

Avatar Interfaces for Biobehavioral Feedback

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Abstract. The combination of inexpensive wearable sensors, powerful mobile phones, and always-connected cloud computing are enabling new, real-time feedback and coaching via mobile technologies. This paper explores the use of avatars - digital representations of the self - as an ideal user interface for mobile health application. Specifically, a justification for using avatars is provided, both based on empirical studies and the psychology of human body interpretation. We then provide an organized, theoretical description of how an avatar's traits (appearance, behavior, and virtual environment) can be manipulated to convey specific health-related behavior change messages.

Keywords: avatars, development, Proteus Effect.

1 Introduction

Through real-time processing of sensor and self-report data, mobile health (mHealth) systems can provide appropriate and timely biobehavioral feedback anytime and anywhere. Indeed, several mHealth systems have changed health behaviors [24] and outcomes [20] with varying levels of success. One under-explored source of feedback are avatars, digital representations of the self. While some research and commercial health systems use avatars [11,12,17,18,28-30], the work to date does not provide a clear explanation for why avatars could be a good tool for behavior change, nor is it clear how to best use avatars for effective behavior change. When the avatar is a more prominent part of the interface, its evaluation is minimal, or there is no discussion of what aspects of the avatar were influential. Direct comparison of systems is difficult due to differences in domain, implementation, and design of previous works. Methods of comparison between implementations are not well explored in this area, and the components which make up an avatar interface are not well defined. In this paper, we begin to address this gap in the literature by providing 1) *a clear motivation for the use of avatars in behavior change applications*, and 2) *a design language and methodology to facilitate more structured design, analysis, and evaluation of avatar-based behavioral change interventions*.

1.1 Why Use Avatars?

The use of avatars as an interface allows for the use of a visualization primitive which can encode a great deal of information simultaneously and leverages our innate abilities to interpret the human form. The 'bandwidth' of traditional visualization strategies is being strained by the ever-growing influx of data, and an increasing push towards 'affective computing' [21] suggests that the future will call for a retooling of interfaces relying on only informative methods. Avatars are uniquely suited to fill the role of influencing behavior due to their use of the human-like form as a communication medium. Humans constantly communicate using their bodies by changing their appearance and behavior, and understanding the meaning behind these changes - social cognition and perception - is typically hard-wired into humans [19]. The bandwidth of this interaction is immense when contrasted with current data visualizations; humans have evolved to interact with other humans (and we do it very well), whereas graph interpretation must be learned and can only span a few dimensions before becoming convoluted. Thus, manipulating the form of human-like avatars seems to have the potential to be a powerful, effective, and easy-to-understand communication format.

In addition to the theoretical support for avatar interfaces, there is also significant empirical evidence that human-like avatars do influence behavior. Previous research indicates that there are at least two mechanisms whereby digital self-representations can influence individuals: the Proteus Effect and operant conditioning.

The Proteus Effect. The Proteus Effect states that behaviors of an individual will conform to implicit cues from an avatar. Several studies on the Proteus Effect in non-mobile contexts indicate that manipulating an avatar's appearance and behavior affects a user's behavior in the real world. For example: seeing one's avatar running on a treadmill can encourage physical activity [10]; using an elderly avatar improves attitudes towards the elderly and increases saving for retirement [15, 26]; using an avatar to saw virtual trees encourages less paper use [1]; and manipulating an avatar's gaze can make the avatar more persuasive [2, 25]. In these cases, the Proteus Effect demonstrates how an avatar can exert an influence over users' perception of themselves and over their behavior. Although the precise psychological mechanism for this influence requires more investigation, one plausible theory is that users see their avatar as a model for their own behavior [3]. Alternatively, the avatar's influence could be explained by a perceived relationship between the user and his/her avatar (i.e., a shared identity [4] or an empathetic bond [5]).

Operant Conditioning. Secondly, operant conditioning can influence behaviors by having an avatar function as a visual representation of success or failure. Even when avatars do not take an explicitly human form, they appear to influence behavior via this mechanism. For example, previous work has explored

the use of an avatar as an operant conditioning agent and feedback mechanism for promoting physical activity. In this work, the physical activity of an individual is mapped to the actions and mood of an anthropomorphized virtual bird avatar [12, 17]. As physical activity increases, the bird becomes happier and more playful, flies faster, and sings more songs. Pilot work suggests that this avatar can promote increased physical activity among individuals [17]. Moving one step further from 'user-likeness', Fish'n'Steps translates daily steps into the growth and happiness of a virtual fish [18]. Even more abstract from the concept of 'avatar', UbiFit displays a garden on the background wallpaper of a phone. The garden is similar to a historical avatar, providing feedback on the user's physical activity when glancing at the phone [6].

These examples, though spanning varying degrees of 'avatar-ness', still serve in some sense as virtual representations of the self. Behavior change applications nearer the abstract edge of the user-likeness spectrum allow for more creative designs, but may lose some benefits of innate interpretation. The distinction between avatar and non-avatar systems is not well defined currently, but in future research we may learn that the display must meet some (personalized) criterion of realism, interactivity, self-presence, customization, or abstraction to be considered a 'true' avatar which is fully capable of utilizing user the Proteus or similar effects.

This evidence, when combined with conceptual knowledge of human-avatar interaction, suggests that the use of avatar-like interfaces may create behavior change through motivation, rather than purely informative visualization methods. Thus, avatars may be a powerful new technological medium for providing core methods for behavior change based on behavioral science (i.e., goal-setting, self-monitoring, modeling, and positive reinforcement).

2 The Language of BioBehavioral Feedback

Before we are able to identify guidelines for the use of mobile avatars in biobehavioral feedback, we must first have an abstract model of information flow and interaction in any biobehavioral feedback system (with or without avatars). Figure 1 is a pictorial representation of the components of a generic biobehavioral feedback system and the information flow within it. It is important to note here that we use the term 'feedback' in a loose sense in which it represents any output to the user based on user input which may affect future user behaviors. Starting from the top-left of the figure, a description of the user's current behavior (input) is provided via self-report or sensor. This description of in-the-moment user behavior is passed to a feedback algorithm, along with any relevant historical information. Some examples of historical information which may be taken into account are the previous day's user behavior, feedback given to the user previously, or data on the impact of a particular form of feedback on the user. With in-the-moment and historical information, the algorithm then generates the feedback. Output is then observed which may or may not immediately convey the feedback. As a demonstration of this model, consider a typical time-series

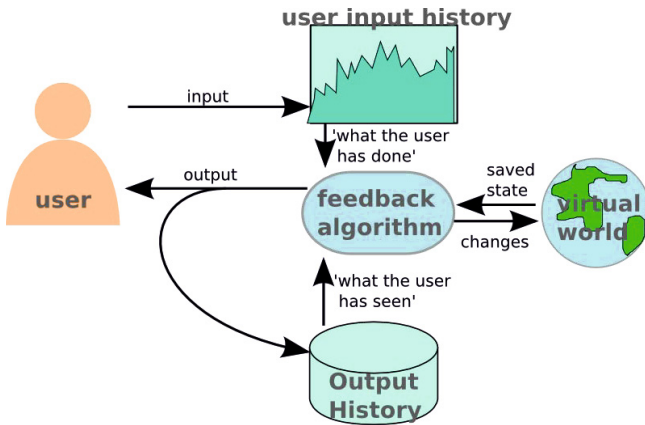


Fig. 1. Information flow diagram for bibehavioral feedback algorithms

feedback visualization which displays level of physical activity inferred from accelerometers. The input in this scenario is the accelerometer data. The feedback algorithm includes the method of inferring physical activity, as well as the mapping of activity level to a 2D plot of timestamps and activity. The graph of past physical activity (created from the mapping, user settings, and/or input parameters for graph creation) makes up the virtual world, and the user navigates the world through a pan/zoom window, which determines the output.

3 Adding Avatars to the BioBehavioral Feedback Model

An avatar-based implementation of the model presented differs from a more traditional visualization system only in the feedback algorithm and the output to the user. Design of the feedback algorithm to map input to output is a complex task, which can not be properly explored without better knowledge of the avatar outputs available.

Guidelines for the outputs of conventional data visualization are well established [16]; *here we aim to identify and organize the wide variety of outputs available to an avatar display and move towards the identification of similar guidelines.* Just as the use of item location, color, and size can be used to convey information in a chart or graph, we propose that characteristics of the avatar display can be altered to convey information. However, the critical difference between innate avatar interpretation and learned graph reading suggests that the most useful encoding attributes of an avatar are based in the psychology of avatar perception.

3.1 Encoding Attributes in the Avatar's Physical World

Encoding attributes available in an avatar display are more numerous than those available in other visualizations due to the extremely vast amount of information humans can gain from interaction with another human-like entity. Many of these attributes, however, may have subtle or implicit influence, and impact can differ significantly from person-to-person. Here we present a generalized hierarchy to describe all conceivable changes which can be made to the physical world of an avatar. A consideration of this hierarchy can help a designer find the proper encoding attribute(s) to ensure that the effect on targeted behavior is maximized while reducing other, undesired user perceptions of avatar trait changes.

Physical - Changes to the avatar primitive in the most obvious form modify the avatar itself in some tangible way. Much like existing visualization strategies, an avatar's size, location, shape, color, etc. can be used to convey information, though in the case of an avatar these encodings often have built-in meaning to a user. For instance, inversely relating the level of daily physical activity into the width of the avatar (so he/she appears to grow thinner with exercise) is intuitive, but encoding the same value proportionally seems to send the wrong message to users, since he/she would appear to grow less fit with additional physical activity.

Behavioral - In addition to the encoding attributes available in an avatar's appearance, avatars provide an additional ability to convey information via a change in their behavior. Changes can be as simple as a change of behavior 'class' for pre-scripted avatars (e.g. from a physically active behavior to a more sedentary behavior) or may involve character attributes that should be reflected in avatar behavior. For example: a case in which an avatar demonstrates increases in strength by an ability to lift heavier objects is more than just a change in avatar behavior (lifting objects); it is a change in avatar traits (strength). Another set of behavioral attributes available to designers are the 'behavioral biometrics' - i.e., the personal characteristics of behavior such as gait, voice timbre, and typing rhythm [23].

Environmental - In addition to manipulation of the avatar primitive, algorithms may manipulate the virtual environment in which the avatar resides in order to affect user perception of the avatar. Changes to the environment can be cosmetic or more complex, and in many cases can have profound impact on the avatar display. For instance: avatar location and surroundings can be manipulated to go along with a behavioral avatar change (e.g., the avatar takes a trip to the beach to encourage the user to relax). Environmental changes can play an even larger role for avatars used in games; changes in the virtual environment can be used as gameplay elements. Location and virtual object removal/addition/manipulation can be used as indicators of progress or accomplishment. Similarly, aspects of the environment may be manipulated to behave differently towards the avatar (e.g., a computer-controlled agent becoming more friendly to one's avatar as a social reward for desired behavior).

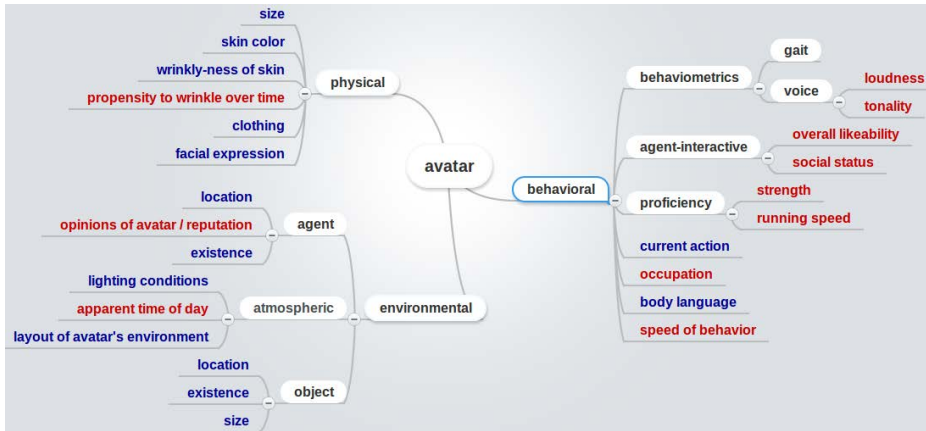


Fig. 2. A hierarchal organization of potential avatar encoding attributes

The hierarchy represented by Figure 2 demonstrates the wide variety of encoding attributes available to visualization designers organized by the categories outlined. This is not intended to be an exhaustive list of possible encoding attributes, but encompasses many possibilities in an organized fashion, so that we may have a language to discuss avatar display changes just as we would discuss changes in shape, color, location, etc. of a traditional data visualization. Though all possible attributes cannot possibly be included, we believe that all possible encoding attributes logically fall within the first-level categories presented (physical, behavior, environment). Some further subdivision is shown, and attributes themselves can in some cases be further broken down (i.e. size subdivided into size of individual body parts).

Each encoding attribute can also be divided into two primary types: 1) *literals* - these changes have a relatively obvious, immediate effect on the avatar and are constantly observable. Examples include height, body shape, facial expression, current behavior, and current avatar location. 2) *traits* - these changes typically have a more subtle effect on the avatar; they are numerical values which describe a certain intangible property of the avatar or virtual environment. Examples include avatar proficiency at a task, behavioral biometric characteristics, and virtual character interaction characteristics. Avatar traits are a common theme in modern games, where a user may achieve a new 'level' or acquire a new 'power up' which will modify their gameplay. Traits typically will trigger a change in the value of a literal, but this change may not be apparent until a certain action is performed or as time passes. Strength, for example, is only observable when performing a strength-dependent behavior, and may display in multiple ways (e.g. speed of lifting, reduced apparent strain of lifting, increased lift height). These primary types of attributes can be found at any place in the formulated hierarchy; more examples of 'traits' and 'literals' can be identified by color as blue and red, respectively, in Figure 2.

In many cases, multiple physical attributes of the avatar could be changed. This is the case for dramatic changes in avatar identity, such as changing an human-like avatar to a plant-like creature as a reward for adopting environmentally friendly behavior or transforming the avatar's head into a greasy cheeseburger to encourage changes in diet. It must also be considered that many of these principles can perhaps apply for individual body parts (e.g., eye color, hair length, etc.). To design for these more dramatic changes and not become overwhelmed with possibility, we must consider a higher level of abstraction based on psychological interpretation of the human form.

3.2 Encoding in the Psychological

Changes in avatar appearance can be simple changes to physical or behavioral literals (e.g. change in avatar height or change in running speed), but these types of changes do not differ in principle from more traditional data visualization unless they can be interpreted without explanation. That is, a non-intuitive encoding strategy such as using avatar height to encode sleep quality is, in principle, a bar graph with human-shaped bars. However, when using an avatar primitive, simple encodings will almost always have a complex psychological effect on the user. For instance, encoding a user's caloric intake in the overall size of an avatar could have the unintended consequence of making the user view the avatar as more attractive as he/she grows taller. This complication arises because the mapping from the user's interpretation of the avatar to the physical or behavioral space of the avatar is not well defined; indeed, a simple change in the physical space almost always creates complex changes in the user's perception of the avatar.

Avatar displays designed to leverage the psychology of avatar interpretation should instead aim to adjust the user's perception of a specific, high-level trait of the avatar which is relevant to the targeted behavior change. For instance, one could aim to change the perceived abilities of the avatar by making it appear frail, weak, or elderly. By attempting to encode values in high-level interpretation rather physical traits, we can utilize heuristic knowledge of human-form interpretation in our intervention design. Figure 3 provides a minimal demonstration of selected 'low-level' physical attributes and 'high-level' psychological encoding attributes.

4 A Guide to Application of Avatar Interface

The work of Yee et al. [27] provides some example of avatar visualization design from the psychological perspective. Experiment designers wished to modify a psychological construct (the attractiveness of the user) and did so by using height as a proxy based on existing research. To further deepen the effect, other modifications could have been made to the avatar in order to modify the perceived attractiveness. For instance, adjusting the facial features [7] could have also been used. Care must be taken not to assume that multiple changes combine linearly, however. In general, adjustment of multiple encoding attributes could cause an entirely different effect than the original two.

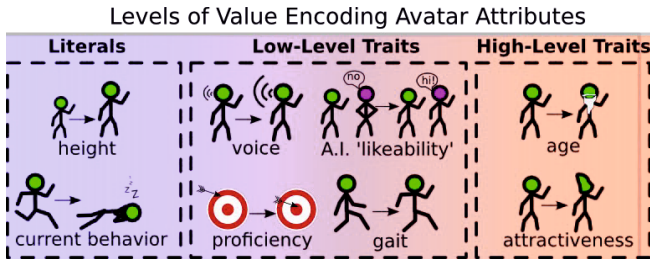


Fig. 3. Various levels of encoding attributes used to modify user perception

Below we describe suggested stages of development for designing an avatar interface. Like many design processes, traversing the stages is iterative in nature; progression through the stages often reveals a need to return to a previous stage to further refine the design. A constant re-checking of past decisions is crucial to creating an avatar interface that is coherent across all dimensions of the system. We present some novel examples as well as some from literature at each suggested stage in Figure 4.

1) *Identify Behavior Change Plan* In this step one must identify our general plan for behavior modification. The targeted behavior must be explicitly defined and a theoretical basis for motivating a change must be found. In this paper we argue that motivation for change is generated with avatars through both the Proteus effect and operant conditioning, but other psychological theories could be applied here as well. Existing literature provides additional guidance on the use of behavioral theories within an HCI context [14], as well as explanation and tools for defining, understanding, and describing behavior change [8,9].

2) *Identify Target Trait in User's Perception* Once we have an overall plan for motivating change, we must identify precisely what part of the user's perception of the avatar we aim to use as the encoding attribute. The resulting 'high-level' trait(s) should come from behavior change literature or designer intuition and not from the hierarchy of low-level traits and literals.

3) *Map the Target to Avatar's Physical Encoding Attributes* Once the targeted high-level encoding attribute is found, the desired effect should be mapped to physical changes in the avatar such as those laid out in Figure 2. At times an easily manipulable physical attribute can act as a proxy for conveying a more psychosocial concept (e.g.: perceived attractiveness could be changed by manipulating height or facial symmetry), but in many cases there may not be significant literature on perception of the targeted attribute. Sometimes this mapping is so intuitive that researchers may (rightfully) not see it worthy of investigation; for example: perceived age can certainly be conveyed via wrinkling of the skin and whiteness of hair. However, it is important to explicitly consider this process of assumption to ensure that the targeted trait is conveyed most effectively. Returning to Figure 3, this process moves us leftwards away from the high-level user-perception space. In fact, encoding attributes must be reduced leftwards completely to the avatar's physical space in order to implement encoding

attributes, which, in turn, forces the user to do a great deal of interpretation. Here an understanding of the target audience is extremely important, since cultural or personal differences can greatly change user interpretation. Just as in human-human interaction, subtleties such as clothing, posture, and body language carry a great deal of information to the user - even if designers do not intend them to. In this way, all physical attributes are constantly interpreted, so implementations should be carefully checked for potential misinterpretation. Ultimately, some confounds and unintended effects are inevitable, but at this stage we minimize potential harm through careful consideration and iterative testing of many possible mappings.

	Outline Behavior Change Plan	Identify targeted trait(s)	map to Avatar's Physical Encoding Attributes
Time to Eat [21]	to improve eating habits subjects are shown a virtual pet with mood determined by the healthiness of breakfast	mood of the pet is the targeted trait	mood of the pet is conveyed on a scale between happy and sad through images with varying facial expression, posture, and text.
MILES [17]	The happiness of a bird avatar is determined by user level of physical activity.	perceived level of happiness of the bird is the targeted avatar trait	the mood of the bird is shown via increased flight speed, and increased song singing.
Yee et al. [24]	hypothesis: increase in avatar attractiveness changes subject's social behavior	Perceived avatar attractiveness is targeted trait.	Avatar height used as a proxy for 'attractiveness'
stressReduce	Desire: reduce overall stress. Motivate behavior change via operant conditioning; users see avatars receive rewards and experience happiness when avatar is relaxed, unhappiness when avatar is stressed.	levels of stress' and 'levels of happiness' need to be conveyed	level of stress' conveyed via frizzing of avatar's hair, hands placed on temples, bags under eyes, amount of steam coming out of ears. 'level of happiness' via smile achieved through manipulation of mouth and eyes.
ActivitySuggest	to increase user physical activity (PA) via the proteus effect user is presented with PA avatar to increase desire to be PA. Avatar mirrors user level of PA as measure from accelerometers most of the time, but occasionally 'suggests' a higher level by simply displaying it.	Aim is to modify user's perceived level of avatar physical activity	scale of perceived level of PA created using activities of varying intensity. Running, bicycling, swimming are 'high' PA level; walking, playing catch are 'medium' PA level; sleeping and studying are 'low' PA level.

Fig. 4. Example applications (some from literature and some hypothetical) described at each stage of interface development

5 Open Questions and Concerns

The dangers of unintended consequences via misinterpretation may become more serious as we develop systems with more powerful behavior change methods and as we first explore these uncharted methods for providing feedback via avatars. The problem of misinterpretation becomes an even greater concern for the described systems since the method of interpretation for these outputs to the user is no longer something which is taught, but can be entirely dependent on the user's perception of the avatar. For example, a user who may suffer from distorted bodily self-perception may interpret the body shape of the avatar much differently from the norm.

One of the largest challenges remaining for an implementation of human-in-the-loop feedback with avatars is that the method of mapping inputs to outputs (the algorithm itself) may need to vary from application to application and from user to user. Due to the large search space, identifying the best mapping from input to output may require significant iterative design and personalization along with advanced analytic methods such as the use of control systems engineering and dynamical systems modeling [13].

Through the use of described methodology, the design process for avatar interfaces is given some foundation, but much more exploration is needed to address the questions posed throughout this article. Through additional implementations guided by behavior change theory, it is our expectation that avatars will prove an extremely powerful tool for behavior change science.

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