

ActivMON: A Wearable Ambient Activity Display

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Abstract: Global increases in overweight and obesity are linked to a trend towards decreased levels of physical activity. In combating this problem, we present ActivMON – a wearable ambient display which illuminates with a varying colour to provide a user with an intuitive visualisation of their daily activity level, as well as using a pulsing illumination to provide an indication of the activity level of other users. ActivMON is able to progressively increase a user's daily activity goal to encourage a sustained increase in physical activity. We present an initial evaluation of ActivMON, as well as discussing possible future research directions involving the use of wearable ambient displays to motivate physical activity.

1 Introduction

According to the World Health Organisation, over 1.6 billion adults are overweight, with this figure projected to climb to 2.3 billion by 2015 [Wo10]. The global increase in overweight and obesity is attributable to a higher intake of energy-dense foods, as well as a trend towards decreased levels of physical activity. Our research seeks to combat the problem of decreased activity levels, by employing wearable ambient displays to increase users' awareness of their level of physical activity, and to challenge them to achieve a sustained increase in their daily activity level.

Engaging with physical activity programs is difficult because physical activity itself is often not enjoyable. To sustain user engagement, it is important to set challenging but achievable goals, and to be able to monitor and visualise user progress towards these goals. Devices and tools such as pedometers and online progress charts exist to assist users in setting goals and monitoring their progress. However many of these tools require the user to feed in data and interpret progress on an ongoing basis.

We present ActivMON (Fig. 1), a wearable ambient display which can be attached to a person's wrist. ActivMON monitors the user's level of physical activity, and illuminates with a colour representing the person's cumulative daily activity as compared to a daily activity goal. ActivMON illuminates red when switched on at the beginning of each day, when no activity has been monitored, and gradually changes colour to green as the user performs more and more activity and approaches their daily goal. Rather than having to remember a daily activity goal, the colour of the device provides an intuitive visualisation of a person's current activity status.



Fig. 1: ActivMON device on user's arm

ActivMON can also provide users with a real-time visualisation of the level of physical activity of a group of other, possibly geographically dispersed, users. A dedicated web interface allows ActivMON users to form into groups. Each user's device periodically connects to the web server and uploads the activity level of that user. The activity levels of all group members are then synchronised and aggregated to produce an indication of the activity level of the group as a whole.

This group activity level is then presented to each user in the group via a pulsing illumination of the user's ActivMON. A high pulse rate indicates that many members of the group are currently performing a high level of physical activity, whereas a low pulse rate indicates that the activity level of the group members is low. Therefore, when any member of the group starts performing physical activity, this becomes visible to other group members, possibly triggering them to also perform physical activity [Fo03].

ActivMON is capable of uploading a user's activity information to the Internet, allowing this information to be shared through social media websites. Previous works discuss the principles of normative influence, social comparison, competition and recognition in persuasive computing systems [Fo03, OH08, WFL08]. Aside from the motivation provided by the ActivMON device, the ActivMON's compatibility with social media websites provides users with a mechanism to communicate with others with similar goals (normative influence), compare their performance with others (social comparison) and to possibly compete with other users in achieving activity goals (competition).

ActivMON is able to challenge users to achieve a sustained increase in activity levels, through the use of personalised activity goals. ActivMON is able to monitor a user's daily activity levels over the course of a week, and to suggest an increased activity goal for the following week. If the user achieves this new goal in the following week, the goal will be increased again the next week. Each increase is nominally 5% of the previous week's average activity level. It should be mentioned that the user remains in control of the activity goals, as they are provided with a web-based interface allowing them to adjust their personalised goal.

We conclude with a preliminary assessment of ActivMON, using data sets collected from a user performing sedentary and non-sedentary activities in real-world situations. We demonstrate that ActivMON is effective in discriminating between these activity types.

This paper provides two main contributions. Firstly, we present a wearable ambient display, providing users with an intuitive visualisation of their daily activity levels by displaying one of a continuum of colours, and a method for adaptively increasing a user's daily activity goal to challenge the user to achieve a sustained increase in physical activity levels. Secondly, we present a method for visualising the aggregate level of physical activity of a group of users through a wearable ambient display using a pulsing illumination.

The paper is organised as follows. In section 2, we provide an overview of related works involving the use of activity monitoring technologies to promote an increase in physical activity. In section 3 we discuss the design and development of the ActivMON device, with specific reference to design considerations mentioned in the literature. In section 4 we discuss the operation of the ActivMON device, in displaying an individual user's activity level, displaying the activity level of a group of users, and in adaptively setting activity goals for the user. In section 5 we present a preliminary assessment of the ActivMON device in a real-world usage scenario, and in section 6 we present our conclusions and propose future research directions.

2 Related Work

There has been some previous work on the use of ubiquitous displays to promote awareness of a person's activity levels. Lin et. al. developed the "Fish'n'Steps" social computing game (Fig. 2) [Li06]. Each participant was represented by a virtual fish, displayed on a computer screen, that grew larger depending on their activity level (measured using a pedometer). The fish could be "happy", "angry" or "sad" depending on whether the user was achieving a predefined daily target. In the group version of the game, the water in the virtual fish tank would become darker if any individual team member failed to meet at least half their daily goal.

Similarly, Consolvo et. al. developed the “UbiFit Garden” (Fig. 3) - a mobile, personal glanceable display to encourage a person to monitor their level of physical activity [Co08]. The UbiFit garden is a stylised garden image displayed on the wallpaper of a user's mobile phone, that is updated to reflect that user's activity levels. Flowers and butterflies are added to the garden to reflect activities the user has completed, as well as to acknowledge achievement of weekly goals. Data was collected both through self-reporting, as well as using a wireless “exercise monitor” worn on the user's waist.



Fig. 2: Fish'n'Steps

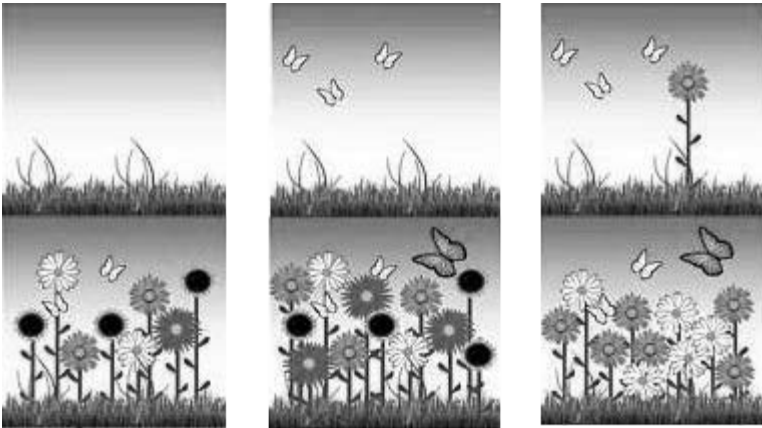


Fig. 3: UbiFit Garden

Previous work [Co08], [Li06] has centred around using a pedometer or accelerometer attached to a person's waist to measure physical activity. However, whilst evaluating their “Houston” pedometer-based system, Consolvo et. al. [Co06] reported that study participants complained there often wasn't a reasonable place on their clothing to attach a pedometer. Fujiki et. al. [Fu08] employed a wearable accelerometer in their “NEAT-o-Games” system, and reported that female participants in their study expressed a strong desire to wear a sensor like a watch or bracelet.

In the Fish'n'Steps system, users were required to manually enter data from their pedometers into the computer system. UbiFit Garden addresses this concern by using activity monitors that are able to communicate wirelessly to the user's mobile phone. However in both of these systems, some effort was required both to notice the display (either by looking at a computer or phone screen) and to interpret the data. In this paper, we present the case for wearable ambient displays to provide a more glanceable and intuitive indication of user's level of physical activity, to challenge users to achieve a sustained increase in their level of physical activity.

3 Design and Development

In developing the ActivMON device, we addressed the considerations of Berkovsky et. al. with regard to sensing technologies [BCH10]. Specifically, that the ActivMON device should be unobtrusive (not requiring the user to manually feed activity data to a computer), wireless (not requiring a cable to upload data) as well as compact and wearable (so as not to interfere with the user's motion).

In deciding where to locate the ActivMON device on the user's body, we also considered where to best position the device such that the user would be most likely to notice it and act on the information presented. Harrison et. al. suggest users are most likely to respond to a wearable display if it is located on the wrist [Ha09].

Fujiki et. al. [FPT09] report that it is possible to approximate a user's metabolic expenditure using measurements from a wrist-worn accelerometer. Although the relationship between accelerometer measurements and expenditure is less linear than if the accelerometer were to be placed on the user's waist. A limitation common to all activity monitors is that they are only able to operate if placed on a part of the user's body that is moving. ActivMON is able to record activity when the user is moving their arms whilst walking or running, but is not able to recognise activity if the user is only moving their lower body, for example if using an exercise bike or using a treadmill and holding the hand rails.

3.1 The ActivMON Device

The ActivMON device was developed in-house, and consists of a microcontroller (Microchip PIC18F2620), red-green-blue (RGB) three-colour light-emitting diode (LED), a three-axis accelerometer (Freescale MMA7340/7341), a Bluetooth radio (Roving Networks RN-41) and a rechargeable battery. ActivMON is compact (approx. 50x40x15 mm) and lightweight (15 grams) and can quite comfortably be worn on the wrist even while exercising.

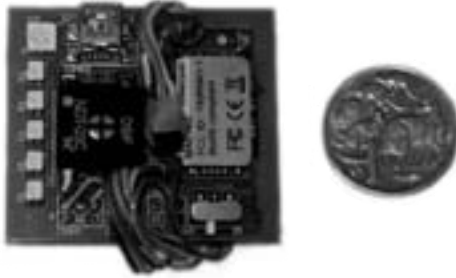


Fig. 4: ActivMON Device Circuitry

3.2 Physical Activity Capture and Data Processing

ActivMON uses an on-board accelerometer to continuously measure acceleration forces in the X and Z axes (horizontally across the user's wrist as well as vertically through the wrist). The accelerometer is set to +/-3g sensitivity in each axis. Output from the accelerometer for each axis is digitised to an eight-bit value (giving a reading in the range 0-255). These readings are then summed to create an "activity" reading (with a range 0-511):

$$a = x + z$$

An initial activity reading is taken at bootstrapping time and is considered a zero activity point. Each subsequent reading is then compared to this zero point. Small changes above and below this zero point are ignored. When a larger change is registered, ActivMON increments an internal "activity counter". It then re-zeroes using the new activity reading. Thus small movements are ignored, and the "activity counter" represents only larger movements of the user's arm.

In deciding which accelerations to register and which to ignore, we conducted testing using a number of different activity thresholds. If the thresholds were too low, the activity counter would increment in response to purely sedentary activity. However if the activity thresholds were too high, the activity counter would not increment even during physical activity. We arrived at an optimal threshold value of approximately a 4% deviation of the full range of the activity reading from the zero activity point.

For the purposes of this prototype, the "activity counter" is more a low-resolution tool in determining the transition between sedentary and physical activity rather than an attempt to accurately measure the magnitude of that activity. This is much the same approach taken by Fujiki et. al. [FPT09] and Berkovsky et. al. [BCH10] Future work might involve using one or more algorithms (such as those suggested by Fujiki et. al.) to transform the accelerometer readings into a more accessible form. For example, using k Cal instead of an "activity counter".

4 ActivMON Features

4.1 Ambient Display

Each of the red, green and blue segments of the device's RGB LED can be individually set to one of 64 brightness levels. As the device registers activity, the brightness of the red segment is reduced and the brightness of the green segment is simultaneously increased. This causes the illumination colour to change smoothly across a spectrum of colours from red to green, representing how close the user is to achieving their daily activity goal. The brightness levels of the red and green segments at a given time are determined as follows. First, we calculate an intermediate value s , representing the current colour step:

$$s = \frac{a_c}{a_g/64}$$

Where a_g is the current daily activity goal and a_c is the current value of the daily activity counter. The value s is then rounded to the nearest whole number. Next, we use s to calculate the brightness levels of the red and green segments (r and g):

$$r = s$$

$$g = 64 - s$$

In our implementation, 64 represents completely off and zero represents completely on. Given the above, s will increase in the range zero to 64 as the user approaches their daily activity goal, causing the red and green segments to combine to display a colour on a spectrum of red to green.



Fig. 5: Spectrum of colours displayed by device. From red (no daily activity) to green (daily goal achieved).

ActivMON's wearable ambient display reduces the user's cognitive load in determining their current progress toward their daily activity goal. With a standard pedometer, the user needs to read off a step count and compare this to a daily step target. Even the ambient mobile phone display presented by Consolvo et. al. [Co08] requires the user to interpret graphical elements on a screen. Through encoding activity status as a colour, ActivMON allows the user to gain a near-instantaneous awareness of their activity state, in the same way that the colour of a traffic light conveys a near-instantaneous message to a driver.

4.2 Team Collaboration

ActivMON employs a pulsing illumination to provide the user with an intuitive visualisation of the level of physical activity of a group of other users. A dedicated web interface allows ActivMON users to form into groups. Each user's device periodically connects to the web server and uploads the activity level of that user. The activity levels of all group members are then synchronised and aggregated to produce an indication of the activity level of the group as a whole. This group activity level is then presented to each user in the group via a pulsing illumination of the user's ActivMON.

A fast pulsing indicates that other group members are performing a high level of physical activity, and a slow pulsing indicates that the group members are not very active. The rate of pulsing is calculated as follows.

Each ActivMON device periodically connects to the ActivMON Internet server via the user's Bluetooth-enabled mobile phone, in order to report the current value of the device's activity counter. If each report consists of an activity counter value v_i , and a time-stamp t_i , it is possible to calculate the rate of recent activity (using a unit of measure "counts per hour") as follows:

$$a_i = \frac{v_i - v_{i-1}}{t_i - t_{i-1}}$$

Where a_i is the activity level in counts per hour for the current report i , $v_i - v_{i-1}$ represents the difference in activity counter values between the current report and the previous report, and $t_i - t_{i-1}$ represents the difference in time between the current report and the previous report (calculated as fractional hours from the two reports' time-stamps).

For example, assume we have two activity counter readings. The first (v_{i-1}) a reading of 1000 and the second (v_i) a reading of 1500 and that the readings were taken 15 minutes apart (so $t_i - t_{i-1} = 0.25$ hours). We would calculate a_i as follows:

$$a_i = \frac{1500 - 1000}{0.25}$$

We assumed that, for most users, their day would consist of some sedentary activity, interspersed with some physical activity. We wanted to devise a method to detect a shift from sedentary activity to physical activity between reports, that would work reasonably well for most users without the need to establish a prior baseline for either category of activity. To this end, we calculate an average for a sliding window of the most recent n calculated rates of recent activity, a_i , for a particular device:

$$avg_i = \frac{1}{n} \sum_{j=i}^{i+n-1} a_j$$

Where avg_i is the average for the i 'th window, calculated from the current and $n-1$ previous values of a_i , as defined above. The following chart shows successive values of a_i , calculated from successive (t_i, v_i) pairs:

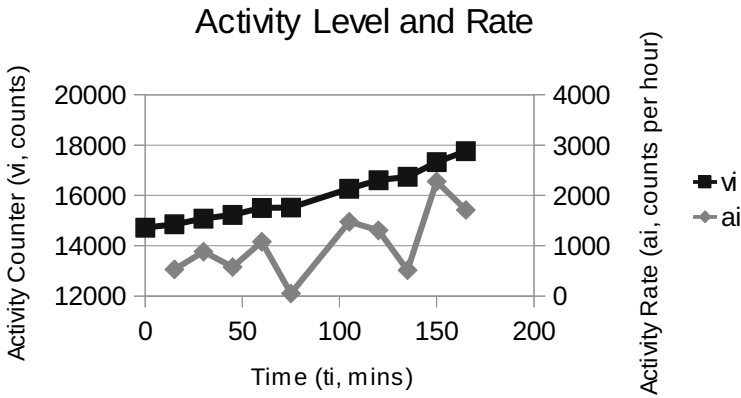


Fig. 6: Activity rate calculated from activity level

The average (avg_i) for this window of ten a_i values is 1039.3.

Upon receiving a new report, we calculate a value a_i for that report, and find the difference between that value and the current avg_i :

$$d = a_i - avg_i$$

If the difference d is positive, the user has engaged in an increased amount of physical activity over the most recent reporting period as compared to the sliding window average for previous periods. Otherwise, the user has engaged in a decreased amount of activity. We can then calculate the average value of d for m number of devices in a given group of users, as follows:

$$d_{groupavg} = \frac{1}{m} \sum_{k=1}^m d_k$$

We then take the inverse of this value, and scale it in the range 0-30. We refer to this value as d_{scaled} . When a device which is a member of a group uploads an update to the ActivMON server, the server calculates a new value d_{scaled} for the group and returns this to the device. The device's RGB LED will pulse at a rate of once every d_{scaled} seconds. As other devices in the group connect to the server, they will also receive this value and pulse at a similar rate. If one or more group members are being physically active, this will cause the devices of all members of the group to pulse at a faster rate. This may prompt sedentary members to increase their level of physical activity.

Consider four users, whose d values are calculated from their latest a_i and current avg_i :

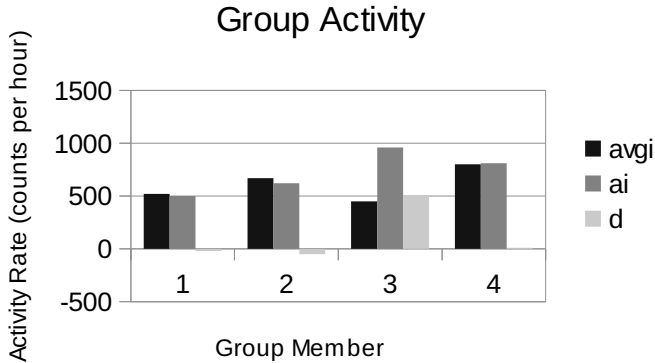


Fig. 7: Change in group activity rate

The third and fourth group members have engaged in a higher than average level of activity in the past reporting periods, as reflected by their positive calculated values of d . The group average $d_{groupavg}$ is calculated as follows:

$$d_{groupavg} = \frac{1}{4} \times 850$$

Yielding a value for $d_{groupavg}$ of 212.5. Scaling is performed by calculating how many times larger the current value of $d_{groupavg}$ is from the previous value. E.g. If the previous value for $d_{groupavg}$ was 20, the current value is approximately ten times larger. This would translate into a pulsation rate of 10 Hz ($d_{scaled} = 10$).

4.3 Adaptive Goal Setting

During the first week of operation, ActivMON learns the user's typical activity level, and sets a goal for the following week of 5% above this level. At the end of each subsequent week, the system calculates an average of the daily activity counts for that week. If this average is below the weekly goal, that same goal remains for the following week. If the average met or exceeded the weekly goal, the next week's goal is set at nominally 5% more. This is a form of individually adapted health behaviour change [Ka02]

This week's activity goal: 15000



Fig. 8: Goal setting interface

Users can influence the goal-setting behaviour of the system using buttons on a web interface (Fig. 8). “Less” and “More” buttons allow the user to request smaller or larger goal increments (1% less or more each time the button is pressed). A “disable” button is provided to disable goal personalisation. When pressed, this button will reset the user's goal to the most recently achieved goal, which will then remain unchanged.

The ActivMON device, through its wearable ambient display, constantly challenges the user to achieve their current activity goal. And as the user meets each new goal, the device will transparently calculate and provide a new goal. The user is afforded a mechanism to indicate to the system whether they wish to be presented with more challenging goals, less challenging goals, or that they have reached a comfortable level of activity and to disable further automatic goal increases.

5 Prototype Evaluation

In order to validate this approach, we adapted the ActivMON device to capture the current value of the “activity counter” at a rate of one sample per minute. We then collected two data sets (both over approximately 30 minutes). One of a user wearing the device while performing sedentary activity (sitting at a computer using the keyboard and mouse) and another during non-sedentary activity (walking along a street at a moderate pace). For each data set, we visualised the change in the activity counter each minute. In Figure 9 the top line represents non-sedentary activity, and the bottom line represents sedentary activity. As expected, non-sedentary activity resulted in the device's activity counter increasing at a higher rate than sedentary activity.

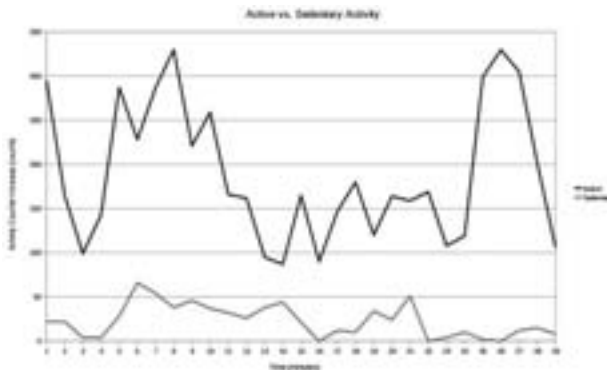


Fig. 9: Active vs. Sedentary activity

We performed an initial assessment of ActivMON in a real-world situation, attaching it to a user for a period of approximately seven hours. The device was configured to upload the current activity counter value to the ActivMON Internet server every 15 minutes via the user's mobile phone. This data was then visualised and presented to the user via an application integrated into a social networking website. This information is presented in Figures 10 and 11.

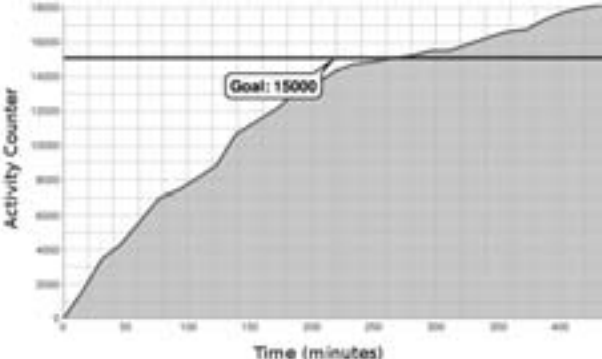


Fig. 10: Cumulative daily activity graph

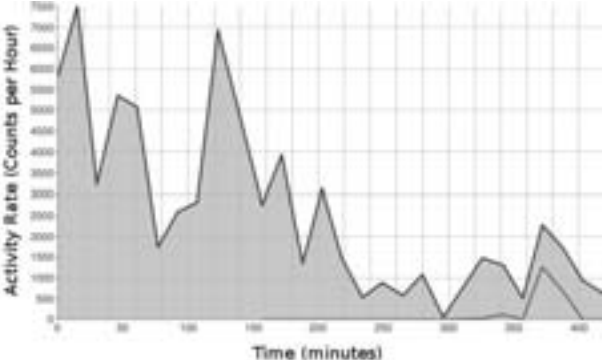


Fig. 11: Daily activity rate graph

Figure 10 shows the cumulative value of the activity counter, with the user's daily goal represented as a horizontal line. Figure 11 shows the values a_i , calculated using successive reports from the device, with the y-axis representing the rate of activity in “counts-per-hour”. The line at the bottom-right of the graph in Figure 11 shows successive values of d for the user, representing the difference between each value a_i and a running average of the last ten reports. The large peaks in the first half of the graph in Figure 11 correspond to periods in which the user was engaged in moderate physical activity (walking). Lower readings in the second half of the graph correspond to periods during which the user was engaged in sedentary activity (eating a meal and watching television).

6 Conclusions and Further Research

In this paper we presented ActivMON, a wearable ambient display providing a user with an intuitive visualisation of their daily activity level. We presented a method for providing a group of users with an intuitive visualisation of the aggregate activity level of the group, using a variable pulsing illumination. We proposed a system of adaptive goal setting for the ActivMON device, in order to constantly challenge users to increase their level of physical activity. Lastly, we performed a preliminary assessment of ActivMON, showing that the device and approach described were effective in discriminating between physical and sedentary activities.

In the future we plan a thorough investigation into user interaction with ActivMON. We will provide a number of users with an ActivMON device that monitors their levels of physical activity, but does not provide any visualisation. After we acquire a baseline measurement of the users' physical activity, we will enable the ambient display component of the device and assess whether an increased awareness of their level of physical activity will encourage the users to perform a greater level of activity. We will then enable the group visualisation feature of ActivMON, and assess whether awareness of others' physical activity can encourage individual wearers to engage in physical activity of their own.

Also of interest would be determining design requirements for wearable ambient displays to maximise their effectiveness, and to ensure long-term user acceptance. This could involve exploring the privacy implications of such displays. ActivMON's group activity visualisation provides only aggregate information about the group. This would seem to maintain some level of privacy, however this may be dependent on the size of the group and the user's knowledge of each other's routines. The individual activity visualisation could potentially reveal the user's level of physical activity to others who are aware of the colour code, causing possible distress to the wearer if they consider this information to be sensitive. However allowing the wearer to choose their own colour code may mitigate this risk.

Our wider goal in conducting this research is to explore the possible role of ubiquitous and wearable computing technologies in motivating users to achieve sustained lifestyle changes. Possible directions might include the embedding of intelligent artefacts into the user's environment which are able to convey information to the user about their activity levels. For example, objects that react sympathetically to an increase or decrease in activity levels of an individual user or group of users, ubiquitous technologies that are able to prompt small but beneficial lifestyle changes, or ubiquitous environmental treatments that are able to make physical activity more enjoyable or playful.

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