A Just-In-Time Intervention Technology to Encourage Healthy Behavior Using Operant Conditioning

Abstract. This paper describes a prototype mobile computing system that uses context-aware, tailored, just-in-time presentation of information and operant conditioning, a training technique, to encourage brisk walking. The system uses subtle audio cues as positive reinforcement. The prototype is an example of a ubiquitous computing health intervention that presents behavior-specific prompts and encourages incremental behavior change using successive approximation.

1 Ubiquitous Computing for Preventive Healthcare

Medical systems in industrialized countries face an impending crisis: how to pay for the care of an increasingly aging population. One way to curtail rising healthcare costs is to focus on health maintenance. Ubiquitous computing systems could be utilized as a healthcare prevention tool to help people stay healthy by exploiting common electronic devices such as phones. These systems might accomplish this goal by delivering “just-in-time” information intended to motivate behavior change. In this paper we describe a prototype instantaneous behavior shaping system (nicknamed InShape) that is designed to encourage walking behavior.

Sedentary behavior has been consistently shown to correlate with being overweight, particularly in children [18], and walking is known to provide health benefits [1]. Obesity has been identified as an independent risk factor for coronary heart disease, hypertension, Type 2 diabetes, stroke, gallbladder disease, osteoarthritis, sleep apnea, as well as endometrial, breast, prostate, and colon cancers [11]. In the U.S., the rise in the percentage of obese and overweight individuals now outranks smoking and alcohol abuse in its deleterious effects on health and healthcare costs [19], and medical experts are now proclaiming the rise in obesity and associated health problems to be of “epidemic” significance.

The InShape prototype is designed to motivate walking behavior by incorporating two ideas: context-aware, tailored, just-in-time presentation of information and operant conditioning, a behavior training technique and learning theory. The device is intended to motivate incremental behavior change over long periods of
use without becoming a burden to the user. We argue that subtle, well-timed, and positive feedback about the user’s own behavior will be well received and, over time, encourage increased frequency and intensity of walking behavior. We are in the planning stages to evaluate this prototype, and we conclude with a discussion of some evaluation challenges.

2 Motivating behavior change

Persuasive user interfaces motivate behavior change by providing information to users at points of decision, behavior, or consequence [7]. The InShape persuasive device pulls together two ideas: context-aware, just-in-time, tailored prompting and operant conditioning using positive reinforcement, a well-validated training technique based on learning theory.

2.1 Context-aware, tailored, just-in-time prompting

A context-aware application adapts its behavior based on information sensed from the physical and computational environment [4]. Real-time context-aware systems that can automatically detect a user’s behavior may offer extraordinary preventive health opportunities if strategies for delivering feedback in a non-irritating way can be developed. The power of just-in-time message prompting to motivate behavior change has been convincingly demonstrated in a variety of non-IT fields. Prompts delivered at points of decision have been shown to encourage seat belt use [9], increase recycling [9], reduce electricity consumption [16], motivate better nutritional decision making [21], and encourage exercise in public spaces [5]. These prompts only work for some of the people some of the time, but the impact can be dramatic (e.g. doubling the number of people who take stairs [5] or reducing air conditioner use by 15% [16]). Prompts that are not only timely but tailored to the individual are known to be even more effective at motivating behavior change (e.g. [12]).

Electronic pedometers make it possible for users to easily track their walking activity and compare daily walking performance with friends and family [2]. Only recently, however, has it become possible to detect a specific user behavior in real time without proactive input from the user and automatically deliver a tailored message at the point of behavior. For example, one recent system uses motion sensors in a shoe to detect walking behavior, and the shoe plays music during walking to motivate patients to walk during therapy at particular speeds [13].

A review of the preventive health prompting literature suggests that there are four components to an effective strategy to motivate behavior change using just-in-time information:

1. Present a simple, tailored message that is easy to understand
2. At an appropriate time
3. At an appropriate place
4. Using a non-irritating strategy (even after hundreds of presentations).

The InShape device described in Section 3 has been designed to meet each of these criteria. Unlike prior work (e.g. [13]), the InShape device is designed for everyday use by the general population, and it has been designed to use operant conditioning to motivate behavior change.

2.2 Positive reinforcement operant conditioning

The fourth criterion for effective prompting – presenting information in a non-irritating way – may be the greatest ubicomp challenge. One way to minimize the likelihood of a message becoming annoying is to ensure that each message has a high perceived value to the user.

This is a challenging design goal because the tendency when developing computer systems that motivate behavior change is to present messages to the user telling him or her what to do and when. For example, the computerized nutritional kiosks developed by health professionals tell users to buy one product (e.g. skim milk) instead of another (e.g. whole milk). Similarly, telephone linked care systems provide strong recommendations on what to eat, how to get exercise, and how to take medications. Both types of systems have proven effective in clinical trials [21, 8]. Notwithstanding the results of these studies, however, most people feel strongly that a computer making suggestions about what they should be doing is not a computer system they wish to be using for long.

The conundrum is that we must provide longitudinal feedback to the user where each bit of information conveyed is simultaneously subtle and ignorable but also of high perceived value to the user. No messages should be sent that could appear to be judgmental.

Learning theory provides one possible solution. *Operant conditioning* is a learning technique where the probability of a behavior occurring is increased or decreased by stimuli presented during or just following the behavior. We use context-aware computing for operant conditioning. Successful operant conditioning depends upon timing and consistency. Timely and consistent pairings of behavior with stimuli lead to fast learning of desired behaviors in many animals, including people [14]. A computer that can detect a target behavior in real time has the potential to be an infinitely patient, extremely effective, operant conditioning trainer.

*Positive reinforcement* is operant conditioning where the stimuli presented are desirable to the animal (e.g. money, food, praise, play, etc.). Presentation of positive reinforcement at points of behavior is known to be highly effective at encouraging desired behaviors [14]. The InShape device uses well-timed, positive reinforcement to reward the user for desirable behavior when that behavior occurs. Therefore, every prompt the user receives is praise, and the device is never telling the user what to do or providing information that might be construed as criticism.

Prior work in learning theory and animal training convincingly shows the motivational influences of positive reinforcement. Here we review the operant
conditioning learning strategies that motivated the InShape device design, which is described in Section 3. To our knowledge, use of these strategies in a context-aware mobile computing device has not been previously proposed.

The InShape device exploits successive approximation, known as shaping by animal trainers. This is the strategy of rewarding small moves toward a desired goal. With consistent presentation of rewards, simple or short behaviors can be successively shaped into more complex or lengthy desired behaviors. The complex, novel behaviors in animal shows are trained using successive approximation [15].\(^1\) The immediacy of reinforcement is known to be important when motivating behavior. A positive stimulus will be more effective in motivating behavior change when presented closer in time to a behavior. Even a several second delay diminishes the impact of the reinforcer, potentially corresponding to some other behavior. Computers have the potential to provide timely reinforcement, even over weeks, months, or years. An important goal when training behavior is to provide tailored rewards. A stimulus that is rewarding to one person may not be rewarding to another, and different people will have different baseline performance against which behaviors should be judged. The goal is to gradually improve the baseline performance. Regression is a normal deterioration in the process of learning. A trainer’s response to regression is to lower the barrier for reward temporarily to provide more positive reinforcement, which stimulates further learning and interest.

Differential reinforcement is the selective reinforcement of particular target behaviors that are judged to be of higher quality than others being observed at that stage of learning. Differential reinforcement will gradually increase baseline performance. When an extraordinary effort is observed, the size of reinforcement can be increased, which is known to lead to faster learning. Rewards that are much bigger than the normal reinforcer and that are unexpected are called jackpots and are used to mark a breakthrough in behavior learning. A variable schedule of reinforcement is one where a target activity is not reinforced at each observance. The unpredictability of reinforcement is known to increase behavior maintenance so that when a reinforcer is not received (e.g., if a sensor is malfunctioning), the person is more likely to keep trying the learned behavior. Training longer behaviors sometimes requires interim, secondary reinforcers. These special reinforcers signal that the trainee is on the path to success but has not completed the behavior yet. Eventually, a string of interim reinforcers will be followed by the primary reinforcer if the behavior persists. Finally, a conditioned reinforcer is a stimulus that has been paired with the reward. The conditioned reinforcer, which may be a special tone, signals to the animal that a reward is imminent, and it provides the trainer a mechanism to precisely mark the be-

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\(^1\) The power of successive approximation is difficult to convey without a first hand demonstration from an animal trainer experienced at providing positive reinforcement. Good trainers can train animals such as dogs to perform completely novel tricks in just one hour-long training session with less than 100 reinforcements.
havior being rewarded even if the reward cannot be provided at precisely that moment.2

These learning and training strategies are well understood, effective, and used widely in animal training [14]. They are known to work on most higher-functioning animals, including fish, dogs, cats, birds, dolphins, and humans. Although people often have sophisticated reasons for making decisions, consistent application of positive reinforcement is often an effective way to motivate and maintain human behavior change.

3 Prototype: motivating physical activity

Our goal is to develop a motivational technology that requires no proactive input from the user, that does not become burdensome, and that uses continuous just-in-time feedback to motivate behavior change. We assume a single individual uses the device and keeps a small sensor attached to his or her shoe at all times. A PDA provides only positive feedback, in form of audio stimuli, and only at points in time when bursts of walking, brisk walking, or running are detected.

3.1 Design

We targeted the four criteria for an effective message prompting technology listed in Section 2.1. To present a simple, tailored message we use sound cues. To present a message at an appropriate time, we use automatic detection of walking behaviors from a mobile sensor placed on the shoe. To present a message at an appropriate place we use a mobile computing device that we assume would be carried with users nearly everywhere they go.3 To satisfy the last and most challenging criterion – long-term message presentation that does not become irritating – we use operant conditioning exclusively with positive reinforcement. An interface perceived as disruptive or annoying, even on a single occasion, could lead the user to turn off the software.

3.2 System hardware

The InShape prototype uses a commercial wireless pedometer to detect a person’s movement. A 5cm by 4cm “footpod” is attached to the user’s shoe laces with an elastic band.4 The footpod consists of a 1 axis accelerometer and on board processor that continuously detects and counts steps and (based on a mean stride length) computes walking speed. It is powered by a 3V coin cell

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2 E.g., when porpoises jump, a conditioned reinforcer (whistle) is used to mark the event that is being rewarded (jump). When the jump is completed, the animal swims over to get the reward (fish) that the conditioned reinforcer stood in for.

3 For research convenience, we have used PDAs. The technology might ultimately be built into phones and watches with more convenient form factors.

4 The footpod is made by FitSense Technology and sells for U.S. $75. The receiver sells for U.S. $360 [3].
Fig. 1. (a) A footpod wireless accelerometer attached to a user’s shoe laces. (b) A PDA and receiver device, worn on the hip.

battery, and it transmits speed data to the receiver once per second. A user wearing a footpod is shown in Figure 1a.

In addition to wearing the footpod, the user carries an iPAQ model 3870 PDA mobile computer with a 3.5cm by 5cm FitSense receiver plugged into the serial port. Figure 1b shows a user with the PDA and receiver in a belt-mounted carrying case. Here the receiver hangs down, but it could also be attached to the back of the iPAQ with a modification to the connector. The device can also be carried conveniently (and less conspicuously) in a coat pocket. The mobile computer continuously monitors the incoming signal by computing a mean speed over each 10 second window and categorizing the mean speed into either “not walking,” “walking,” “walking briskly,” or “running.” The thresholds for these categories are set experimentally in our current system and must be adjusted slightly based upon a particular user’s stride length. The PDA is set so that it processes input continuously with the LCD display turned off.

3.3 Stimuli

The interface is designed to motivate physical activity by providing a positive reward. We have chosen to use audio cues, in particular, a variety of pleasing and entertaining chimes, as our reward stimulus. It is an assumption on our part that a library of carefully designed, clever chimes will be perceived as rewards by end users.\footnote{Anecdotal evidence suggests that simple audio cues can become powerful stimuli, such as “you’ve got mail” chimes on desktop computers.} This is a research question we plan to explore. The reward actually consists both of the chime itself (which may be humorous or enjoyable) and the knowledge represented by the chime that the user is getting some exercise.

Audio is potentially a disruptive feedback modality because it cannot be easily ignored and the sounds will be heard by other people nearby. Therefore, we have limited the audio cues so they consist only of pleasant, short, soft chimes that do not disturb the user or those around him. Most chimes last only for 1-2
seconds unless they are special rewards. Although the chimes could be disruptive if a user is in a quiet room (e.g. meeting situation), the chimes are only presented when the user is engaged in walking, brisk walking, or running.

The audio cues logically map onto the intensity level of the physical activity, becoming slightly louder, longer, and more upbeat with more intense movement. However, all the cues have been selected to be sufficiently subtle so that they do not become irritating over time, even when other people are around.

### 3.4 Using learning theory

The interface relies heavily on successive approximation, tailored rewards, and the other learning strategies introduced in Section 2.2. The device computes a custom baseline for each individual, which is tracked over time. The user’s raw speed is averaged over each 10s segment and classified into not walking, walking, brisk walking, or running. For each classification except not walking, a histogram is stored with $N$ days of data (e.g. $N = 30$), where the histogram records the number of contiguous 10s intervals of activity at a given activity level. A typical histogram will contain many short periods of brisk walking ($< 1$ minute) with fewer longer walks. Within each classification, a *moderate* effort is defined as one in the 50-69th percentile (where the 100th percentile is the longest effort), a *good* effort as one in the 70-90th percentile, and an *extraordinary* effort is defined as one in the 90th+ percentile. The reward varies with the effort and exploits shaping with differential reinforcement. Over time, if the baseline performance regresses, the standards required for rewards will relax, just as a trainer would advise. The user always has a realistic chance of obtaining a positive reward to stimulate interest in motivating behavior change.

The size of the reinforcement stimulus is scaled by changing the volume, type of chime, and length of chime. Good and extraordinary efforts are rewarded with longer and more vibrant auditory stimuli. Jackpots for extraordinary efforts are intentionally long (and sometimes humorous) audio cues that are presented for only the top 5% of effort in each movement category. For example, when an extraordinary period of running is detected, the device will sometimes play a short sound clip such as the theme from the classic running movie, Chariots of Fire. This element of surprise and playfulness helps to keep the user curious about and engaged with the interface over time [10].

Interim reinforcers are used during long bouts of walking, acting as a “keep going” signal. For example, if the user takes a brisk walk that is detected to be moderate relative to past performance, a moderate stimulus will be presented. From that point on, a short interim reinforcer will be presented once every 5-10 minutes with some random variability. If the effort reaches good, a good reinforcer is then presented. Interim reinforcers can be simple chimes or sequences of chimes that fit together in a theme.

Rewards are only presented 50% of the time for moderate performance (those in the 50-69th percentile range) to create a variable schedule of reinforcement. The variable schedule of reinforcement could be problematic given that users may confuse lack of reinforcement with malfunctioning technology. However, the
uncertainty is likely to lead to higher levels of effort. If a user thinks a reward was deserved but did not get one, he or she is likely to walk bit further or faster to attempt to trigger the device. The mildly mysterious nature of how the rewards are selected is an intentional strategy to increase user engagement [10].

The InShape device provides immediacy of reinforcement by presenting rewards only during the behavior of interest. The user can therefore easily map the reward onto the target behavior. The current implementation does not use conditioned reinforcers because the only reward provided is the audio cues themselves. However, if an external reward (e.g. financial incentives) were available that accrued over time based on the user’s behavior, the audio cues might act both as reinforcers and as conditioned reinforcers.

Small timing decisions can dramatically impact operant conditioning. For example, our first instinct was to wait until a burst of walking was completed and then to present a big reward. However, learning theory suggests the chimes will most effectively motivate when presented during the activity itself. Otherwise, the reward may become associated with the end of the activity [14]. The InShape device, therefore, only provides rewards during the target activity.

An important goal was to avoid creating a system that might use reinforcers to unintentionally discourage, not encourage, the desired behavior. In an early prototype, for example, the device used upward musical tones to indicate increases in walking speed and downward musical tones to indicate a slowing of walking speed. The downward tones, however, were effectively punishing slower speeds and have been removed. Because not walking and regular walking are unavoidable behaviors in everyday life, punishing these behaviors to encourage brisk walking will lead to resentment on the part of the user toward the user interface. These feelings may build gradually over time and give a user a reason to deactivate the technology – a failsafe way to avoid the aversive stimulus. For these reasons, we eliminated all negative reinforcement from our design.

3.5 User experience

Any user interface device intended to be worn on the body and run continuously for days, months, and even years, must create a calm user experience [20]. From the user’s perspective, our prototype’s “interface” requires no proactive effort – the user interacts with the software only through movement and receives feedback only through sound. The interface requires no training or computer experience, and it can be used by all ages. The user simply wears a footpod and carries the PDA. Occasionally the user hears a pleasant chime. In reality, the

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6 Intuitively, consider the following situation. A user is walking briskly and thinks he should get a reward. The system should be designed so that he keeps walking, not stops walking, to confirm that a reward has been received.

7 In practice, the current prototype does require some proactive maintenance to keep both the footpod and the PDA charged, but future technology built into phones (that users charge anyway) and shoes (that generate power or use a small solar cell) could require no conscious effort on the part of the user to keep the technology operational.
device is continuously monitoring and waiting for opportune times to present positive reinforcement. It is the timing and the persistence of the message delivery, not the individual messages, that create the interface's motivational power.

The interface always leaves the user in control. It simply presents information—positive information—about the user's behavior. All feedback is supportive, and the device does not intrude on the user’s autonomy by commanding, scolding, or making the user feel bad about performance. The user stays in control. Satisfaction, health, and mood are known to improve perceptions of control [17].

4 Challenges

To date we have built an InShape prototype and informally used the device in our lab. However, we have not formally measured the ability of the device to motivate behavior change. This is, in part, because our work is in its early stages and, in part, because a proper test will be lengthy and (consequently) costly to execute. Positive reinforcement operant conditioning is known to be an effective technique for motivating behavior change when properly applied. We suspect, however, that a heavy-handed application of feedback that requires too much attention from the user will lead to a device that may be novel and appealing in the short term but that would aggravate the user over time. Instead, we propose a subtle application of operant conditioning, where the power comes not from any individual message but from long-term, consistent presentation of small bits of positive reinforcement during target activities.

A consequence of this design decision is that measurable changes in physical activity will be detectable only after long periods of use. To run a subject in an experiment testing the device may require a month or longer to establish activity baselines, a month or longer for dissipation of the novelty effects, and then several months or longer to allow for measurement of small changes in activity patterns. We expect changes to be small. For example, the device might result in a person purposely parking at far ends of a parking lot with the hope of receiving a reward. Measuring such small changes given the high variance in daily walking patterns will require large sample sizes. During such a study self-reported user impressions might provide some information about the perceived value of the system over time. Even if the InShape device does not motivate sufficiently large increases in walking or walking intensity to have measurable health benefits, it could play an important role in priming an individual to be receptive to other types of motivational interventions if it boosts feelings of self-efficacy.

Some specific problems we must study are (1) if cleverly-designed audio stimuli can act as sufficiently powerful (but yet non-annoying) rewards for most people, (2) if subtle audio stimuli presented during physical activity to positively reinforce behavior becomes annoying over time, and (3) if small lags (10s) due to chunking of sensor data create confusion for the user about the reason for rewards. Another issue worth exploring is what users think if the device is used and then removed. Will the prompting create external justification for walking activity that will dissipate over time when the incentives are gone [6]?
In summary, the problem we face when evaluating the InShape device is one we think may become increasingly common within ubicomp research: the subtlety of the interface is what may make it tolerable for extended use, but that same subtlety is what may make it difficult to evaluate without costly and time consuming large-n studies. Our current work includes planning a small-n pilot study to provide preliminary data used to design and statistically power a larger study.

5 Conclusion

In summary, we have developed a prototype persuasive computing device that uses context-aware, tailored just-in-time messaging and positive reinforcement operant conditioning to encourage the healthy behavior of brisk walking. By providing positive reinforcement (via the pleasant chimes) for movement and by always rewarding efforts that are unusually intense or long in duration, learning theory suggests the interface will gradually encourage longer and more intense walking. By eliminating all negative reinforcement and punishment from the interface and by leaving the user completely in control of decision making, the interface should not generate user resentment. The passive but subtle interface design using soft, short, and pleasant tones makes it possible to run the algorithm continuously, even in public settings, without disruption. In future work we plan to test the prototype in a small-n longitudinal study.

References


