Animating Embedded Behavior Change Support Systems in Physical Environments

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Abstract. Behavior change support systems (BCSS) are computing systems intended to form, alter, or reinforce attitudes or behaviors without using coercion or deception. Grounded in substantial theories and models, there are principles and frameworks for designing and evaluating BCSS in the forms of general information systems. With increasingly prevalent integration of technologies, like sensors, networks, and displays, into physical objects and environments, embedded persuasive systems can motivate people at relevant time and context to perform or change a behavior for personal, social, or environmental wellness. This paper first argues that embedded persuasive systems should show "animated" features (cues) to break habitual routines and create affective sensorimotor experiences of indirect or contingent outcomes to prompt alternative actions. It then proposes a matrix that maps major persuasive design principles with framework of tangible and embodied interaction. The matrix informs design considerations for animating embedded persuasive systems. To illustrate the approach, two design cases are discussed. One is in a public environment, and the other is in a home setting.

Keywords: Persuasive design, animation, liveliness, tangible and embodied interaction, blending.

1 Introduction

Persuasive systems, or behavior change support systems (BCSS) to be more specific, are computing systems intended to form, alter, or reinforce attitudes or behaviors without using coercion or deception [1, 2]. Grounded in substantial theories and models, there are principles and frameworks for designing and evaluating persuasive systems in the forms of general information systems. Persuasive systems of these forms work well in task-specific situations, yet they may not be applicable in occasions when users' attention is directed to other daily routines (e.g., picking up a coffee to go, washing hands in restrooms, or browsing a smartphone while sitting comfortably in a couch). Insights from social psychology indicate that an individual's behavior depends on two intertwined threads of thinking, namely conscious and automatic. While conscious intention plays a key role in goal-directed behaviors [3], many of our everyday behaviors are interfered by the automatic environment-perception-behavior link [4] developed after repeated practice (e.g., we may thoughtlessly dry our hands using tissue paper after wash in restrooms; one may automatically fetch the phone from the pocket while sitting down in a couch). Habit is a learned functional act initially goal-directed and later turned into automatic. People can become less attentive to new information or alternatives in case of strong habits [5].

With increasingly prevalent integration of technologies, like sensors, cameras, networks, and displays, into physical objects and environments, persuasive systems embedded in varied daily environments can stimulate users at relevant time and context, and draw their attention toward latent motivation for changing or performing a behavior for personal, social, or environmental wellness. Informed by social psychology theories and advances in tangible and embedded interaction, this paper argues that embedded persuasive systems should (1) blend in the specific locations, (2) show "animated" features, or cues in psychological terms, to break habitual routines, (3) create affective sensorimotor experiences of indirect or contingent behavioral outcomes, and (4) make interactions with animated cues visible to facilitate social learning. It proposes a matrix that maps major persuasive design principles and social psychology insights with framework of tangible and embedded interaction. The matrix informs important design considerations for animating behavior change support systems embedded in daily physical environments. Two design cases are discussed to show how the matrix assists uncovering design possibilities.

2 Theoretical Background

2.1 Two threads of thinking (blend in & light up)

Research in social psychology indicates that human behavior depends on both conscious intention and non-conscious automaticity. Theory of Planned Behavior (TPB) [3] focuses on the conscious thinking behind a performed behavior. An individual's intention to perform or change a behavior depends on one's beliefs about the consequences (e.g., immediate pleasure vs. pain, foreseeable hope vs. fear, etc.), about subjective references from others (e.g., family members, authorities, etc.), and about the likelihood of success. With intention, however, the road to action is still interfered by automatic thinking (e.g., after washing hands in restrooms one may thoughtlessly dry the hands using tissue paper ready to hand, even though knowing that shaking off water first would save some paper). Supported by empirical evidence from experiments, behavior is found to be sometimes automatic via an environment-perception-behavior link [4], which is developed through frequent and consistent pairing of environmental cues (e.g., wet hands, a paper towel within reach, etc.) and mental processes (e.g., impulsive desire to dry hands). The act can be unintentional (e.g., actually intending to use less paper for environmental conservation), but just performed for efficiency. Habit is a product of these two intertwined threads of thinking. It typically starts from an initial intention toward an act, which later turns automatic in response to specific cues, even though it may become unintentional on occasions [5]. To break an automatic routine or form a new habit, provoking one into conscious thinking in particular context is necessary. Hence, persuasive systems should “blend in” relevant daily environments (e.g., the hand-washing basin and the paper towel container in restrooms), meanwhile showing *animated cues* (e.g., an animation showing fast-growing plants on the container or next to the basin if one shaking off water before grasping tissue paper) that “light up” (among other regular cues) in the environments.

2.2 Persuasive design principles

Fogg’s Behavior Model (FBM) [6] considers both immediate outcomes (e.g., pleasure vs. pain) and foreseeable consequences (e.g., hope vs. fear), in addition to social influence, as major motivators for performing a behavior. A type of trigger, called spark, draws one’s attention toward motivators (e.g., hope or fear) at timely moments and relevant contexts. Sparks also can highlight new motivators that are alternatives to routines. Another type of trigger, called facilitator, enables certain actions and hinders others, which in our view here seems to create physical affordances (i.e., action possibilities). Oinas-Kukkonen and Harjumaa [1] extend the model and develop a framework comprising a comprehensive list of principles for designing persuasive information systems. Those relevant to embedded persuasive systems include simulating the cause-effect link of a behavior, visual appeals, enabling social learning and social facilitation. Midden et al. [7] discuss the roles of technology in behavioral intervention and particularly point out that virtual environments can create sensory and affective experiences of distant or indirect cause-effect relationships regarding a behavior. Studies that follow include investigating how mobile technology can augment a daily environment (e.g., a supermarket) to create location-based triggers [8]. To sum up, embedded BCSS should provide *affective sensorimotor experiences of indirect behavioral outcomes*, which highlight the motivators for users. They should also tap into spatial or environmental features of the locations to create *affordances* for preferred actions, which also enable *social learning and facilitation* in the public environment.

2.3 Tangible and embedded interaction

Hornecker and Buur [9] review major approaches to tangible and embedded interaction design, including physical representation and manipulation of digital data (mainly from computer science), bodily interaction with physical objects (mainly from product design), and digitally augmented spaces (mainly from the arts and architecture), resulting in a framework of four interrelated themes, each of which comes with a set of terminology. Tangible Manipulation (TM) highlights physical aspects of representation of the digital, including *tactile contact* and *haptic or sensory feedback*, constant feedback, and direct mapping between data and representation. Spatial Interaction (SI) covers the *meaningful place* that people inhabit, *non-fragmented visibility* among them, and possibilities of full-body interaction. While tangible manipulation is like a close-up view to us, spatial interaction is like a wide shot. Embodied Facilitation (EF) is directly relevant to intervention. It refers to structures of the physical representation that offer action possibilities or limit them. These *affordances* or *constraints* (actual or perceived) are embodied because they are built on users' motor skills or social experiences. Expressive Representation (ER) finally looks at the balance between the physical and the digital. They should blend into each other, wherein actions and effects demonstrate *perceived causality*, or we say a co-occurrence that "makes believe". Hornecker and Buur's framework has a few concepts pertaining to behavioral intervention. They (in italic in the paragraph) are tactile contact and haptic or sensory feedback, meaningful place and non-fragmented visibility, embodied affordances or constraints, as well as perceived causality in physical-digital hybrid.

3 The Matrix

Both existing persuasive design principles and tangible interaction framework lack direct guidelines for breaking routines and stimulating thinking of alternatives. This gap can be filled by the idea of animation as a kind of sensorimotor experience that stimulates imagination and emotion [10]. In the tangible interaction framework, TM refers to the physical aspects, including the concepts tactile contact and sensorimotor feedback. We call it "Physicality". SI oversees the overall interaction stage, which we call "Spatiality", consisting of the concepts meaningful place and non-fragmented visibility. EF singles out the physical structures to examine the basis from our bodily structure, which is technically the concept embodied affordances. It is named "Structure". Finally ER looks at the mappings between the physical and the digital, particularly perceived causality. It is "Representation". These four inclusive aspects are cross-divided by the two levels of thinking behind the performance of a behavior, as suggested by insights from social psychology. The resulting matrix (Figure 1) has the four aspects of tangible and embedded interaction along its horizontal dimension and two levels of thinking on its vertical. It is populated by the relevant concepts from both dimensions, together with the idea of animation.

	Physicality	Spatiality	Structure	Representation
Automatic	Tactile contact Sensorimotor feedback | Animated cues	Meaningful place for a behavior | Social facilitation	Embodied affordances | Facilitators	NIL
Conscious	Tactile contact Sensorimotor feedback | Animated cues	Non-fragmented visibility of animated cues and interactions | Social learning	Embodied affordances | Sparks	Perceived causality in physical-digital blends | Experiences of indirect behavioral outcomes

Figure 1. The matrix mapping behavioral intervention with tangible and embedded interaction

Each concept in each aspect of tangible and embedded interaction (i.e., in each column) is identified with a concept in one or two levels of thinking (i.e., one or two rows), based on the former's potentials in or likelihood of leading to the latter. Hence, an interaction concept might be able to elicit automatic, conscious, or even both kinds of thinking. For example in the Physicality column, sensorimotor feedback can be an animated cue intervening the automatic environment-perception-behavior link (e.g., hands are wet after wash yet animation of fast-withering plants has been seen when hands approach the paper towel container); the animated cue can also contingently direct one's attention toward the preferred behavior (e.g., the animated plants becomes flourishing if one shaking off water to the basin).

In the Spatiality column, the place of interactions means something to people and facilitates a socially assumed behavior (e.g., the hand-washing area in a restroom gathers people who wants to wash their hands). This social assumption is largely unconscious at most times. Meanwhile, if the place is a public environment, its physical setting follows the social code allowing people to see the actions of each other. If one acts in response to an animated cue, others will see and try to make sense of the interaction. If it is sensible, people can learn to act accordingly.

The Structure column has one concept, embodied affordances/constraints, which by definition facilitate or hinder certain actions in accordance with users' motor or social habits. For instance, a control resembling a doorknob invites one to grasp and rotate it clockwise rather than anti-clockwise. Sometimes embodied affordances/constraints fairly act against one's routine and stimulate conscious consideration of alternatives and consequences of a behavior. Consider the squared roll of toilet paper designed by architect Ban Shigeru [17]. Each squared corner meets the edge of the metal dispenser, setting slight resistance and noise to the user's automatic pull action. It acts as a spark to highlight the consumption of every piece of paper.

The Representation column has a concept mapping only in the conscious thinking. User actions and technology-enabled animations take place together at the physical-digital hybrid. This perceptual co-occurrence enables first metaphorical mapping in the brain [11] and then blending [12] into an experience that makes one momentarily believe the physical-virtual cause-effect relationship. If the effects are designed to represent indirect consequences of a behavior, the perceived causality extends to imaginative beliefs about the behavior-consequence link, what the first author calls blended causality [13]. This influences one's conscious intention or attitude to perform a behavior. Consider the interactive public installation "The Social Swipe" [14] that invites a potential donor to swipe a credit card to cut a piece of bread on the video wall. The animated video makes one believe that the electronic donation directly goes to become food for the needy.

The resulting matrix is a map showing the connections from designed components of interaction to intended cognitive responses, which hopefully increase the probability of a behavior to be performed. It can be used as an analytical tool to guide the design of a work-in-progress, or to evaluate a design by checking if there are unaware design considerations or underexplored design possibilities.

4 Case Studies

To demonstrate how the matrix informs design considerations and possibilities, two case studies are presented. Each case starts with the design description, followed by the intended intervention, the context of interactions, the digital contents, and intended scenarios. The design is then scrutinized, according to the following guiding questions, which are generated from the connections inside each cell of the matrix.

- Spatiality-Automatic: How the place of interactions means to people? What actions and behaviors are socially assumed?
- Physicality-Automatic: How feedback is perceived? What surfaces or interfaces the user touches? Do animated cues intervene automatic behavior?
- Structure-Automatic: Are the user actions enabled by physical structures of the design? Are some actions hindered as well?
- Structure-Conscious: Do the physical structures hinder some routine or habitual actions? Does this stimulate conscious thinking of possible alternatives and their consequences?
- Physicality-Conscious: Do animated cues make users consciously review indirect and contingent outcomes?
- Representation-Conscious: How do the user actions and animations co-occur in a hybrid way? Do the effects represent indirect or imaginative consequences of a behavior?
- Spatiality-Conscious: Can one's interactions with the animations be seen by others? Can others try to learn to do the same?

Through contemplating answers for the above guiding questions, corresponding components in the design are examined, or missing parts are identified. It is not necessary to fulfill every question in the guidelines. Overall, a design consideration is a link from a design component of tangible and embedded interaction (e.g., sensorimotor feedback) to an intervention instrument (e.g., animated cues). One can see how many design considerations are identified, and how many cells are underexplored. This informs new design possibilities. The first design case is generated from a project of the first and fourth authors. The second design case is from another project of the first, second, and third authors.

4.1 Swing Compass Table

Swing Compass Table is an interactive public bar table whose round tabletop allows turning and displays relevant information of surrounding areas, for example, directions for nearby recycling bins, trashcans, or water dispensers (Figure 2). The design combines concepts of bar table and compass or radar.

Figure 2. Swing Compass Table situated in open area with other public furniture near a café

Purpose: It aims to recommend recycling and even reuse of the container after finishing a drink.

Context: It is supposed to stand at public area near a café or convenient store.

Content: The four fan-shaped screens evenly arranged on the tabletop display varied drinks and their disposers found in the corresponding directions around the table (Figure 3). The displayed items in each direction include, for example, a bottled drink together with the location of a recycling bin (the PET bottle can be recycled), or a cold drink together with the location of a trashcan (the container and straw cannot be recycled). Turning the table shows items in different directions like radar.

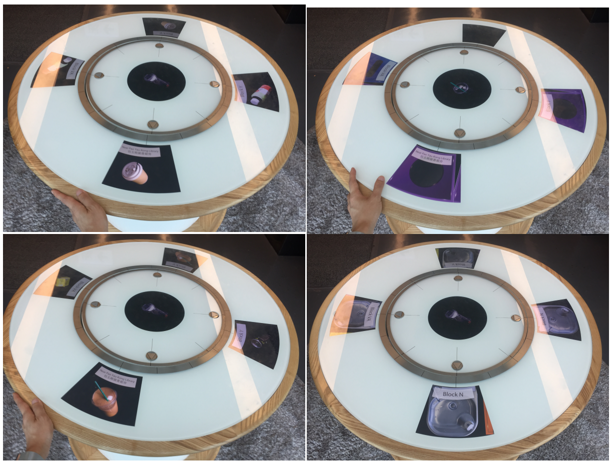

Figure 3. The display at each side of table refers to a drink container and locations of disposers or dispensers found in the corresponding directions.

Scenario: Imagine a person has just bought a drink and walks to the table. The table's appearance and height invite one to approach. The tabletop allows turning in small angles to reveal a similar drink and its disposer on a particular table display. One knows a disposer can be found nearby at the corresponding direction. Turning it further by 90 degrees results in a very different set of information. Water dispensers nearby at different directions are shown and drink containers are suggested for reuse.

The design and development of Swing Compass Table iterate at different stages of prototyping, laboratory testing, and lately field trials and observations. Some initial findings from the laboratory have been published earlier [15]. A field trial has been conducted between February and March 2018 in a university campus. Based on the observations and interviews (13 participants) in the field, together with the proposed matrix, we interpret the details of the intervention. This shows how the proposed matrix supports interpretive analysis that points out important links between interaction and intervention that cannot be missed.

Spatiality-Automatic: Swing Compass Table is situated with other public furniture in an open area near a café. The area is meant for people to hang out after buying a drink. People may stand around the table, put the drink on it, or even working on their notebook computers.

Physicality-Automatic: The standing height of Swing Compass Table invites one to casually stand next to it with the drink. The round tabletop, the groove between the outer ring and the inner circle, and the marking on them, implicitly suggest instrument that can be turned [15]. When one grasps the rim of the outer ring, the shape fits the hands and the weight allows slow turning. The animated cue comes from the displays on the tabletop. When the outer ring is turned in one way, the displayed items (e.g., a bottled drink) moves in reverse like sliding under the tabletop, resembling radar. This breaks the automatic routine of trashing the finished drink.

Structure-Automatic: While the inner circle is fixed, the separate outer ring can be turned clockwise or anti-clockwise. Its weight does not assume turning too fast.

Structure-Conscious: The rotating track of the outer ring is meticulously designed and built inside the table (see Figure 4). When it is rotated toward 45 degrees clockwise or anticlockwise, there is a spring resistance effect. One needs to give a little harder force to get through 45 degrees to 90 degrees. One may think that it opens up new possibilities.

Figure 4. Rotating track of the outer ring inside Swing Compass Table

Representation-Conscious: The user action of turning is perceptually blended with the visual effect on the displays, giving an illusion that the displays are windows for looking through the tabletop. A drink and a recycling bin (or trashcan) are seen together in one direction, suggesting a kind of relation between them. To a user holding a drink, it shows the ways to disposing the container after finishing the drink. If the table is turned 90 degrees, it recommends reuse rather than disposing by showing water dispensers nearby together with the container.

Physicality-Conscious: The overall sensorimotor feedback (haptic, visual, and audio when rotating the table) becomes animated cues making one reconsider different ways of dealing with the finished drink (trash, recycle, or even reuse).

Spatiality-Conscious: Through rotating the table, the user also turns around it and looks at different options in different directions. His or her actions can easily be seen by others in the area. Anyone can observe what direction the user looks at and heads toward, and can guess what the user has chosen to act. Others can follow.

Reflections on Swing Compass Table

Swing Compass Table is designed to not only provide relevant location-based information but also recommend alternatives for consideration. The intervention is relatively subtle. In other words, providing information is users' perceived function, yet intervention is designers' real goal. Based on the analysis at the automatic level across the tangible interaction aspects, users perceive and act on the physical aspects (e.g., turn-able ring) and then relate to the digital contents that move like under the tabletop. To accord with this illusion, the items are visualized in top view.

The 45 degrees are boundaries between two sets of information, namely the routine and the alternative. Whether a user see this depends on (1) the perception of the resistance effect, and (2) the contrast between digital contents across the turning boundaries. For (1), the mechanical design of the rotating track now renders the resistance quite obvious. For (2), the disposers are now visualized in stark contrast to the water dispensers in both shape and color (the former in blue, purple, and brown, while the latter in silver).

4.2 Lamb Lamp

Lamb Lamp is an interactive side table with a lamp. Its tabletop allows resting a preset number (2 or 3, based on family members) of smartphones for inductive charging. With all phones together, the lamp brightens up to recommend physical activity (Figure 5). The design concept draws on the metaphor togetherness is full moon.

Figure 5. Lamb Lamp in a sitting room falls asleep while waiting for smartphones.

Purpose: It aims to invite all family members to put down their smartphones and act physically.

Context: It is supposed to be home furniture.

Content: Each smartphone rested on the tabletop makes the lamp brighten up a little. With all phones rested, come the full brightness, a smiley, and a random number (see Figure 6), which points to a physical game set stored under the table.

Figure 6. Lamb Lamp brightens up and smiles when all smartphones are together; it pops up a random number indexing a game set under the table.

Scenario: Imagine each member rests the smartphone on the table. The lamp gradually lights up and displays a smiley emoticon with a random number for a game. While the whole family is playing the game together, one member's phone notification triggers a pickup of the phone. The lamp turns off and disrupts the atmosphere. The member feels embarrassed and put the phone back on the table. The lamp can be turned off after finishing the game.

A minimum viable prototype of Lamb Lamp has been built and deployed to family participants recruited through a local NGO. Initial findings from 6 families have been published elsewhere [16]. This section focuses on the interpretive analyses of the intervention and underexplored design directions informed by the matrix.

Spatiality-Automatic: Lamb Lamp is deployed in families who live in apartments. It is supposed to be put in the common area (e.g., sitting room), where family members gather to have family activities, for example, watching television together, playing games together, or having refreshing drinks together.

Physicality-Automatic: The tabletop has three (determined by family members) inductive charging positions with signs. The lamp displays an animated emoticon of worrying when there are no phones. A family member back home perceives the inductive charging signs and casually rests the smartphone on one empty position. The lamp brightens up a little and starts to smile. This animated cue breaks the routine of browsing the phone in the sitting room.

Structure-Automatic: The number of charging positions is determined by the number of participating family members. Users cannot put more phones for charging. Meanwhile, the lamp has no switch; users can only switch it on by putting phones on the side table.

Structure-Conscious: The side table facilitates users' typical habitual action of casually resting a mobile device for inductive charging. When all family members have their phones in place, the lamp fully brightens up with a random number. The number reminds family members of physical activities other than using phones. Conversely, the light cast on the phone hinders looking at the phone screen even when notification messages pop up.

Physicality-Conscious: To check notifications, one has to pick up the phone, which immediately turns off the lamp. This animated cue embarrasses the member and makes one rethink the choice between family togetherness and personal matter.

Representation-Conscious: The user actions of putting down or picking up the phones co-occur with the light brightening or diming. One may perceive this as a lighting control. The animated emoticon adds implications of the acts to the representation. If all family members put down the phones, there will be happiness.

Spatiality-Conscious: Every member's actions in the sitting room are definitely visible to any other members. In fact, one can rest the phone to light up the lamp as a gesture to invite others to follow. When two or more members rest their phones and play physical games, remaining members can see and learn to join.

Reflections on Lamb Lamp

Lamb Lamp is small-sized home furniture. The varied home settings make the environmental cues less predictable. Fortunately, the inductive smartphone charger has become known in urban societies and its signs can trigger the automatic user action. To prevent the lamp from becoming unnoticed, just like common home furniture, animated emoticons are used as cues to remind family members. The cartoon style is applicable to families.

Lamb Lamp first invites family members to put down the phone and then discourages them from picking it up. The way it applies at the automatic level is to cast light on the phone screen to make it visually distracted. It is an idea after embodied constraints are considered. Picking up a phone results in a disruptive change in lighting. This works effectively for multiple users in a communal space like home.

The relation between number of phones rested and light brightness is now perceptually formed but the link is still not strong. To further strengthen the visibility, new ideas include adding color index. Each phone can be given a particular colored case, which gives respective colored light onto the lamp. With all phones together, all colored lights mix to form a white light, which represents balance.

5 Discussion

The proposed matrix shows potential connections from aspects of tangible and embodied interaction to strategies of intervention. Through scrutinizing a design according to the guidelines, one can acquire a comprehensive view (from physicality to spatiality, from structural to representational) of the user experiences across multiple levels of cognitive responses. This analytical lens examines existing connections and reveals underexplored links for consideration.

The two design cases have different application contexts (public space vs. home environment), different purposes of intervention (for sustainable consumption vs. for family wellness), and slightly different strategies of intervention (via providing information vs. via diverting). They have commonalities in design approaches, both of which combine concepts of artifacts matching the contexts (e.g., bar table, side table, charger, etc.) with others from another domains (e.g., compass, radar, incremental switch, etc.). These approaches of conceptual blending allow the designed artifacts to blend in the related environments, which function at the automatic level of thinking in users. Meanwhile, the artifacts also stand out from the environments in terms of appearance and animation, which stimulate users at the conscious level of thinking. From the analyses, both artifacts feature animated cues for user actions (e.g., turning the tabletop, resting the phone). They provide immediate sensory feedback that couples user actions with animations in preparation for the technology-mediated causal relationship (e.g., directions and items, rested phones and lights). Their physical or electromechanical structures naturally show different outcomes of different actions (e.g., turning across boundaries results in alternatives, missing one phone disrupts the atmosphere). The digital displays also play important roles. The visualization renders the physical and the digital seemingly co-existing and co-occurring (e.g., digital items "under" a side of the table, lights coming from the phones). Some aspects that can be further explored include more visible, materialized links between behavioral acts and consequences or alternatives (e.g., the direction to a water dispenser can be more obvious; the changes in lighting can be traced back to the phones more easily). The following summarizes some insights from the two case studies.

- Blend-in and light-up: The designed artifact should blend in the environment meanwhile being animated to break routines and prompt alternatives. Conceptual blending can be applied in the design.
- Nuances in embodied experiences: Cues, feedback, affordances, and representations all involve sensorimotor experiences resembling some habits or practices. But the nuances actually stimulate conscious thinking.
- Rendering contingent outcomes: Different behavioral acts should be perceptually and/or materially linked to their consequences. This lets users experience, compare, and decide.

6 Conclusion

Research and insights from social psychology inform that human behavior is a combined result of interrelated factors, including belief (i.e., attitude), intention, environment, perception, and habituation, across both automatic and conscious levels of cognitive activities. These cognitive activities are influenced by and also affect our physical and bodily experiences in everyday life. This paper argues and demonstrates how animation, as a kind of imaginative and affective sensorimotor experience, can be used to first break habitual routines and second shift focus onto alternative acts. Overall, behavioral intervention is a challenging topic. The proposed matrix and guidelines support design and analysis, yet it needs to be coordinated with other methods such as experience prototyping, laboratory testing, and field trials, like what have been conducted in the presented design cases.

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