In stage two, we built and informally evaluated three interactive flexible prototypes *in parallel* (Figure 2): (i) a custom LED matrix display; (ii) an electronic ink (e-ink) display; and (iii) a second higher-resolution LED matrix display. Parallel prototyping, which allows designers to compare and contrast design ideas during the design process, has recently received increased attention in the CHI community and has been shown to produce diverse, high-quality design outcomes (e.g., [9]). In the third stage, we selected the best performing prototype and updated our final design based on our pilot study results.

Design goals. Our design goals fall into four categories: *comfort*, *display content*, *robustness*, and overall *user experience*. For comfort, we wanted prototypes that were lightweight and unobtrusive (i.e., that did not physically interfere with the wearer’s run). The *display content* should be real-time, informative, and motivational as well as viewable across multiple lighting conditions (e.g., in shade or direct sunlight) and legible from a distance (~12m). The design should also be *robust* to withstand exercise activity and resistance to sweat/moisture. Finally, for overall *user*

HW Specs	Prototype 1: Custom Flex LED	Prototype 2: PL Flex e-Ink	Prototype 3: Erogear Flex LED
Power / Battery	2 x 3.7V Lithium Ion Polymer; 2000 mAh	4 x 1.5V AA; 2000 mAh	2 x 3.7V Lithium Ion; 2200 mAh
Physical Dimensions	8.4" x 2.4" (8.4" x 4.8")	8.4" x 2.4" (8.4" x 4.8")	8" x 3" (8" x 6")
Thickness	2.85 – 13.47mm	2.78 – 4.86mm	2.19 – 4.79mm
Flexibility	High	Medium	High
Resolution	24 x 6 (24 x 12)	320 x 240	32 x 8 (32 x 16)
Pixel Density	~16 ppi	85 ppi	~12 ppi
Color	Single color per panel	Grayscale	Single color per panel w/65k illumination levels
Refresh Rate	5 Hz	~1.1 Hz	38 Hz
Controller	2 x Arduino Pro Mini w/ATmega168 8MHz	BeagleBone w/ custom PL display driver	2 x 32-bit MCU, 16-bit PWM LED matrix driver
Controller Location	Built into fabric panel enclosure	Connected via extension cable & worn on waist	Built into fabric panel enclosure
Weights			
Battery	61.0 grams	121.6 grams	114.3 grams
Controller	24.8 g	127.2 g	N/A (could not be separated from display)
Display*	66.9 g	25.4 g	46.8 g
Holder (Belt)	N/A	136.2 g	N/A
Interconnects	0.2 g	1.3 g	0.1 g
Total	152.9 g (0.34 lbs)	411.7 g (0.91 lbs)	161.2 g (0.36 lbs)

Table 1: Hardware specifications and weights of the three prototypes. A precision scale was used (0.1 g rating). *Includes fabric enclosure.

experience, our goal was to design a system that was fun, enjoyable, and helped support the group run experience.

THE THREE INTERACTIVE PROTOTYPES

Here, we describe our three interactive prototypes, which embody different aspects of our design goals (e.g., different sizes, weights, display technology, aesthetic qualities, etc.).

Prototype 1: Custom Flexible LED Matrix

Our first prototype is a custom LED matrix display made from a flexible printed circuit board (PCB). This design was the lightest of the prototypes (including all components), had intermediate brightness and “pixel” density, and the lowest resolution (Table 1). As this was the only prototype

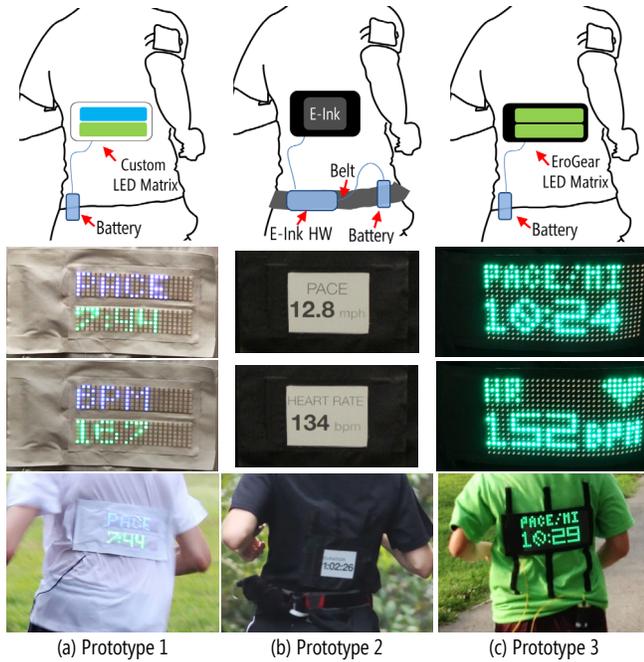


Figure 3: (Top) The required components of the three prototypes. **(Middle rows)** Two of the four display screens along with fabric enclosures. Not shown: duration and distance. Sizes are relative. **(Bottom)** Prototypes in action during our internal pilot studies.

completely constructed in our lab, we also had more control over its design and individual components.

Initially, we created early versions of Prototype 1 with breadboards, LEDs, and Arduino Unos. With these early prototypes, we investigated different LED matrix configurations, tested their impact on brightness and outdoor viewability, and implemented early font sets and visual feedback designs. Because Arduinos have a limited number of I/O pins, we used a technique called charlieplexing, which takes advantage of the tri-state logic capabilities of microcontrollers to efficiently multiplex the output signal (e.g., [8]). Charlieplexing, however, increases circuit complexity, has dimmer visual output, and greater susceptibility to failure. After multiple iterations, we created a final design with a 24x6 LED matrix. To produce the prototype used in our pilot studies, we sent a custom-built flexible PCB schematic to outside manufacturing. We stitched two flexible PCB panels together (one blue, one green)—each driven by an Arduino Pro Mini integrated with the enclosure (Figures 2a and 3a).

Prototype 2: Plastic Logic Flexible e-Ink Prototype

For our 2nd prototype, we investigated flexible e-ink displays because of their size, thinness, weight, wide-viewing angles, superior viewability in direct sunlight, and low-power requirements. In comparison to our other prototypes, this design was the thinnest and offered the best outdoor viewability. However, it also had the smallest physical dimensions—which affected viewing distance—the slowest refresh rate, and no self-illumination (i.e., it could not be seen in low-light conditions).

We sourced a 4.7” monochrome flexible e-ink display with a resolution of 320x240 (85 ppi) from Plastic Logic. The system consisted of an “engineering sample” display, a BeagleBone Linux computer, and a custom daughterboard display driver. For rendering, we wrote a custom application in C to display fonts/images. Unlike the other prototypes, the hardware components (e.g., microcontroller, display driver) were not integrated into the display. Consequently, this design had two potential comfort advantages: without integrated hardware, the shirt display itself was very lightweight (25.4 g) and the hardware could be moved to more insensitive load-bearing parts of the body. However, the components themselves were heavier and required an additional belt (Figures 2b and 3b).

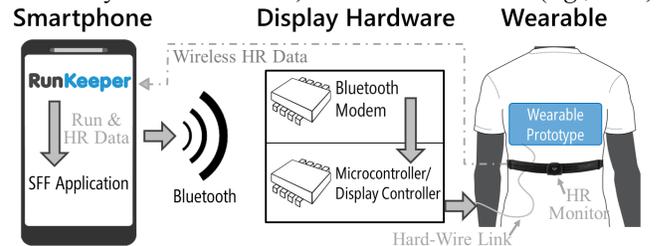
Prototype 3: Erogear Flexible LED Matrix

For our 3rd prototype, we collaborated with a small e-textiles start-up company, Erogear (erogear.com), who provided us with a set of pre-release flexible LED matrix displays. These displays are similar to those described in Prototype 1 except that the Erogear versions have a higher resolution (32x16 per panel vs. 24x6), higher refresh rate (38Hz vs. 5Hz), contain brighter LEDs, and have a thinner profile. To program the displays, we used the Erogear SDK for Android, which provides an API to render bitmaps and full-motion video in Java (Figures 2c and 3c).

SFF SYSTEM OVERVIEW

Though each of our designs differed in terms of display technology and hardware platform, the system architecture was the same: (i) smartphone-based software that tracked runs and wirelessly transmitted this data over Bluetooth in real-time; (ii) an embedded hardware system that processed the data and interfaced with a display controller; (iii) the display prototype; and (iv) an optional wireless chest-worn heart rate monitor by Polar (Figure 4).

For the run-tracking software, we collaborated with RunKeeper, a company that makes a popular mobile phone-based fitness-tracking application with the same name. RunKeeper developed a custom version of their application to interface with our Android SFF software. This version appeared to the user as a normal RunKeeper application, but also broadcasts via Android *intents*: run information (e.g., pace, duration, distance), the runner’s heart rate as sensed by the Polar sensor, and user interactions (e.g., start, Smartphone



1. Sense & process running/HR data. Wirelessly transmit to display hardware.
2. Receive running data; process & send to the display
3. Visualize running data on the wearable display

Figure 4: The general system architecture of SFF composed of three main components. The wireless heart rate (HR) monitor is optional.

stop). Our custom software sniffed these intents, processed them, and wirelessly transmitted the running and heart rate data via Bluetooth to the display's embedded hardware system (which was either integrated into the display itself or linked via a flexible wire; see Figure 3).

Display screens. All three prototypes auto-rotated through four screens: pace, duration, distance, and heart rate. These screens represent the key metrics of a run and are used by most run trackers (e.g., Nike+, Garmin). By virtue of the wearer running with others, pace, duration, and distance are shared across the running group; however, heart rate is not—it is our sole *egocentric* measure. We were interested in exploring how wearers would feel revealing their physiological data and how others in the group would respond to seeing another runner's heart rate. As heart rate is correlated to exertion level [17], SFF visualizes how hard the wearer is working at the current pace.

SFF shirt. We explored three primary characteristics: the placement of the display on the back, the attachment mechanism, and how the size, shape, and weight of the display interacted with placement and attachment during runs. While we ultimately envision an SFF jersey with a seamlessly integrated e-textile display, we pursued a more modular design for our prototypes. The displays were attached using various Velcro configurations.

PILOT STUDIES AND FINAL DESIGN

During the design process, we performed 11 internal pilot studies with members of our lab. Pilots were with one to four runners; most were with two. Whenever possible, two runners would wear a display. These informal pilots were intermittently spaced to test new prototype iterations and aimed at: (i) determining how display weight, component distribution, and placement affect running; (ii) examining the viewability of the displays under different conditions; (iii) gaining qualitative reactions from our participants about the aesthetics, function, and design of the displays. The results were used to select and refine our final design.

We quickly determined that even a moderately weighted display could pull the shirt neckline uncomfortably against the throat and that the original placement—on the upper backside of the shirt close to the name lettering location on professional sports jerseys—affected the movement of the runner's shoulder blades. As a result, we began further optimizing for weight—including the amount of fabric used for the enclosures and attachment materials. We also created a Velcro rail system so that a display could be easily moved to fit the runner's preference. Generally, the most comfortable placement was about 3/5ths down the back (opposite the sternum). Based on feedback, we also built protective fabric around the waist-worn battery clips to reduce discomfort. Wiring was eventually routed through a sleeve in the left Velcro rail so that it was hidden.

In terms of the prototypes themselves, while we were initially concerned with the e-ink display's smaller physical dimensions, we found that the increased resolution was

largely compensatory. However, the viewing distance was still less than the two LED matrix prototypes. This was especially true in low-light conditions (shadows, morning/evening runs). And, though the e-ink display had greater viewability in direct sunlight particularly compared to Prototype 1 (the custom LED matrix), we found that Prototype 3 (the Erogear LED matrix) was sufficiently bright to work in most lighting conditions. In addition, Prototype 3's large, illuminated lettering was viewable from the greatest distance. Of the three colors tested (red, green, and blue), green had the best outdoor viewability.

With regards to comfort, all three prototypes performed well. The Velcro rail attachment system greatly reduced complaints about discomfort from the displays. Most criticisms were directed toward components worn at the waist, especially for the e-ink prototype, which required a running belt to hold components.

Final SFF System

Based on our pilot studies, we determined that Prototype 3, the Erogear display, had the most potential. It was bright, lightweight, comfortable, and had good visibility under most lighting conditions. Additionally, based on feedback from our pilot participants, we decided to add an additional display screen: a social support goal-system. With this feature, a running group decides on a target pace and enters it before the run. The wearable display then compares the group's recent average pace with the target pace via a moving bar graph visualization (Figure 5). As mentioned in the introduction, this feature was primarily aimed at motivating runners to achieve their target pace and remain together as a group. Goal-setting is a well-known strategy in the behavioral and sports science literature for training [1,15]. And, since the target pace is collectively set by the group, it serves as a public commitment [26] that is continuously visualized throughout the run.

FIELD STUDY OF RUNNING GROUPS

To examine the impact of the final SFF prototype design on group running dynamics and performance, we conducted two exploratory evaluations: a field study of ten running groups and two case study deployments in races.

Field Study Method

Participants

Running groups were recruited via mailing lists, word-of-

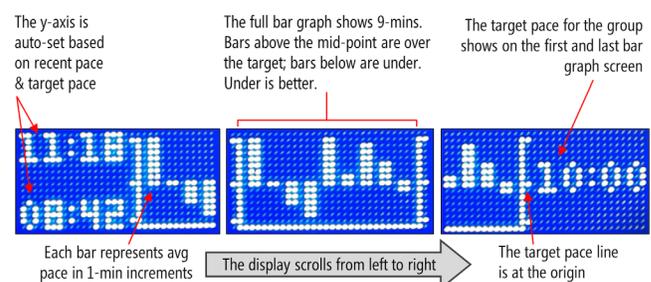


Figure 5: The target pace visualization animates across three screens comparing the group's average pace to the target pace over the last nine minutes (each bar represents the average pace for one minute).

mouth, and direct contact with running clubs. Our recruitment material specified that we were looking for pre-existing running groups of at least 4-10 runners, all over the age of 18, to take part in a study of wearable running displays. Session slots were filled on a first-come, first-served basis. Each participant was paid \$20 for their time.

We recruited eleven groups; the first served as an external pilot (their results are not reported here). The remaining ten groups had a total of 52 participants (35 female) with an average age of 42 ($SD=14.69$). See Table 2. The average group size was 5.2 ($SD=1.87$)—87% participants reported running at least occasionally with their respective group. Professions varied from graphic designer to chief financial officer; 12 were students and four reported no employment (e.g., retired). Participants had active lifestyles: 50 out of 52 (96%) reported working out once a week or more.

In terms of group running and run tracking behavior, 43 out of 52 participants (82.6%) reported that they ran at least occasionally with one or more other people (24 stated almost every run). The reasons provided include socialization, motivation, accountability, and fun. Participants reported their typical running group size as $avg=6.4$ ($Median=5$, $SD=6.94$). Most participants reported tracking their runs (92%); 71% do so almost every run. The most popular tracking tools included Garmin watches (40%), followed by a tie between the Nike+ and RunKeeper (19%); 11 participants (21%) reported using pen and paper.

Procedure

Each running group was sent an informational flyer, a consent form, and the pre-study questionnaire in advance. Upon arrival at the study session, participants were greeted by one or two research assistants who handed out clipboards with the aforementioned materials. The consent process and pre-study questionnaire took approximately ten minutes. Afterward, we demonstrated the SFF system including each display screen. If the group did not have regular pace leaders, we asked for two volunteers to wear the SFF system, including the shirt, display, battery pack, heart rate monitor, Android phone, and armband. Wearers were also asked if they would like to disable any of the display screens (e.g., heart rate, distance). All declined.

Before the run, each group was asked to collectively decide on a target pace, which was entered into the SFF software on both wearers' phones. Our aim here was not to study whether SFF enabled groups to reach their goals—a different, more controlled study design would be necessary here—but rather to qualitatively examine the perceived benefits and/or limitations of SFF on the group running experience. Groups were asked to run for at least 30 minutes. We also explained that a research assistant would follow the group from a distance on a bicycle in case of technology failure or emergency. All participants, including the wearers, were welcome to use their own trackers as well during the study (although unfortunately we did not collect precise data on this). After the run, the wearers and non-

Group ID	# of Participants (Females)	Avg Age	Study Target Pace (per mi)	Study Run Distance (mi)	Study Run Time
G1	4 (4)	31.0	10:20	3.04	00:35:03
G2	6 (4)	50.0	11:30	3.12	00:34:41
G3	4 (0)	21.2	08:30	3.99	00:32:12
G4	4 (4)	49.2	10:15	3.34	00:38:46
G5	4 (0)	20.7	09:00	2.93	00:34:53
G6	8 (5)	54.2	10:30	5.29	00:58:28
G7	9 (9)	47.1	12:00	2.98	00:32:18
G8	5 (5)	43.6	10:30	3.02	00:31:35
G9	4 (2)	43.0	09:45	4.42	00:44:43
G10	4 (2)	22.0	10:00	2.49	00:31:00
Avg	5 (3)	40.7	10:14	3.46	00:36:04

Table 2: Demographics and run data from the 10 field study groups.

wearers were provided with separate post-study questionnaires, which took ~12 minutes to complete. We also recorded informal verbal comments during this time. Though our target study session length was 60 minutes, this varied depending on run length.

Data and Analysis

In summary, our data includes responses from the pre- and post-study questionnaires, verbal comments made after the run, and pictures captured at 2-3 points during each run by the trailing research assistant (Figure 6). Both questionnaires included Likert scale questions and short open-form responses. The pre-study questionnaire gathered data about demographics, exercise routines, running habits, and use of run-tracking tools. As noted above, different post-study questionnaires were provided to the wearers and non-wearers. Both questionnaires included questions about the perceived impact of SFF on motivation, group cohesiveness, mental affect, group- and self-awareness, and questions about the display. The wearer questionnaire also asked how wearing the SFF system affected the participant physically and mentally. As an exploratory study, we report on descriptive statistics indicating trends in our data, which are contextualized with participant quotes.

Field Study Results

For Likert questions, unless otherwise specified we used 7-point agreement scales ordered *strongly disagree* (1) to *strongly agree* (7); 4 was neutral. We report means ($M=X$) and standard deviation ($SD=X$). Due to a dead battery, one group (G8) ran with only one display. Thus, we had 19 wearers and 33 non-wearers. We use group 'G' and participant 'P' to refer directly to a participant. Wearers are indicated with a '-W' suffix (e.g., G1P1-W).

Reactions to Visual Content

Overall screen preferences. Most participants found the displays useful in providing feedback about their performance. In terms of the individual screens themselves, participants ranked the order of importance of each screen from '1' to '5' ('1' was most important) on two criteria: helping them meet the target group pace and most valuable overall. For both aspects, *average pace* was ranked as most useful followed by *distance* and *duration* (Table 3). For example:

"The pace and distance helped motivate me more to reach the goal time; other displays were just nice to have." (G10P1-W)



(a) G4 (N=4) (b) G9 (N=4) (c) G6 (N=8) (d) G2 (N=6) (e) G7 (N=9)

Figure 6: We conducted field trials of SFF with 10 running groups; a subset is shown above. See Table 2.

“Pace is important to keep me on track but duration is next to important because it tells me how much time I have left to reach my goal.” (G10P2-W)

While we developed the target pace visualization (Figure 5) specifically to help group members reach their goal, most found it confusing or unnecessary—as they could mentally compare the average pace screen with their goal pace: *“[The] graph was hard to read and get value out of.” (G3P4)*. One participant (G6P2-W) commented that the SFF system did not incorporate running up or down hills, which impacts pace. Unsurprisingly, the heart rate screen was deemed least important as represented by G4P4: *“I am not concerned about someone else’s heart rate.”*

Importance for Helping Meet Target Pace	Avg. Rank (SD)	Importance in Providing Useful Run Feedback	Avg. Rank (SD)
Average Pace	1.3 (0.83)	Average Pace	1.5 (0.8)
Distance	2.5 (0.9)	Distance	2.2 (0.9)
Duration	3.1 (0.8)	Duration	3.1 (0.8)
Pace Visualization	3.9 (1.3)	Heart Rate	3.9 (1.1)
Heart Rate	4.3 (1.0)	Pace Visualization	4.3 (1.1)

Table 3: Results of participants rank ordering the display screens.

SFF vs. other run-trackers. Although we did not explicitly ask participants to compare SFF to their experiences with other run tracker applications, many participants drew these comparisons in their responses. Interestingly, even participants using their own tracking applications during the study found value in the display:

“It was fun having the display and being able to see it on someone [rather] than [on] my wrist app.” (G1P3)

“Was looking at it instead of my Garmin.” (G6P5)

Others specifically mentioned how the SFF display offered a common, shared screen and that this changed the dynamic of the information:

“I assumed my phone app was sufficient but this added an extra challenge with the group.” (G1P3)

“Most [of us] use Garmin for tracking, this introduced a shared screen vs. independent watching; this felt very novel” (G4P4)

Still, some questioned whether SFF offered significant value over watch or smartphone applications that provided the same information: *“maybe not useful to the run if you’re used to using them [other technology]” (G4P4)*.

Enjoyment/fun. All of the wearers (N=19) reported enjoying wearing the display, rating it on average 5.2 (SD=0.9) on a 7-pt scale. Reasons included making the run

more fun, social, and motivational (e.g., G9P1-W: *“I think it is useful and made the run fun.”*). A number of participants mentioned that SFF prompted group members to “call out” information when it was displayed: *“The display encouraged me to meet my goals because everyone read the information to me.” (G1P2-W)*.

Awareness and Motivation

Motivation. A majority of participants (65%) agreed that SFF motivated them to run at or faster than the target group pace. The average agreement rating was 4.8 (SD=1.7). Reasons included increased determination and focus:

“Motivated me to go faster than the pace displayed.” (G7P7)

“Made me feel like I was pushing my efforts, which is good. Challenged myself.” (G7P8)

Interestingly, a number of wearers cited additional reasons such as feelings of accountability and pressure to perform: *“It made me feel that I had a responsibility to run a target pace for the group” (G3P2-W)*. One non-wearer also stated that she *“felt more stress to perform” (G9P5)*. For those participants that did not feel increased motivation (N=18) common reasons included feeling little difference from a normal run, feeling distracted by the displays, and/or not seeing value over personal run trackers.

Group cohesiveness. A majority of participants (62%) felt that the display motivated the group to stay together. The average agreement rating was 4.8 (SD=1.5). G3P3, for example, noted: *“Yes, it was different. It made me want to keep up with the others.”* However, 11 participants (21%) disagreed, most often because they felt no difference.

Performance awareness. Participants reported feeling more aware of both their individual performance (M=5.1; SD=1.7) as well as the group’s performance (M=5.2; SD=1.5). As G2P2-W stated: *“It made me more aware of our pacing and kept me more focused on the run itself...”* Again, those who disagreed (N=7 for individual awareness; N=6 for group) commonly felt no difference.

Wearers Only: Self-Consciousness and Comfort

We also asked the 19 wearers about the physical and mental impact of the display.

Self-consciousness. Overall, wearers did not feel self-conscious wearing the display or in revealing their running data to their group or onlookers (e.g., from passing cars, others on the run route). When asked about feeling self-

conscious, most wearers disagreed ($M=2.7$; $SD=0.4$ —recall that 1 is strongly disagree); for example, “Yes, I expected to feel more conspicuous; didn’t really mind it.” (G2P2-W). However, five wearers did feel self-conscious, one of whom indicated that it was because of insecurity regarding pace.

Relatedly, we specifically asked about comfort level in revealing heart rate, the most personal metric, vs. all other running data to two audiences: the running group and to coincident onlookers. Generally, wearers were not concerned about either although heart rate data did seem to cause slightly more tension. Only two wearers (G1P1-W, G6P1-W) reported feeling uncomfortable revealing their heart rate to both audiences. In addition, G6P1-W reported discomfort revealing the *other* running data to her group.

Physical comfort. Most wearers did not find the SFF display or the requisite components physically obtrusive during the run. Each component was rated individually on a 7-Point Likert scale (7 is best). The battery pack was rated most comfortable ($M=5.5$, $SD=2.1$) followed by the e-textile display ($M=5.2$, $SD=2.1$), the HR monitor ($M=5.1$, $SD=2.0$), and then the armband and phone ($M=4.0$, $SD=2.1$). When first introduced, most wearers were concerned with the number of required items; however, after the run, these concerns abated:

“I thought it would be uncomfortable; it turned out to be unnoticed.” (G5P2-W)

“Arm band is heavy; other [equipment] was fine; cotton t-shirt is uncomfortable.” (G2P1-W)

This latter quote represents a common feeling about the armband, especially for those not used to running with any equipment. Additionally, as most of our study sessions occurred in temperatures of 80-90F (27-35C), the cotton t-shirt was also a common complaint. Women, in particular, requested a “synthetic performance” shirt; we created one and made it available after the sixth study session. This was preferred in later sessions.

Summary of Field Study Results

In summary, our field study participants enjoyed SFF: they reported feeling more aware of their own performance as well as the group’s performance, and felt motivated to reach the group-set target pace. Interestingly, as Bond’s [3] self-presentation theory would suggest, some wearers felt increased pressure to perform and two reported discomfort revealing their heart rate to others. Still, however, a large majority of participants indicated interest in wearing SFF again (85% overall and 90% of wearers).

CASE STUDIES: TWO SFF RACE DEPLOYMENTS

To examine the impact of SFF on runners in a race context, we conducted two case study deployments: an 8K race with 189 runners and a 10K race with 364 runners. Races are unique because racers start together in mass and then break organically into pace groups. Four new participants (3 male) were recruited from those who had responded to our initial field study advertisement (Table 4; Figure 8). Our



Figure 8: Four racers participated in our case studies; 2 shown above.

case study procedures were similar to the field study with slightly modified pre- and post-study questionnaires (e.g., removed group running questions, added race-specific questions). In addition, these participants did not run with their own running groups but with fellow racers. All participants ran at different speeds; thus, they could not see each other’s displays. Below, we briefly summarize the results that intersect with the field study before emphasizing new themes that emerged.

Part. ID	Race	Age	Gender	Target Pace	Distance	Time
R1P1	County 8K	34	M	6:15	8K	29:30.0
R1P2	County 8K	33	F	8:20	8K	41:13.0
R2P1	Labor Day Classic	26	M	7:45	5K	22:45.2*
R2P2	Labor Day Classic	18	M	8:30	10K	55:38.6

Table 4: Case study participants for our two race deployments. *R2P1 took 1st place in his division while wearing SFF.

Summary of results. There were no major differences in the racers’ preferences for the display screens compared to the field study. Similarly, all participants felt that SFF motivated them to perform. For example, R2P1 stated “[it] made me want to run faster because my performance was on display” and R1P2 reported feeling “slightly more pressure to perform.” R2P2 participant noted feeling self-conscious about their “performance being shared with others (strangers).” This same participant also felt concerned about what other racers thought of his pace.

Race-specific results. Participants enjoyed how SFF increased their interactions with racers and race volunteers. For example: “The finish line announcer saw me and read out my Heart Rate, 192, as I crossed.” (R1P1). Indeed, all participants mentioned that SFF elicited excitement, curiosity, and encouraging reactions from other racers and race watchers:

“I interacted with about 6-7 people, all of which gave positive response. They mentioned how the information was motivating them to run faster than me. A lot of people made comments such as ‘that’s cool’ or encouraging comments—which motivated me.” (R2P2)

After the races, a number of racers approached the research team and explained that they thought the information was useful during the run emphasizing that it was helpful to have a “pacer” during the race. Another participant commented that a fellow racer passed him mentioning that “it was like a car dashboard [for running].” At both events, race organizers expressed interest in SFF. One organizer repeatedly asked if he could use SFF prototypes for the official pacers in an upcoming marathon.

Summary of Case Study Results

In contrast to the field study, wearers in our case studies did not run with a pre-existing group but instead a large group of racers. Although the wearers could not see their own display (or the display of another wearer), they still reported increased motivation to perform. All participants were particularly enthusiastic with how it increased social interactions during the race; they also felt like they were providing an informational service to other racers.

DISCUSSION AND CONCLUSION

As the first paper exploring shared, wearable feedback displays for group fitness performance, we found support for the motivational properties of SFF, both in terms of encouraging runners to meet their group's target pace and to stay together as a group. Wearers and non-wearers also reported feeling more aware of their performance as well as that of the group. However, more controlled studies are necessary to determine if there is an actual performance impact rather than simply a *perceived* impact.

Limitations

As with any study, there are limitations. First, groups only used SFF on one occasion and, thus, could be reacting to the novelty of the system. Second, our participants may have been susceptible to observation biases. Just as Bond's theory [3] would predict, the presence of the research assistant—and the staging of the study itself—may impact behavior, particularly performance, which is exactly what we explored here. Despite these limitations, we believe SFF shows the promise of a new domain of work—reappropriating personal tracking data for collocated group fitness activities. Future work should explore the longitudinal impact of SFF on group behavior and/or more controlled experiments to compare glanceable textile displays to other forms of feedback.

Design Reflections and Future Work

Motivational Properties of Group Feedback Displays.

The bar graph visualization depicting current vs. goal pace was intended to motivate runners to meet their target pace, but many participants found it confusing. Instead, the practice of collectively agreeing on a target pace at the beginning of the run along with real-time pace feedback seemed to sufficiently motivate participants. More work is necessary to uncover how group goals can be better supported through the wearable displays themselves.

Without prompting, a number of participants mentioned the desire to have words of encouragement in SFF, such as 'good job' or 'keep going'. One participant also proposed using tortoise and rabbit symbols to depict the group's speed, along with jokes. These comments suggest not only that adding encouraging messages would be useful, but also that playfulness and fun are important attributes of a workout that could be supported by the technology.

Comfort. We had initially planned to position the displays across the upper part of the back, which was aesthetically pleasing (*i.e.*, where jersey lettering is located). Pilot



Figure 9: Our original SFF shirt design (left) had a statically positioned attachment on the upper-back. Our final prototype (right) used a Velcro rail system that allowed more flexible placement. Most participants preferred the mid-lower back.

participants, however, reported that this location was uncomfortable. Our final design had a Velcro rail system that allowed flexible placement; most participants preferred the lower back (Figure 9). As well, although participants welcomed the switch from cotton t-shirts to performance fabric, the synthetic material was far lighter and more sensitive to the additional weight of SFF. At 46.8 grams, the Erogear display was already quite light, but we speculate that its weight would need to be 10-20% lower to integrate well with the lighter fabric. Finally, though many participants were suspect of wearing additional equipment during their runs, these impressions were abated by actually running with the system. Regardless, limiting the amount and weight of equipment is an important future goal.

Pressure to Perform. As Bond's self-presentation framing of social facilitation theory would predict [3], we found evidence that some runners felt additional pressure to perform with SFF. Surprisingly, however, only a small number of wearers were uncomfortable revealing their heart rate or pace. More work is necessary to identify *why* participants reacted differently and to examine potential correlates such as personality factors, runner's self-image and fitness level. In addition, we expected but did not see differences between revealing performance information to the group vs. other runners on the trail. This is somewhat in contrast to our own experiences with SFF.

Though SFF was designed for group contexts, we often wore the displays ourselves for individual runs to assess comfort and to test our prototypes. Interestingly, we all felt increased pressure to perform because of the externalization of our activity. If a fellow (random) runner passed, we knew that s/he had seen our statistics. With SFF, it was harder for us to self-rationalize, such as, "I must have been running for a longer period than the person that passed me by" or "I just slowed down briefly." The truth of such statements was now readily apparent, which made an ordinarily relaxing run into a stressful one. This feeling of exposure and self-consciousness points to an avenue of research investigating the boundaries of reappropriating personal tracking data for public-facing applications and how these boundaries change across deployment contexts.

SFF in Race Deployments. We believe SFF has many potential applications in races. For example, a number of participants mentioned that official race 'pace leaders' could wear SFF. SFF could also support Twitter integration so that friends and family could send supportive messages to the wearer and runners around them. Finally, SFF could show positional information (*e.g.*, 8th place) and update it throughout the race.

Conclusion

In conclusion, this paper contributes new knowledge to two rapidly growing areas: personal-tracking (e.g., Quantified Self) and wearables. Through parallel prototyping, iterative design, and our exploratory field studies, we demonstrated the potential of using shared, glanceable displays to motivate individual and group fitness performance, increase group cohesiveness, and enhance group awareness. Future work should investigate fully integrated jersey displays, new types of visual content and motivational strategies (e.g., encouragement), and the use of shared, glanceable e-textile displays in other athletic contexts (e.g., bicycling).

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