Disability and Rehabilitation: Assistive Technology

ISSN: 1748-3107 (Print) 1748-3115 (Online) Journal homepage: https://www.tandfonline.com/loi/iidt20

Envisioning future cognitive telerehabilitation technologies: a co-design process with clinicians

Tuck-Voon How, Amy S. Hwang, Robin E. A. Green & Alex Mihailidis

DISABILITY AND REHABILITATION: ASSISTIVE TECHNOLOGY, 2017
VOL. 12, NO. 3, 244–261
http://dx.doi.org/10.3109/17483107.2015.1129457

RESEARCH PAPER

Envisioning future cognitive telerehabilitation technologies: a co-design process with clinicians

Tuck-Voon How[a], Amy S. Hwang[a], Robin E. A. Green[b,c] and Alex Mihailidis[a,b]

[a]Intelligent Assistive Technology & Systems Lab (IATSL), University of Toronto, Toronto, Canada; [b]Toronto Rehabilitation Institute – University Health Network, Toronto, Canada; [c]Department of Psychiatry, University of Toronto, Toronto, Canada

ABSTRACT

Purpose Cognitive telerehabilitation is the concept of delivering cognitive assessment, feedback, or therapeutic intervention at a distance through technology. With the increase of mobile devices, wearable sensors, and novel human–computer interfaces, new possibilities are emerging to expand the cognitive telerehabilitation paradigm. This research aims to: (1) explore design opportunities and considerations when applying emergent pervasive computing technologies to cognitive telerehabilitation and (2) develop a generative co-design process for use with rehabilitation clinicians. **Methods** We conducted a custom co-design process that used design cards, probes, and design sessions with traumatic brain injury (TBI) clinicians. All field notes and transcripts were analyzed qualitatively. **Results** Potential opportunities for TBI cognitive telerehabilitation exist in the areas of communication competency, executive functioning, emotional regulation, energy management, assessment, and skill training. Designers of TBI cognitive telerehabilitation technologies should consider how technologies are adapted to a patient's physical/cognitive/emotional state, their changing rehabilitation trajectory, and their surrounding life context (e.g. social considerations). Clinicians were receptive to our co-design approach. **Conclusion** Pervasive computing offers new opportunities for life-situated cognitive telerehabilitation. Convivial design methods, such as this co-design process, are a helpful way to explore new design opportunities and an important space for further methodological development.

ARTICLE HISTORY
Received 24 July 2015
Revised 13 November 2015
Accepted 4 December 2015
Published online
30 December 2015

KEYWORDS
Co-design; cognitive rehabilitation; design methods; pervasive computing; pervasive health; telerehabilitation; traumatic brain injury

➤ IMPLICATIONS FOR REHABILITATION

- Designers of rehabilitation technologies should consider how to extend current design methods in order to facilitate the creative contribution of rehabilitation stakeholders. This co-design approach enables a fuller participation from rehabilitation clinicians at the front-end of design.
- Pervasive computing has the potential to: extend the duration and intensity of cognitive telerehabilitation training (including the delivery of 'booster' sessions or maintenance therapies); provide assessment and treatment in the context of a traumatic brain injury (TBI) patient's everyday life (thereby enhancing generalization); and permit time-sensitive interventions.
- Long-term use of pervasive computing for TBI cognitive telerehabilitation should take into account a patient's changing recovery trajectory, their meaningful goals, and their journey from loss to redefinition.

Introduction

Technology is increasingly becoming a part of our everyday lives and activities. Today, we see a proliferation of mobile devices, wearable sensors, and novel human–computer interfaces all embedded in the world around us.[1] This trend is often described as a rise in *pervasive computing*, and it is believed to open new doors for health care and rehabilitation. More formally, pervasive computing refers to devices that are seamlessly integrated into our physical lives, and that interweave our physical and virtual worlds together.[2] Under this definition, there is an evolving list of applicable technologies; recent examples include: smartphones, wearable sensors, and augmented reality.

Pervasive computing in health care is thought to usher in a new era of patient-centric technologies,

CONTACT Tuck-Voon How tuckvoon.how@mail.utoronto.ca Intelligent Assistive Technology & Systems Lab (IATSL), University of Toronto, 160-500 University Ave., Toronto, ON, M5G 1V7, Canada

reliable monitoring systems, and improved health management.[3] However, these possibilities are not without their unknowns. Bardram has described how an entire research field of *pervasive health care* has emerged to investigate and debate the role that these technologies have within our health-care system.[4] He has also stated that there should be further exploration into how pervasive computing could aid collaboration between home-based patients and hospitals.

Of interest to us is how pervasive computing can be applied to *cognitive telerehabilitation* – which refers to the use of technology to conduct cognitive assessment, feedback, and therapeutic intervention for patients with neurological disorders who are outside of the hospital/clinic.[5] With the shift toward a pervasive computing society, there is added potential for all these aspects of rehabilitation to be done within the context of real-world situations, thereby enhancing 'ecological validity', a known factor for rehabilitation success. Additionally, richer modalities of human–computer interaction (HCI) are thought to expand the repertoire of remote assessment and treatment tools.[6] Yet, although these possibilities exist, the actual embodiment of pervasive computing into cognitive telerehabilitation remains an area to be explored.

The aims of this research are to both: (1) explore the intersection between pervasive computing and cognitive telerehabilitation (in terms of designs for therapy and assessment) and (2) develop a design approach that aids health care and technology disciplines in this joint exploration. In this paper, we begin by describing the context of our patient population and the current state of cognitive telerehabilitation technologies for these patients. We then outline the motivation and methods for our co-design approach. Finally, we present our findings on design opportunities and design considerations (i.e. important insights when creating technologies) for new cognitive telerehabilitation technologies and end with a critique of our co-design approach. This study adds to literature by expanding the role that rehabilitation clinicians can take in the design of new rehabilitation technologies and by adding to our understanding of how current pervasive computing technologies could be used for cognitive telerehabilitation.

Background

Although multiple patient populations can benefit from cognitive telerehabilitation, the scope of this research focuses on the moderate–severe traumatic brain injury (TBI) population. TBI is caused by the exertion of forces to the brain from blunt and/or penetrating trauma to the head; these can result in both local injuries and diffuse damage across the brain. Due to the diversity of injury mechanisms and consequences, moderate–severe TBI (in contrast to concussion or mild TBI) is seen as a complex heterogeneous disorder, where each patient has a differing constellation of impairments. TBI can have a deleterious and persisting impact on: the basic sensory/motor and perceptual functions; a range of cognitive functions (including memory, language, attention, visuospatial, and executive functions); mood and emotional regulation; and personality.[7] All of these interact with premorbid personality and socioeconomic factors. Long-term consequences of TBI may include the inability to return to work or school, reduced leisure activities, difficulty in completing activities of daily living, depression or other mental health disorders, and social isolation.[8]

A typical recovery from TBI will start with stabilization of the patient in an acute care hospital. Following this, the patient may be transferred to an inpatient rehabilitation facility or immediately released home with outpatient rehabilitation support. The goal of rehabilitation – both in- and out-patient – is to improve a patient's functional performance after injury through therapy that either remediates (i.e. restores) or compensates for a patient's impairments and ultimately promotes community integration. The rehabilitation team for moderate–severe TBI patients may include physiotherapists, occupational therapists, speech-language pathologists, social workers, rehabilitation therapists, and neuropsychologists.

One area of need, and a compelling motivation for telerehabilitation, is the lack of rehabilitation services outside of the hospital. This service gap is caused by a number of factors including lack of insurance coverage, lack of proximity or access to care centers, and insufficient clinical resources.[9] In some cases, patients may be sent home from acute care without any outpatient rehabilitation. For those who do receive rehabilitation services, these services are finite in duration, and for many patients may last on the order of weeks. The short duration of care is of consequence, in part, because the first year post-injury is considered the time when patients will benefit most from rehabilitation. Likewise, moderate–severe TBI is increasingly seen as a chronic disease process,[10] and a progressive one,[11] where ongoing rehabilitation is needed to prevent the increasing disability. Without sustained rehabilitation services, patients may not achieve their optimal level of functional performance or they may experience further cognitive decline years after injury.[12]

Overview of TBI cognitive telerehabilitation

Telerehabilitation is one way to extend outpatient therapy and increase the access to rehabilitation services.[5] Over the last 20 years, there has been varied work on cognitive telerehabilitation technologies for the TBI population. Although the literature expands into domains such as professional training, this overview will focus on the research interest of cognitive therapy and assessment.

Typically, the way that technology has been used for TBI cognitive telerehabilitation has varied by discipline. In medical-/rehabilitation-oriented disciplines, most work on TBI cognitive telerehabilitation has used technology as a *means of communication* either to deliver therapy or to assess the patient. Some examples include using a telephone to provide psychiatric nurse support to a TBI patient's home,[13] or using internet instant messaging to deliver calendar training for memory impairments.[14] Collaboration with technology-oriented disciplines has produced research on *customizing technology* to meet rehabilitation goals. For example, Tost et al. has explored training functional tasks in virtual environments at home,[15] and Cole has pioneered work in creating custom software or 'cognitive prosthetics' that adapt the user's computer interface to help a TBI client use computing devices more easily.[16] Additionally, there has been work in creating individualized treatment programs, with remote therapist oversight, through the use of customizable training software that can provide a variety of functional challenges, as reported by Tam et al.,[17] and more recently the Guttmann Neuropersonal Trainer.[18] Rehabilitation goals supported by custom technologies have varied from a restorative approach (i.e. to regain lost function) to a more compensatory approach (i.e. using technology as a way to augment/aid for lost function) as reviewed by Gillespie et al.'s overview of assistive technologies for cognition.[19]

Generally, there have been positive outcomes with a TBI cognitive telerehabilitation approach. Comparative studies have shown that clinical efficacies of certain telerehabilitation systems can be similar to face-to-face alternatives, which support their ability to increase the access to rehabilitation services. For example, improved mood, coping skills, and community integration were observed in a teletherapy study delivering cognitive behavior therapy to depressed/emotionally distressed brain-injured patients in the chronic stages of injury over the telephone, and the benefits were as strong as a face-to-face approach within the same study.[20,21] Schoenberg et al. also compared computer-based teletherapy against in-person speech language rehabilitation and both programs provided similar functional outcomes (i.e. independent living, return to work/school, and independent driving) for adults with severe TBI.[22] Likewise, Salazar et al. found similar overall benefits for cognition, behavior, and quality-of-life measures when comparing a standard hospital cognitive rehabilitation program to a new telephone support program for adults with moderate-to-severe TBI.[13] Custom technologies have also shown their usefulness. For example, the Guttmann Neuropersonal Trainer has shown high usability for its software with clinicians and patients and a significant cost savings when compared to face-to-face treatment.[18]

When interpreting these outcomes, it is important to note that the clinical efficacies of telerehabilitation systems are dependent on both the *content of the rehabilitation assessment/intervention* administered and the *technology modality* that is used. With this in mind, it should not be surprising to find variations in literature between the uses of the same technology modality when applied to different rehabilitation techniques. For example, Schopp et al. found that rural residents with brain injury were more satisfied to repeat the experience of videoconferencing psychotherapy assessment than those who had the assessment done in person.[23] In contrast, Man et al. found that patients who underwent self-efficacy training in a face-to-face study had shown greater improvements than patients administered the same intervention through videoconferencing.[24] This underscores the importance of exploring how different rehabilitation assessments/therapies could work with various technologies.

This brief overview of TBI cognitive telerehabilitation raises two important points: (1) there are a *broad* range of cognitive rehabilitation techniques to which technology could be applied and (2) there is a continued need to *re-envision* how technology can apply to these areas as the sophistication of technology progresses. Both Gillespie et al.[19] and Cole [16] have commented separately on the second point, stating that there are new opportunities to support cognitive rehabilitation with recent advances in mobile technologies (e.g. smartphones, augmented reality, eye-tracking, etc.).

Designing telerehabilitation technologies: opportunities and challenges

The continued drive to *re-envision* how new technologies can be applied to support *broad health-care areas* is an important space for further methodological development, as there is a growing need for front-end design methods that support early exploration.[25] In comparison to the traditional 'problem-driven' design approaches used by many health-care technology engineers,[26] a re-envisioning process is similar to the 'technology-inspired' approach suggested by Rogers et al.[27] In this regard, the capabilities of new technologies serve as an *inspiration to creatively explore* new conceptual designs. Although there is merit in the focused nature of a 'problem-driven' approach, there is also merit in the opportunistic nature of a 'technology-inspired' approach. In the latter case, we can broadly envision new health-care technologies that may be overlooked when only considering problem areas in health care. As Pullin has stated, 'not all design is about solving problems', some ideas may need to be faced with open-ended and even playful exploration.[26]

There are, however, important challenges to consider when envisioning new telerehabilitation technologies, especially when these technologies have the potential to alter rehabilitation paradigms in ways that were not previously possible. This is often the case when applying pervasive computing to health care; as Linden et al. expresses, pervasive computing enables 'the development of very new experiences that are not readily comparable to health scenarios that patients or designers are familiar with.'[28] Rogers et al. have also commented on the difficulties of exploring untried novel experiences, stating that technology designers have to grapple with concepts of intangibility, and that they should be willing to creatively experiment on ideas.[27]

Yet, for telerehabilitation applications, this creative experimentation has added constraints. Without proper grounding in both technical and clinical knowledge, new conceptual designs could far exceed the capabilities of emergent technologies or they could fail to use the clinical principles that are necessary for effective rehabilitation. As such, it is important that both technical and clinical disciplines be represented when first envisioning new telerehabilitation technologies. One way to ensure this is through the process of co-design.

Co-design for opportunistic exploration

As described by Sanders et al.,[29] co-design is the act of facilitating joint creativity between technology designers and key stakeholders of the technology. It is particularly well suited for early front-end design or predesign, when ideas are first being conceptualized. Co-design makes use of *scaffolds* [30,31] to facilitate collaboration and to help designers empathize with stakeholder considerations or to help stakeholders participate more actively in the ideation process. Scaffolds take the form of carefully designed materials, structures, or activities. At its core, co-design creates new 'design spaces' where co-designers can collectively explore new technology ideas.

Sanders believes that the use of co-design creates new 'domains of collective creativity', which in turn requires new sets of tools and methods to promote collaboration in these domains.[32] In line with this idea, this research seeks to add to the literature of co-design, by customizing a design process that can facilitate a *broad 'technology-inspired' exploration* between technology designers and rehabilitation clinicians.

Although full cognitive telerehabilitation systems involve rehabilitation clinicians and TBI patients (possibly also informal caregivers), we situate this co-design process as a front-end means to broadly explore new *rehabilitation ideas* and to *sensitize* us to important design considerations, rather than a means to finalize patient health-care experiences. The creation of quality health-care experiences for the patient (and other stakeholders) will evolve out of this initial stage of design and will require future patient participation. As such, it is the clinical voice that we focus on in this co-design process. Rehabilitation clinicians have the foundational knowledge needed to formulate new cognitive therapies or assessments, as enabled by emergent technologies.

Surprisingly, the value of the clinical voice is still a contended perspective in the design of health technologies. There is debate within literature as to what clinicians can contribute in the design of these systems, especially when they themselves are not the primary users of such technologies. Some have argued that clinicians offer a disjointed perspective from the everyday lives of patients,[33] whereas others contend that clinicians have a unique insight to a patient's needs, family situations, and are empathetic advocates for their patients.[34] This tension is likely driven by a generalization of clinical work that does not reflect the unique roles or expertise offered from specific clinical disciplines. Our work explores how rehabilitation clinicians (specifically working with TBI outpatients) can be involved in a co-design process and what their *perspective* and *access* brings.

Moreover, our work delineates from previous design approaches that involve rehabilitation clinicians by seeking to expand their *role* in the design process and by leveraging their *unique access* to outpatient environments. Typical involvement of rehabilitation clinicians in design has been done through focus groups, feedback interviews, or as facilitators for patient–designer interaction – outcomes of these practices have ranged from understanding issues with a patient population (e.g. [34,35]) to generating requirements of new rehabilitation technologies (e.g. [34–39]) and gathering clinical feedback on conceptual prototypes (e.g. [34,35,37,38]). Although these works have been fruitful in creating new rehabilitation technologies, they nevertheless constrain the degree of creativity and exploration that domain experts (i.e. rehabilitation clinicians) have in the design process. A promising shift toward more participatory clinician engagement, however, is evidenced by recent work with DIY (do-it-yourself) toolkits that sought to empower rehabilitation clinicians with the ability to explore and make their own occupational therapy ideas based on soft-object technology.[40] Our work further extends this approach to enable creative idea generation that is inspired by not just one technology but also multiple emerging technologies. In this way, we seek to *broadly re-envision* new possibilities for cognitive telerehabilitation. The motivation for our approach stems from Illich's idea of *convivial tools*: 'which give each person who uses them the greatest opportunity to enrich the environment with the fruits of his or her vision.'[41] Sanders has built upon this concept, describing how the field of design can benefit from convivial tools that enable people to creatively explore and make their own desired future.[42] Essentially, we seek to create a convivial co-design process that *enables clinicians to create new possibilities for rehabilitation* as they work with outpatients.

Research goals

This research has two contribution goals: (1) to explore design opportunities and design considerations when applying emergent pervasive computing technologies to TBI cognitive telerehabilitation and (2) to expand the toolset of co-design as applied to rehabilitation – by creating a generative approach that aids rehabilitation clinicians and technology researchers conceptualize new technologies in *broad rehabilitation areas*.

Methods

In the following sections, we outline the specifics of our co-design process. By understanding the rationale of why we made design decisions, we hope that future researchers can adapt or build upon this process for their own goals.

Configuring the co-design space

At the broadest level, our co-design space involves the intersection of two domains: technology and health care (Figure 1). The 'Technology Domain' comprises of selected emergent technologies that could *inspire* new design ideas, and the 'Health-care Domain' comprises of health areas that are of interest for developing new technological applications. In our project, the 'Technology Domain' is a subset of emergent pervasive computing technologies (described in 'Co-Design Scaffolds' later) and the 'Health-care Domain' focuses on cognitive rehabilitation for TBI patients outside of the hospital (i.e. TBI cognitive telerehabilitation).

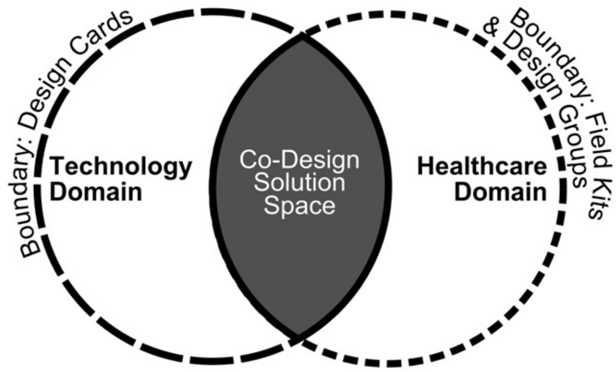

Figure 1. Our co-design space is the intersection between a 'Technology Domain' and a 'Health-care Domain' of interest. The primary outcome of this co-design process is to generate design ideas within this intersection. Certain tools in the co-design process act as mediators to control the boundary (i.e. what is included/excluded) in each domain.

The intersection between these two domains creates a solution space for our co-design process. By controlling the boundaries of each domain (i.e. what is included/excluded in each domain), we can in turn fine-tune the scope of our solution space (i.e. what design ideas we consider or exclude). In our co-design process, we use co-design scaffolds (in addition to their role of promoting collaboration) to shape what is included in these boundaries. It is noted that these boundaries are adaptable and are not concretely set. As solution ideas are generated, new interests may cause the boundaries to adapt accordingly.

Selecting co-design participants

Rehabilitation clinicians were selected to be co-design participants based on their expert knowledge in cognitive rehabilitation. Additionally, we follow Allen's et al. approach of domain experts, where a clinician's knowledge can act as proxy to the TBI patient perspective because of their intimate experience with a patient's needs.[43] Domain expert's representation is helpful due to the diversity of TBI patient impairments – one clinician can represent a multitude of patients, which is beneficial for predesign conceptualization and is often missing in patient-driven participatory design.[44] In this regard, clinician co-designers offer both their professional perspective and an initial representation of TBI patients.

Inclusion criteria for clinical co-designers were as follows: 19 years or older, at least 5 years of clinical experience in rehabilitating TBI outpatients (including community experience or visits to patient homes), and specializes in an occupation that performs cognitive rehabilitation (either treatment or assessment) on the brain-injured population. A total of eight clinicians were recruited following approval from research ethics. Clinicians had a variety of occupations including: occupational therapy, speech language pathology, psychometry, behavioral therapy, and clinical neuropsychology. The age range of participants was between 29 and 60 years old ($\bar{x} = 44.0$ years, $s = 8.4$ years). Clinical experience with TBI outpatients ranged from 5 to 19 years ($\bar{x} = 11.9$ years, $s = 4.9$ years). One clinician was also a TBI survivor.

Co-design scaffolds

Three scaffolds were customized for our co-design process: (1) *design cards*, (2) *field kits*, and (3) *design groups*. The *design cards* were used to shape the boundary of the 'Technology Domain', and the *field kits* and *design groups* helped shape the boundary of the 'Health-care Domain' (Figure 1).

Design cards

Cards have been used for a variety of purposes throughout HCI design research, including: conveying the capabilities of technologies,[45] evoking thoughts on long-term/systemic effects of technologies,[46] and engaging different experiences as they relate to technologies.[47] The value of design cards are that they bring to focus the idea on the card for participants, enable persistency of ideas throughout the design process, and allow creative exploration by combining card ideas.[46]

Similar to Halskov's Technology cards [45], we used design cards to convey the capabilities of technologies (see Figures 2, 3 × 5″ cards). In total, 15 design cards were created that introduced/elicited aspects of pervasive computing. The process of creating the design cards involved first surveying literature and media to determine emergent pervasive computing technologies (e.g. [48,49]) and then selecting a broad spectrum of technology concepts to include in our 'Technology Domain'. Whether a technology concept was included as a design card was at the discretion of the research team. The process of deciding which technologies to include in the 'Technology Domain' is similar to Buxton's idea of 'curating experiences.'[50] In essence, the research team is bringing together a number of technology experiences/capabilities that are of interest to be probed for relevancy in the 'Health-care Domain'. Rehabilitation clinicians who participated in this co-design process help with this probing (as explained in 'Field Kit' and 'Design Groups' sections later). It is important to note that *we do not assume* that any of the technology concepts have relevancy in the 'Health-care Domain' – it is through the co-design process that we discover this. It is therefore important to welcome both positive *and* negative reactions to the technology concepts, which demonstrates a 'technology-inspired' – rather than 'technology-led'– approach and avoids imposing certain technologies on final solutions.[27] It is also important to note that the design cards were not presented as final ideas, but as malleable entities that could be explored and built upon in the co-design process.

Each design card belonged to one of three categories. These categories used simple descriptions to help co-designers organize the design cards and recall them during the design process:

- Sensing Everyday Life (six cards) – *'New technologies give us an increased ability to observe an individual's activity and physiology as they go about their day'*. Cards included: wearable cameras, wearable EEGs (electroencephalograms), gaze tracking, physiological bands, motion activity, and self reporting (via a mobile device).
- Interacting with Technology (six cards) – *'Our interaction with technology is becoming more intuitive and similar to how we interact with objects in the physical world'*. Cards included: gesture interfaces, tangible interfaces, augmented reality, speech & audio, ambient & portable displays, and haptics.
- Decisions for Use (three cards) – *'These cards help us to consider important aspects of health technologies'*. Cards included: how to support care relationships (with technology), how to make use of data, and how to make use of contextual information.

On each card, there was a title, description of the concept, examples of how it could apply to health care, a colour code to distinguish the category of the card, and two pictures to showcase the concept. All card concepts were first introduced to participants before their use (see 'Study Timeline' below). The design cards could be probed singularly or combined together as building blocks for new conceptual ideas.

Field kits

Complementary to the design cards, field kit notebooks (Figure 3) were created so that clinician co-designers could take technology concepts *into* their work environments. These field kits are a form of design probes. Mattelmäki has summarized how design probes have been used in HCI research to facilitate collaborative insights, stating that they can promote *inspiration* for

Figure 2. Sample design cards – each card included pictures and descriptive text to help co-designers recall and explore the technology concept on the card.

solutions, convey *information* about users, increase *participation* of stakeholders in the design process, and facilitate *dialogue* between technology designers and stakeholders.[51] Our field kits were constructed with similar purposes: (1) to prolong the time spent thinking about how the technology concepts (i.e. design cards) could apply to a clinician's rehabilitation with patients (*in situ* exploration), (2) to further sensitize clinicians to their work and patients, (3) to engage the clinicians as active co-designers in the design process, and (4) to act as a point of dialogue between technology and clinicians co-designers.

To these ends, the constructed field kits introduced a three-step thought process that clinicians could follow: (1) *Observe* – 'By reflecting on your current practice, can you identify areas of need, opportunities, or considerations for new technologies?'; (2) *Envision* – 'If you consider the capabilities for new technologies (i.e. the design cards), can you think about how they might be used to improve outpatient cognitive rehabilitation? How can technologies either fill a gap that is currently lacking in practice, or altogether enhance the rehabilitation process?'; and (3) *Review* – 'Critiquing our ideas is always an important part of the design process. Can you reflect on your ideas, improve/build upon them, or inspire new ones?'

Clinicians were encouraged to reflect on these steps as they progressed through their day and to write down their thoughts as they occurred. For each step, there were additional sub-questions and examples to help with the thought process. Since the field kits probed a specific clinical role (i.e. outpatient cognitive rehabilitation) with the TBI patient population, they helped define the boundary of our 'Health-care Domain' (Figure 1).

Design groups

The final co-design scaffold was 'design groups', which each comprised of one-to-two technology researchers and two-to-three clinicians. Every group met two times over the course of our co-design process. The purpose of these meetings was to facilitate learning of the design cards, use of the field kit, and also to provide a forum for discussion around new conceptual ideas. During discussions, the technology researchers would use open-ended questions to facilitate the exploration of conceptual ideas. The focus of these questions also helped to define the boundary of the 'Health-care Domain', as they

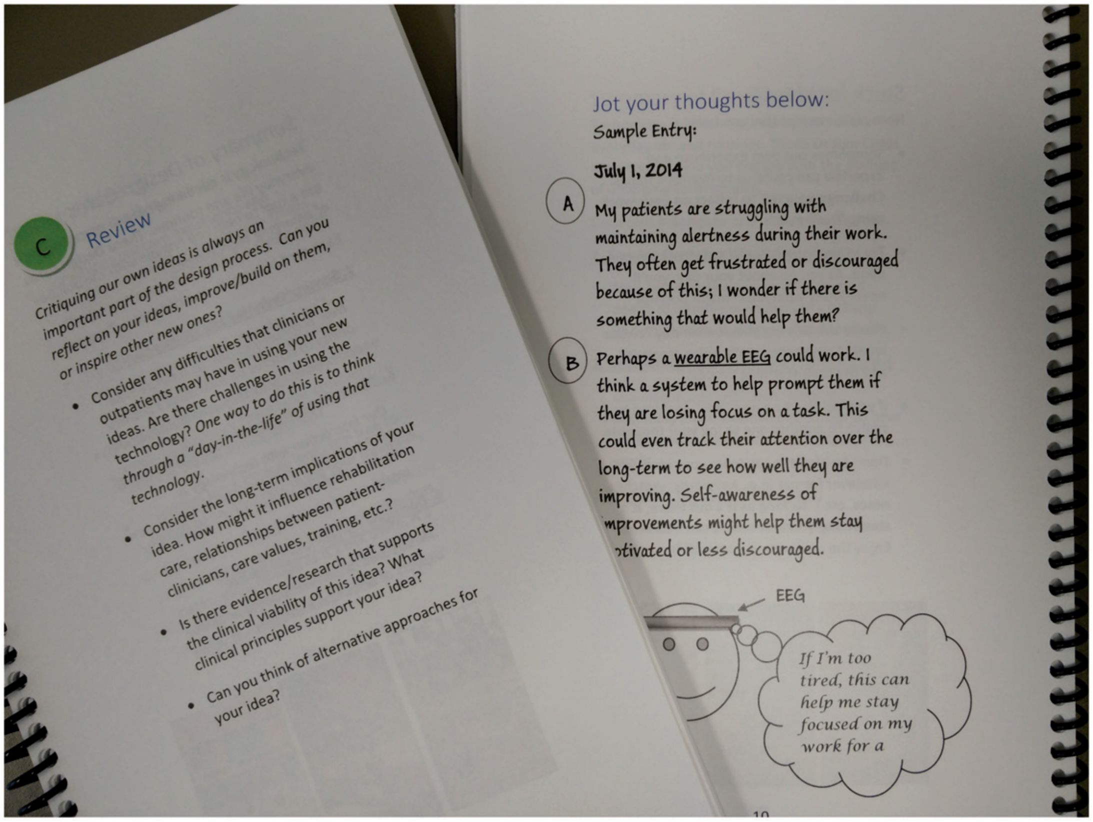

Figure 3. The field kit included explanatory steps and questions that clinicians could think about as they worked throughout their day. Clinicians were encouraged to jot down their thoughts in the field kit.

would direct discussions to applications of interest. The small size of the design groups was chosen to ensure each co-designer's participation and to accommodate scheduling practicalities with clinical work hours.

Study timeline

All clinicians were randomly assigned to one of three design groups. Sequentially, our co-design process followed three steps (Figure 4): (1) *Initial Design Group Meeting* (1.5 h) – co-designers were introduced to each other and then clinicians were taught to use the design cards and field kits. For each design card, videos were run to showcase the capabilities of the pervasive computing technology. As well, negative considerations for each technology were presented, which is believed to elicit a broader range of comments as oppose to just an optimistic representation of technology [52]; for example, 'wearable cameras' have issues related to privacy and maintenance of the device. The field kit's steps were taught through practice design exercises; (2) *Week-Long Field Kit* – each clinician was given additional time to think about how pervasive computing concepts (i.e. design cards) applied to their rehabilitation work and patients. They took with them a set of design cards and the field kit notebook to jot ideas in their workplace; (3) *Second Design Group Meeting* (1.5 h) – co-designers convened again to discuss their overall experience with the field kit and to collaborate together to explore possible cognitive telerehabilitation systems. Each clinician shared their generated conceptual ideas and then all co-designers critiqued these ideas for refinement. All design groups met separately and made use of visual aids (e.g. post-it notes and drawings) to track the progress of their discussion.

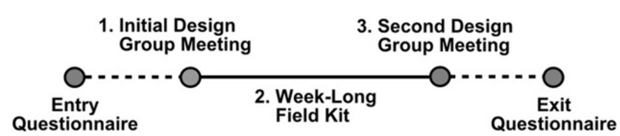

Figure 4. Study timeline: steps one to three occurred over a one-week period. The entry and exit questionnaires occurred within a one month timeframe of this period.

In addition to the design groups, all clinicians completed a custom entry and exit questionnaire. These questionnaires gauged the clinicians' familiarity to technology before the study, their thoughts on the

Table 1. The percentage of conceptual ideas to contain a given ICF code (note: one idea can apply to a number of codes).

ICF Body (b), Activity/Participation (d) Code	No. of ideas with code
d230 – Carrying out a routine	47% (14)
b144 – Memory functions	33% (10)
b164 – High-level cognitive functions	30% (9)
b140 – Attention functions	26% (8)
b130 – Energy & drive functions	23% (7)
d720 – Complex interpersonal interactions	23% (7)
b152 – Emotional functions	13% (4)
d845 – Acquiring & keeping a job	10% (3)
d760 – Family relationships	10% (3)
b114 – Orientation functions	7% (2)
d450 – Walking	3% (1)
b160 – Thought functions	3% (1)
b210 – Seeing functions	3% (1)
b760 – Control of voluntary movement	3% (1)

co-design process after the study, and were used to member check analyzed data to ensure that it accurately conveyed their clinical perspectives. Questions were issued in a Likert or open-ended format.

Data collection and analysis

All design group sessions were audio/video recorded. After the completion of the design groups, the data from entry questionnaires, field kits, and design group discussions were transcribed to text by the first author. Analysis was done using a generic inductive qualitative analysis approach as defined by Thomas.[53] Text was coded in relation to the research goals at the sentence/paragraph level to determine common themes/categories. Groupings of *design opportunities* and themes for *design considerations* were finalized by the first and second authors, and then presented back to the clinicians for member checking agreement. Feedback on the co-design process was coded and analyzed separately by the first author.

To help prioritize design opportunities, each conceptual idea from the design groups was labeled with the International Classification of Functioning, Disability and Health (ICF) Core Set for TBI.[54] The ICF is a widely-used framework that describes an individual's disability and functioning. It does this by classifying an individual's functional limitations via: *body* functions and structure, core *activities* of life, and *participation* in the world. To streamline the many ICF classification codes, ICF Core Sets were made for specific diseases. These Core Sets provide a common set of codes that health professionals can make use to evaluate the most pertinent aspects of functioning that are affected by a given disease. By linking conceptual ideas with the ICF Core Set for TBI, opportunity areas can be informed by functionally relevant aspects of a TBI patients' life.

Findings

Design opportunities

In total, the three design groups yielded 34 conceptual ideas for TBI cognitive telerehabilitation; this was further reduced to 30 ideas by removing repeated ideas. After labeling conceptual ideas with ICF codes, the most frequent ICF codes (Table 1) were compared with commonalities in the 30 conceptual ideas to create 6 opportunity areas for pervasive computing technologies.

Each opportunity area was then rated by clinicians in the exit questionnaire with a Likert score to determine the approximate proportion of TBI patients with that issue (1 – none at all and 5 – all/almost all). Later, we present each opportunity area, their average Likert rating, their associated ICF codes, and an example idea that design groups proposed (note that these are not final ideas, but bridging-off points for further exploration and design):

Executive function difficulties

(Rating: 4.4; ICF Codes; b164, d230, b144, and b140) – Many TBI outpatients have executive function impairments such as distractibility, decreased concentration, and poor planning. This can interfere with their planning and execution of tasks during the day. Meta-cognitive interventions are internal strategies that help a patient cope with these issues (e.g. 'Goal-plan-do-check' [55]). Pervasive computing technologies could facilitate learning and application of these meta-cognitive interventions in real-world situations. *Technology Example*: 'Meta-Cognitive Aid' – The client could use a smartwatch that has visual, haptic, or audio cues to remind them of their meta-cognitive strategies throughout the day. Contextual information such as time, location, surrounding noise, could be taken into account when prompting the client: 'you're leaving the house, take a moment, and think about what you have to remember'. The use of a smartwatch would be aimed at promoting generalization of meta-cognitive strategies and could also be used to provide 'booster' training on such strategies.

Emotional regulation and relaxation

(Rating: 4.0; ICF Codes: b152, d720, d845, and d760) – TBI outpatients may have difficulties with impulsivity, frustration, and emotional regulation. Outbursts of anger can negatively impact interpersonal relationships, which may lead to further social isolation or difficulty re-integrating into life roles. *Technology Example*: 'Emotional Management/Relaxation Aid' – The goal of this technology would be to provide a 'just-in-time' intervention to help a client regulate his/her emotions. A wearable physiological band/smartwatch could be used to monitor the client's physiological parameters (e.g. heart rate, body temperature, and electrodermal activity). These parameters are related to arousal states or agitation. When anger is detected, the watch could cue (via visual/haptics) the client to perform relaxation strategies such as mindfulness or regulated breathing in order to calm down. After the situation has subsided, the watch could ask the client for information about the antecedents/triggers of the situation to help the client build emotional self-awareness. Alternatively, if the relaxation cues are ignored, the watch can later prompt customized damage-limiting strategies: 'Were you at work? Send an email to your colleague to apologize'.

Assessing daily life performance

(Rating: 4.5; ICF Codes: d230, b144, b164, b140, and d845) – There is a gap in understanding how TBI outpatients perform in their daily life and environments. A better understanding of a patient's functional performance can inform therapy and better tailor therapy to a patient's functional needs. *Technology Example*: 'Wearable Cameras for In-situ Assessments' – The goal of this technology would be to help the client record their functional performance in everyday environments. A small wearable camera could be used to record video/audio from the client's point of view (note that this recording is done in a hands-free manner). Due to privacy concerns, the client could opt-in to when they want to be recorded. One potential use case is for clients to be given a functional challenge task by rehabilitation clinicians. For example, 'the challenge today is cooking eggs'. After the task is complete, the video could be reviewed with clinicians on what went right/wrong for rehabilitation of functional abilities.

Energy and mental fatigue management

(Rating: 4.5; ICF Codes: b130, d230, and d845) – Mental fatigue and tiredness are common symptoms after TBI. It is important that TBI outpatients monitor their energy levels and plan their day accordingly. With proper planning, outpatients will be better able to complete tasks that are important to them. *Technology Example*: 'Energy Management Aid' – This aid could be made of two devices: (1) a mobile app for planning activities and self-logging of fatigue states and (2) a physiological band that attempts to monitor fatigue levels in real-time via physiological parameters (e.g. heart rate variability and possibly EEG). The goal of this technology is to facilitate the client's planning and understanding of his/her fatigue levels during the day. Through the app, the client could assign energy points to tasks throughout the day. At the beginning of the day, they can report on how rested they feel and be given a total number of energy points for their day. As they proceed through tasks, they can visually see how their energy bank is decreasing to help manage fatigue levels. The physiological band could monitor their fatigue in real-time and give rest recommendations.

Emotional cues and communication competency

(Rating: 3.1; ICF Codes: d720, b152, and b760) – TBI outpatients may have difficulties recognizing emotional cues from their communication partners. This can lead to awkwardness and failed communication with others. In the long term, patients may withdraw from communication experiences and socially isolate themselves. *Technology Example*: 'Communication Competency Aid' – The client could use augmented reality glasses that resemble everyday eyeglasses to minimize stigma. These glasses could have a front-facing camera and speech recognition to potentially analyze the facial expressions and tone of people the client talks to. The goal of the glasses is to promote successful communication by prompting the client of emotional changes (e.g. sarcasm) in their communication partners. This prompt can be done through a real-time visual cue. Use of the glasses could also support social communication rehabilitation/training by allowing the client to review past video clips of emotional changes. Such a solution, however, calls for privacy considerations.

Training meaningful skills

(Rating: 4.0; ICF Codes: d230, d845, b144, b164, and b140) – Being able to fulfill one's meaningful life-roles is an important goal for many TBI outpatients. Although some patients may never return to their previous state, it is important to help the patient learn new skills/hobbies/activities that are of interest to him/her. Technology can facilitate this learning and engagement. *Technology Example*: 'Augmented Reality Activity Training' – The goal of this technology would be to help clients learn and participate in new skills that are of interest to them. By wearing augmented reality glasses, clients could learn tasks as they are doing a task – for example, cooking new recipes. As the client works on the task, they can be prompted to do the next step by the device in a hands-free manner. This prompt can be given in the client's peripheral view so that he/she can glace at it, but it would not obstruct the view of doing the task. Over time and practice, the client can learn new tasks. Additionally, the social internet of sharing and learning from others could also be integrated into this technology to potentially promote social benefits.

Design considerations

Five design considerations emerged from our co-design process. Each design consideration adds a lens of knowledge that future designers can use when developing new cognitive telerehabilitation systems. The design considerations ranged from the interrelationship between a patient user and the rehabilitation technology (i.e. 'adaptability to different rehabilitation needs and trajectories' and 'transitioning goals') to intrinsic aspects of a patient user (i.e. 'unpacking motivation') and lastly to contextual aspects that affect a patient user (i.e. 'considering social support' and 'the financial impact of TBI').

Adaptability to different rehabilitation needs and trajectories

Clinicians raised the need for new telerehabilitation technologies to be adaptable to the diversity of TBI patient impairments: 'Well I think, wherever possible, to be able to have [the technology] as adaptable as possible to the individual [. . .] That they're able to take each person's individual strengths and challenges, be they cognitive/physical/whatever, energy levels into consideration when designing technologies' (P6). Conformity of technology to each patient's physical, cognitive, and even emotional state is about ensuring appropriate fit for that individual so that his/her potential is maximized and frustration is minimized. The emotional state of a patient is of particular concern, especially when the patient is dealing with a sense of loss post-injury and is more susceptible to discouragement when failing to use a certain device: '[The patient] is already left with a sense of loss, inadequacy. So if the technology right off the bat is. . .if they perceive it as too complicated to use, you've lost them. So it really needs to be a lot more than user-friendly. It needs to be packaged in a way that they do not think that this is a new task for them, that it's going to take away even more of their energy for the day. So it has to be something that is packaged in a way that they don't dread it' (P4).

Clinicians suggested a number of ways that telerehabilitation systems could be designed to take into account patients' impairments in order to maximize their potential. Some examples included: adjusting the speed of information if a patient has information processing difficulties; limiting the use of text and instead using larger graphics if a patient has visual–perceptual difficulties; giving prompts/cue if a patient has memory difficulties; or using analogies to help with planning, particularly if there are executive functioning issues. 'Every patient behaves differently, so we need options' (P8). These adaptations are meant to lessen the burden of device use on patient users. However, there is an added concern of making a device too simplistic: 'Because if somebody is high-functioning, and I go: ''first, put the [. . .*describes task*. . .]'' then they're going to be offended' (P8). This raises the idea of not 'hand-holding' patient users in a way that would patronize them, but providing just enough support/challenge to accommodate their rehabilitation level and current trajectory in recovery.

Transitioning goals: compensation or remediation

There was also exploration of a tension between the goals of rehabilitation technologies. For severe cases of TBI, some clinicians were adamant that functions were permanently lost and that patients would need to be compensated with technology to enable higher functioning: 'No it's gone. The memory is gone. With TBI I always tell to the technology guys, don't think about rehab [i.e. remediation], think about compensation' (P8). However, other clinicians preferred making an attempt to restore/remediate loss function and not to become overly reliant on compensatory technologies: 'I think sometimes we may get in the habit of (not only in this, but in general) going to compensation right away and just accept it, when the person does have the ability to move forward' (P1); and 'It's good that we are relying on [technologies], but we don't want to give up on [the patient] being able to do things on their own. You don't want to be reliant on these things' (P1).

Both compensation and remediation have a role in rehabilitation technologies. However, clinicians also explored the idea of a transitional middle ground between these two groupings, which may be appropriate both when a patient cannot remediate at first, but somehow develops the capacity to later on – *and* – when remediation/restoration of capacity is still possible, but there is a need for compensation to enable a person to function better in his/her everyday life. One clinician was thinking through this idea for a rehabilitation technology that would aid activities of daily living: 'It always seems we like to use a pass or fail system. Either you can do it independently without me coming with you, or you can't do it because I have to cue you. There needs to be that in-between ground of: ''how do I fade my cues?'' So I'm cueing you less often and less obtrusively' (P2). In this way, a compensation technology (i.e. persistent cueing) may be transitioned, through gradual scaffolds (e.g. a change in cueing strategies), into a more remediation purpose (i.e. training to do a task independently).

Understanding motivation

Clinicians described ways to engage patients in rehabilitation – in particular, with the use of remediation-oriented technologies, where self-motivation is crucial. One idea that emerged repeatedly was ensuring that the cognitive rehabilitation is 'meaningful' and therefore interesting for a patient to undertake: 'The rehabilitation context itself needs to be meaningful, and it needs to be relevant to an individual's life. And I think that's an absolutely critical thing for anyone involved in technology to carry forward' (P5). Being 'meaningful' came across as enabling goals related to functional gains, or return to life roles, and is a known aspect of rehabilitation.[56]

Other facilitators of a patient's motivation included establishing a trustful relationship with their rehabilitation clinician, setting goals for their rehabilitation, ensuring that the patient's voice to be heard, and celebrating successes: 'Rehab is like anything it's three steps forward, ten steps back, one step forward, 15 steps back. . .so there's no linear trajectory. And it's being able to celebrate those success, EACH little success, regardless of how insignificant it is' (P5). These successes, over time, lead to a summative change that is important for patients to be reminded of in the rehabilitation process: 'Because that's another thing, that people often in those situations become very frustrated, and they don't actually see the gains. So I often encourage people to journal. Keep track of where you're at because if you're not keeping track, all you see is: I'm not where I was before' (P7). It was also mentioned to keep in mind challenges to motivation. Clinicians expressed how patients could fall into a sedentary lifestyle if they feel isolated from the world, become discouraged from not being able to complete previous life-roles, feel stigmatized, lack goals, or learn helplessness from not needing to do things themselves. 'Keep setting goals too. . .once you leave rehab it doesn't mean that you can stop working toward your goals. Like we've got some people come back to rehab studies ten years later, and they're like: ''well I'm waiting until my arm is better until I cook again'', even though cooking was a huge passion for them' (P4). Taken together, new cognitive telerehabilitation systems can aim to maximize positive facilitators and minimize challenges to motivation.

The concept of supporting patients to 'redefine themselves' was also crucial to motivation: 'Because every single person with a brain injury (or any type of catastrophic injury), they all remember what they were like before, and they all want to go back to what they were before. But that's not life, we're all changing [. . .] It's a sense of: ''this is what I have, this is who I am, this is what I'm working towards . . . but I'm redefining who I am as an individual with a brain injury'' [. . .] it is helping redefine their own sense of self, their own sense of strengths and where do they fit in' (P5). Along these lines, supporting motivation with technology is more than simple rewards or celebrations, but done through an empathetic understanding that patients are on a transitional journey from loss to redefinition. New telerehabilitation systems can seek to walk with patients in a personalized way that respects their journey and goals.

The financial impact of TBI

Clinicians also expressed concerns around the costs of acquiring new technologies. TBI outpatients often experience a loss of income due to the difficulties in working after injury or have limited insurance coverage. This limits their ability to buy technologies on their own: 'Unfortunately, a lot of this stuff is fantastic; it's just not accessible because of the cost [. . .patients] have to spend on their groceries after their rent is taken care of, and their utilities and transportation around. We're talking a lot of these people have no money at all. So free is best' (P2). Clinicians considered alternative models of funding, where hospitals or rehabilitation agencies could loan out technology devices to their clients. However, they also expressed that some agencies cannot afford expensive technologies. As such, new cognitive telerehabilitation systems should strive to be as inexpensive as possible or provide cost savings to institutions to justify their purchase.

Considering social support

Last, there was dialogue on how support networks (i.e. family/friends) could help a patient rehabilitate and how technology might influence these networks. In general, support networks were seen as a positive way to help build a patient's confidence, self-esteem, and to help them readjust to the world. 'Hopefully they do have that support and that family member can give them that prod to go out, or even go with them to a support group. So that [the patient] can take in that environment and say ''okay, I can handle this on my own,'' to build that confidence and esteem' (P1). In one regard, technology may be able to help sustain or even expand a patient's support network. Avenues to expand a patient's support network are helpful as some patients were described as living in a 'restricted world' after injury and may need aid connecting with others.

In addition to socialization and encouragement, support networks were described by their deeds, where family/friends would do something with/for the recovering patient. With this in mind, there may be ways that telerehabilitation systems can seek to complement the deeds of caregivers as they align with rehabilitation goals. For example, one clinician explored how technology could help family members find accessible places for outings that the patient could go to as part of their rehabilitation progress. However, concerns were raised about placing too much burden on support networks and causing burnout. 'Everything is left on the family members to do. . .on top of bathing, cooking, cleaning, financial [management]. . .it's too much' (P8). Technologies should be designed mindfully to avoid placing significant burden on support networks (i.e. reducing the effort needed to maintain a particular technology).

Discussion

Design opportunities

Many of the design opportunities and examples lend themselves to an idea of *situated* rehabilitation. As opposed to simulated models of practice in the clinic or in virtual environments, pervasive computing enables both therapy and assessment to be done in the context of everyday life. In this regard, patients could practice and see improvements in their actual environments of use. This can be a powerful motivator for patients and a way to promote *meaningful* rehabilitation. By themselves, the listed design examples are not final concepts but rather points-of-departures for further discussion and iteration. These examples drive more dialogue into the ways that pervasive computing can extend cognitive rehabilitation both physically (out of clinic) and temporally (beyond formal in-patient rehabilitation services). We see varying use cases of this extension, by how pervasive computing could promote: generalization or booster sessions of previous cognitive rehabilitation training, enable just-in-time interventions, or give new contextual insights that feed into a patient's rehabilitation.

By contrasting conceptual ideas against the ICF TBI Core Set, we contribute an initial mapping of the types of TBI functions that pervasive computing technologies can support with the aim of cognitive rehabilitation. We believe that the use of the ICF is an important tool for health-care technology designers. Although Cole [16] has raised limitations of the granularity of the ICF codes in HCI user-interface design, we contend that another important use of the ICF is the promotion of dialogue between technology designers and health-care professionals. By labeling technology ideas against ICF codes, designers can further probe health-care professionals about patient considerations related to a particular ICF code. Reciprocally, health-care professionals can raise insights related to an aspect of patient functioning that designers may have overlooked.

Design considerations

A number of design considerations that emerged are already being studied in clinical literature: for example, understanding the influences to rehabilitation motivation [56, 57], the changes to sense of self after TBI [58], and the role of support networks to a TBI patient's recovery.[59] What is unique to this process is the attempt to adapt telerehabilitation technologies to these considerations.

In general, our design considerations show agreement with previous work related to human factors for telerehabilitation technologies [60,61] and TBI patients' perspectives related to support technology.[62] These works have raised concerns related to the cost of devices and the need for device adaptation to a patient's unique impairments. Our findings build on this, to express that TBI patients likely have a lower tolerance for frustration due to feelings of loss and inadequacy, which in turn means a higher possibility for device abandonment. In this regard, *adaptability* of a technology is more than matching to a patient's physical or cognitive abilities, but also includes tailoring to the emotional or perceptive aspect of the user. This concept relates to Don Norman's work on Emotional Design, where perceptions of a device influence the use of that device.[63] Norman has argued that perceptions (i.e. aesthetics which influence emotion) and usability of a product should be on equal footing in the design and neither can be ignored. Although this is a growing field in design literature, it has seldom been applied to the design of telerehabilitation technologies.

Adaptability can be further extended *across time* with the concept of a 'transitioning patient', which also emerged in our design considerations. Not only is the patient in a process of functional change after injury but he/she is also adjusting to a new sense of self and may have transitioning goals. Moreover, even in the chronic stages of injury, the brain is continuing to change. With the rise of pervasive computing, we expect to see long-term involvement of telerehabilitation technologies with a patient. As such, it is important to understand how these technologies might *transition* in accordance with the patient's abilities and goals or be used to support their journey of re-establishing their sense of self. It may even be necessary for telerehabilitation technologies to be designed for eventual disuse, for example, if remediation is the goal and the patient no longer needs to rely on that technology. Further insight into these questions will likely come from additional dialogue with TBI patients and their caregivers.

Last, the design considerations have raised the question of 'scope' for a cognitive telerehabilitation system. Is a system meant to focus on one rehabilitation task or does it expand to include larger and complementary aspects of a patient's life? One aspect of life that received much attention was a patient's support network. Pervasive computing enables new realms of social connectivity that could aid with patient support in terms of both facilitating social encouragement or enabling life-based incentives (e.g. social outings, as described in 'Considering Social Support'). How might technology be used to facilitate the necessary care, friendship, and support that a TBI patient needs for recovery? Again, we expect deeper insights to be informed by further exploration with TBI patients and their caregivers. However, work on other pervasive health-care technologies will likely help with this understanding too. For example, wearable fitness trackers have shown the limited utility of simple internet sharing of accomplishments and designers are now considering how to incorporate deeper aspects of 'friendship, support, kinship, competition, and play'.[64]

To summarize, our design considerations can be grouped in terms of: (1) designing for the person (i.e. adaptability to physical/cognitive/emotional state), (2) designing across time (i.e. a patient's changing rehabilitation trajectories and goals), and (3) designing for the larger context of life (e.g. including social aspects). Since much of this discussion has been described in broad concepts, we end this section by presenting how these concepts could be applied to the design of a specific cognitive telerehabilitation system. For this, we consider the example of using a physiological band/smartwatch to help a TBI patient self-monitor their anger. As we reflect upon the design considerations, a number of questions emerge for this system: (1) Is a smartwatch interface appropriate for the physical and cognitive abilities of the TBI client? Would the TBI client enjoy using this system? What can be done to ensure a helpful and enriching experience with this system? (2) How can this system be used to motivate and convey positive improvements to the client in terms of the behavioural self-monitoring? How can the smartwatch's software be adapted to the changing behavioural needs of the TBI client over time? and (3) How might caregivers be sensitized to the changes of a TBI client as they use this smartwatch? How could caregivers offer messages of comfort or support through this system as TBI clients deal with their behavioral self-monitoring issues? These and other related design consideration questions are a helpful step toward designing quality cognitive telerehabilitation systems.

Feedback from clinician co-designers

Clinicians were generally receptive of the co-design process. On average, they indicated high ratings that this co-design process increased their knowledge of new technologies (Likert: 4.6/5; Question: 'To what extent did our co-design process broaden your understanding of new technologies?') and enabled them to contribute their clinical knowledge to a design process (Likert: 4.8/5; Question: 'To what extent were you able to utilize your clinical knowledge in this co-design process'). Many clinicians believed that learning new technologies opened up new possibilities for their practice, and that they could be inspired to think of ideas as they worked: 'I didn't know of that…but now to realize there [are] technologies that could work with these people when I'm doing my task or treatment, that's kind of cool' (P1).

Feedback on the co-design scaffolds was positive with some suggested improvements. Clinicians were able to use the design cards to remind them of technology concepts and probe aspects of their work for ideation: 'So I laid the cards out, and then thought about: "based on [the patients] complaints, what could I 'envision'?" So I found them very helpful' (P4). In addition, many clinicians found that the field kit provided more time to explore ideas, but they recommended a longer duration to work with the field kit as they felt a week timeline was limiting in the number of cases they saw. Last, members of the design groups appreciated the diversity of clinical practitioners, which offered different perspectives for debating ideas about new technologies. Some clinicians also suggested that patient users should be included in later design groups for more representation of their thoughts.

Critiquing the utility of our co-design process

The findings above showcase the type of outcomes that researchers can expect from our co-design process. Through a mediated exploration with clinician and technology co-designers, we could broadly explore opportunity areas for new technologies within a health-care domain and unravel initial design considerations related to this intersection.

It remains to be seen how well each conceptual idea will function with the desired user base; however, we remind the reader that this process serves a predesign purpose in *identifying* areas for further pursuit and refinement. Following this open co-design process, researchers have a number of options in how they

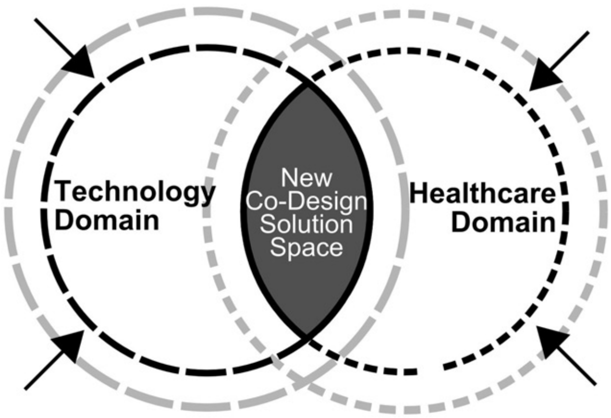

Figure 5. In future co-design sessions researchers may wish to constrain the 'Technology' or 'Health-care Domain'. This in turn constrains the solution space.

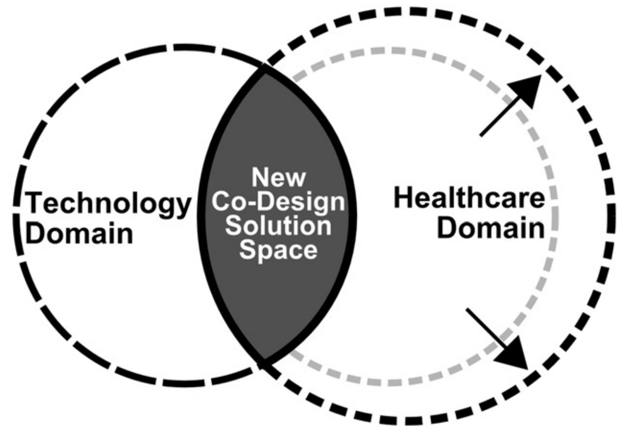

Figure 6. Alternatively, researchers may be inspired to enlarge either the 'Technology' or 'Health-care Domain'. In this example, the 'Health-care Domain' is enlarged to include other patient populations.

could proceed. Some may choose to narrow their solution scope around certain health-care application areas or technology concepts of interest, and then to conduct further design exercises to generate more conceptual ideas in this smaller solution space (Figure 5). Others may wish to conduct multiple design sessions at the original solution space to ensure a broad mapping of conceptual ideas. Still others may find that their conceptual ideas have sparked 'design resonance' [26] with other technology or health-care areas and may wish to alter their solution space to include these new areas (Figure 6). For example, the conceptual idea of an emotional self-regulation aid could have 'resonance' with other populations beyond TBI and therefore future design work could explore how this concept will include such populations.

The value of this co-design process is that it: (1) retains both a strong clinical and technical foundation for idea conceptualization, (2) empowers rehabilitation domain experts to creatively envision ideas (i.e. a convivial tool [42]) as they go about their work, and (3) helps sensitize researchers to design considerations that can be further explored in future design sessions with end-user patients/caregivers themselves. We view this co-design process as an additional tool to complement other ideation methods. In our research, this co-design process has served as initial step to outline future development work on emotional regulation aids. It has also made us aware of design considerations (e.g. rehabilitation trajectories, transitioning goals, etc.) that can be probed in future sessions with end users.

A notable contribution of this co-design process is that it supports the fuller participation of rehabilitation clinicians in design. Many of the co-design scaffolds were tailored to facilitate and empower creative idea generation from clinicians. The design cards and field kits were a way to transfer knowledge of technical concepts (i.e. an understanding of a broad range of emergent technologies) so that clinicians could use these as building blocks for new ideas as they were stimulated by their work. In this way, the design process leverages both the *perspective* of clinicians (i.e. their unique insights about their work to generate new technology ideas) and the *access* of clinicians (i.e. their ability to envision and trial ideas as they consider the patients they work with). To our knowledge, this is the first process to involve rehabilitation clinicians in this manner to broadly explore a health-care domain. Therefore, this is an expansion of the role that rehabilitation clinicians can have during front-end exploration.

Last, although our co-design process has focused primarily on clinician involvement, we believe the field of rehabilitation can benefit from more co-design tools that *facilitate* the voice of rehabilitation technology stakeholders (e.g. clinicians, patients, caregivers, etc.). We encourage other researchers to explore and develop such convivial tools to support the creativity of these stakeholders. Extending upon our work, we see a need to develop design tools that transition conceptual ideas from the front-end of design into finalized health-care experiences. As pervasive health-care faces the challenge of creating untried patient experiences, these new tools will likely need to draw upon methods such as 'experience-based design' [65] to help stakeholders create their desired health-care experiences.

Facilitators and challenges for this co-design process

Upon reflecting on our co-design process, there were several important facilitators for successful ideation:

(1) *Having opportunities to clarify* – As a large amount of knowledge was transferred between technical and clinical disciplines, it was helpful to clarify technology concepts, have time to practice design procedures (i.e. field kits), and be able to expand on conceptual ideas that clinicians generated.
(2) *Technology designers should be versed in clinical language* – This co-design process does not replace the need for interdisciplinary knowledge. In our design groups, technology designers needed an understanding of cognitive rehabilitation to facilitate deeper discussions.
(3) *Mediating the dual voice of the clinician* – Clinician co-designers were voicing opinions based on their own rehabilitation expertise and on behalf of their TBI clients. This dual-voice participation was facilitated by the use of the field kit and through the questions within design group sessions. It is important to understand that design participation can be tailored into various forms [66] and that co-design scaffolds must be carefully configured to ensure the participation of interest (e.g. participant control of design process, participant voice, etc.).

There were also several challenges encountered in this co-design process. These are listed below, along with suggestions of how to address them:

(1) *Idea fixation* – Often clinicians were being introduced to a technology concept for the first time. As such, they were limited in their abilities to generalize the concept to other situations or potential applications beyond the examples presented. As many of the examples presented were videos of high-fidelity product demonstrations, we speculate that presenting lower fidelity examples (e.g. animated scenarios of use) may aid a clinician's ability to generalize or ideate beyond idea fixation. Low-fidelity demonstrations can be more inviting to differing opinions and alterations than high-fidelity demonstrations.[67]
(2) *Creative investment* – There were variations in the time that each clinician invested in their field kit. Some clinicians wrote extensive notes whereas others wrote brief entries. Similar to diary studies in HCI, participants who devote more time into their field kit have a greater opportunity for reflection and ideation. It is important to encourage the use of the field kit, while respecting the demands of a clinical work day. Future field kits could aim to be integrated around work day tasks.
(3) *Making time for broad exploration* – Since the solution scope for this co-design process was set broadly with many technology concepts, it was challenging to cover all generated conceptual ideas within the design sessions. Added to this, the length of each design sessions was constrained by clinical work hours. Future researchers should run a pilot session on their solution scope to estimate the time that is needed to explore it. If necessary and if resources allow it, organizing a professional workday retreat with a number of clinicians may be one way to allocate more exploration time.

Study limitations

The main caution when using the results of our co-design study is that it is based on a smaller sample of eight TBI clinicians. Although we believe the presented results are substantive (due to the depth/years of clinical experience, refer to 'Selecting Co-Design Participants' section), they are by no means a full mapping of design opportunities or considerations between pervasive computing and cognitive telerehabilitation. The types of design opportunities will likely be added to with a larger sample size of co-designers and refined to enable appropriate health-care experiences for patients. Furthermore our findings on design considerations are only an initial representation, but not a first-hand perspective of TBI patients.

Conclusions

Our study broadly explored the intersection between emerging pervasive computing technologies and cognitive telerehabilitation. We conducted a custom co-design process with TBI clinicians to ideate on technology opportunities and understand design considerations that exist within this intersection. Our results show the need for TBI cognitive telerehabilitation technologies to be adapted to the TBI patient's physical/cognitive/emotional state, their transitions through recovery, and their greater life context. Within the described opportunity areas, we assert that pervasive computing technologies have a unique potential to enable situated rehabilitation. Our design process facilitated rehabilitation clinician involvement as creative co-designers and helped ground ideas within clinical/technical constraints. We invite future researchers to adapt this co-design process to broadly explore other health-care application areas.

Acknowledgements

The authors are grateful to all the clinicians who participated in this study. Funding is provided by the CIHR-STIHR Fellowship in Health Care, Technology and Place (TGF-53911), and the CIHR Doctoral Research Award.

Declaration of interest

The authors report no declarations of interest.

References

1. Harper R, Rodden T, Roger Y, et al. Being human: human-computer interaction in the year 2020. Cambridge, England: Microsoft Research Ltd; 2008.
2. Conti M, Das SK, Bisdikian C, et al. Looking ahead in pervasive computing: challenges and opportunities in the era of cyber-physical convergence. Pervasive Mob Comput. 2012;8:2–21.
3. Arnrich B, Mayora O, Bardram J, et al. Pervasive healthcare: paving the way for a pervasive, user-centered and preventive healthcare model. Methods Inf Med. 2010;49:67–73.
4. Bardram JE. Pervasive healthcare as a scientific discipline. Methods Inf Med. 2008;47:178–185.
5. McCue M, Fairman A, Pramuka M. Enhancing quality of life through telerehabilitation. Phys Med Rehabil Clin N Am. 2010;21:195–205.
6. Hill AJ. Report on the potential application of telerehabilitation to adult rehabilitation services in Scotland. Aberdeen: Scottish Centre for Telehealth; 2010. p. 14.
7. Tator C, Bray G, Morin D, et al. The burden of neurological diseases, and disorders and injuries in Canada; Ottawa: CIHI; 2007. p. 59–66.
8. Ragnarson KT, Moses LG, Clarke WR, et al. Rehabilitation of persons with traumatic brain injury. J Am Med Assoc. 1999;282:974–983.
9. Cullen N. Canadian healthcare perspective in traumatic brain injury rehabilitation. J Head Trauma Rehabil. 2007;22:214–220.
10. Masel BE, DeWitt DS. Traumatic brain injury: a disease process, not an event. J Neurotrauma. 2010;27: 1529–1540.
11. Green REA, Colella B, Maller JJ, et al. Scale and pattern of atrophy in the chronic stages of moderate-severe TBI. Front Hum Neurosci. 2014;8:1–9.
12. Till C, Colella B, Verwegen J, et al. Postrecovery cognitive decline in adults with traumatic brain injury. Arch Phys Med Rehabil. 2008;89:S25–S34.
13. Salazar AM, Warden DL, Schwab K, et al. Cognitive rehabilitation for traumatic brain injury: a randomized trial. J Am Med Assoc. 2000;283:3075–3081.
14. Bergquist T, Gehl C, Mandrekar J, et al. The effect of internet-based cognitive rehabilitation in persons with memory impairments after severe traumatic brain injury. Brain Inj. 2009;23:790–799.
15. Tost D, Grau S, Ferré M, et al. Previrnec: a cognitive telerehabilitation system based on virtual environments. Proceedings of Virtual Rehabilitation International Conference; Haifa, Israel; 2009:87–93.
16. Cole E. Patient-centered design of cognitive assistive technology for traumatic brain injury telerehabilitation. In: Baecker R, editor. San Rafael (CA): Morgan & Claypool Publishers; 2013. p. 128.
17. Tam S-F, Man WK, Hui-Chan CWY, et al. Evaluating the efficacy of tele-cognitive rehabilitation for functional performance in three case studies. Occup Ther Int. 2003;10:20–38.
18. Solana J, Cáceres C, Garcia-Molina A, et al. Improving brain injury cognitive rehabilitation by personalized telerehabilitation services: Guttmann Neuropersonal Trainer. IEEE J Biomed Health Inf. 2015;19:124–131.
19. Gillespie A, Best C, O'Neill B. Cognitive function and assistive technology for cognition: a systematic review. J Int Neuropsychol Soc. 2012;18:1–19.
20. Arundine A, Bradbury CL, Dupuis K, et al. Cognitive behavior therapy after acquired brain injury: maintenance of therapeutic benefits at 6 months posttreatment. J Head Trauma Rehabil. 2012;27:104–112.
21. Christensen BK, Colella B, Inness E, et al. Recovery of cognitive function after traumatic brain injury: a multilevel modeling analysis of Canadian outcomes. Arch Phys Med Rehabil. 2008;89:S3–S15.
22. Schoenberg MR, Ruwe WD, Dawson K, et al. Comparison of functional outcomes and treatment cost between a computer-based cognitive rehabilitation teletherapy program and a face-to-face rehabilitation program. Prof Psychol: Res Pract. 2008;39:169
23. Schopp LH, Johnstone BR, Merveille OC. Multidimensional telecare strategies for rural residents with brain injury. J Telemedicine Telecare. 2000;6:S146–S149.
24. Man D, Soong W, Tam S, et al. Self-efficacy outcomes of people with brain injury in cognitive skill training using different types of trainer-trainee interaction. Brain Inj. 2006;20:959–970.
25. Sanders EB-N, Stappers PJ. From designing to co-designing to collective dreaming: three slices in time. Interactions. 2014;21:24–33.
26. Pullin G. Design meets disability. Cambridge (MA): MIT press; 2009. p. 341.
27. Rogers Y, Scaife M, Harris E, et al. Things aren't what they seem to be: innovation through technology inspiration. Proceedings of 4th Conference on Designing Interactive Systems; London, UK; 2002:373–378.
28. Van der Linden J, Rogers Y, Taylor C, et al. Technology inspired design for pervasive healthcare. Proc 5th Int Conf Pervasive Comput Technol Healthc (PervasiveHealth). 2011:609–613.
29. Sanders EB-N, Westerlund B. Experiencing, exploring and experimenting in and with co-design spaces. Proceedings of Nordic Design Research Conference; Helsinki, Finland; 2011:1–4.
30. Sanders EB-N. Scaffolds for experiencing in the new design space. Inf Des. 2002:1:1–6.
31. Akama Y, Ivanka T. What community? Facilitating awareness of "community" through playful triggers. Proceedings of the 11th Biennial Participatory Design Conference; Sydney, Australia; 2010:11–20.
32. Sanders EB-N, Stappers PJ. Co-creation and the new landscapes of design. CoDesign: Int J CoCreation Des Arts. 2008;4:5–18.
33. Ballegaard SA, Hansen TR, Kyng M. Healthcare in everyday life: designing healthcare services for daily life. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Florence, Italy; 2008:1807–1816.
34. Boyd-Graber JL, Nikolova SS, Moffatt KA, et al. Participatory design with proxies: developing a desktop-PDA system to support people with aphasia. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Montreal, Canada; 2006:151–160.
35. Faria Borges D, Filgueiras LCL, Maciel LV, et al. Customizing a communication device for a child with cerebral palsy using participatory design practices: contributions towards the PD4CAT method. Proceedings of the

11th Brazilian Symposium on Human Factors in Computing Systems; Cuiabá, Brazil; 2012:57–66.
36. Ayoade M, Baillie L. A novel knee rehabilitation system for the home. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Toronto, Canada; 2014:2521–2530.
37. Geurts L, Vanden Abeele V, Husson J, et al. Digital games for physical therapy: fulfilling the need for calibration and adaptation. Proceedings of the 5th International Conference on Tangible, Embedded, and Embodied Interaction; Funchal, Portugal; 2011:117–124.
38. Martin DM, Laird R, Hwang F, et al. Computerized short-term memory treatment for older adults with aphasia: feedback from clinicians. Proceedings of the 1th International ACM SIGACCESS Conference on Computers and Accessibility; Bellevue, WA, USA; 2013:1–2.
39. Vourvopoulos A, Faria AL, Ponnam K, et al. RehabCity: design and validation of a cognitive assessment and rehabilitation tool through gamified simulations of activities of daily living. Proceedings of the 11th Conference on Advances in Computer Entertainment Technology; Funchal, Portugal; 2014:1–8.
40. Moraiti A, Vanden Abeele V, Vanroye E, et al. Empowering occupational therapists with a DIY-toolkit for smart soft objects. Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction; San Francisco, CA, USA; 2015:387–394.
41. Illich I. Tools for conviviality. New York: Harper & Row; 1973.
42. Sanders EB-N, Stappers PJ. Convivial toolbox: generative research for the front end of design. Amsterdam: BIS Publishers; 2012.
43. Allen M, Leung R, McGrenere J, et al. Involving domain experts in assistive technology research. Univers Access Inf Soc. 2008;7:145–154.
44. Galliers J, Wilson S, Roper A, et al. Words are not enough: empowering people with aphasia in the design process. Proceedings of the 12th Participatory Design Conference; Roskilde, Denmark; 2012:51–60.
45. Halskov K, Dalsgård P. Inspiration card workshops. Proceedings of the 6th Conference on Designing Interact Systems; University Park, PA, USA; 2006:2–11.
46. Friedman B, Hendry D. The envisioning cards: a toolkit for catalyzing humanistic and technical imaginations. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Austin, TX, USA; 2012:1145–1148.
47. Lucero A, Arrasvuori J. PLEX cards: a source of inspiration when designing for playfulness. Proceedings of the 3rd International Conference of Fun and Games; Leuven, Belgium; 2010:28–37.
48. Holleis P. Integrating usability models into pervasive application development [dissertation]. München: Universität München; 2009. p. 193.
49. Orwat C, Graefe A, Faulwasser T. Towards pervasive computing in health care – a literature review. BMC Med Inform Decis Mak. 2008;8:26.
50. Buxton B. Sampling & synthesis: the two sides of experience sketching. Workshop presented at: SIGCHI Conf Hum Factors Comput Systems; 2014 Apr 28; Toronto, Canada.
51. Mattelmäki T. Applying probes-from inspirational notes to collaborative insights. CoDesign: Int J CoCreation Des Arts. 2005;1:83–102.
52. Mancini C, Rogers Y, Bandara AK, et al. Contravision: exploring users' reactions to futuristic technology. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Atlanta, GA, USA; 2010:153–162.
53. Thomas DR. A general inductive approach for analyzing qualitative evaluation data. Am J Eval. 2006;27:237–246.
54. Laxe S, Zasler N, Selb M, et al. Development of the international classification of functioning, disability and health core sets for traumatic brain injury: an international consensus process. Brain Inj. 2013;27:379–387.
55. Dawson DR, Anderson ND, Binns MA, et al. Managing executive dysfunction following acquired brain injury and stroke using an ecologically valid rehabilitation approach: a study protocol for a randomized, controlled trial. Trials. 2013;14:doi:10.1186/1745-6215-14-306.
56. Siegert RJ, Taylor WJ. Theoretical aspects of goal-setting and motivation in rehabilitation. Disabil Rehabil. 2004; 26:1–8.
57. Arnould A, Rochat L, Azouvi P, et al. A multidimensional approach to apathy after traumatic brain injury. Neuropsychol Rev. 2013;23:210–233.
58. Thomas EJ, Levack WM, Taylor WJ. Self-reflective meaning making in troubled times change in self-identity after traumatic brain injury. Qual Health Res. 2014;24: 1033–1047.
59. Gagnon A, Lin J, Stergiou-Kita M. Family members facilitating community re-integration and return to productivity following traumatic brain injury-motivations, roles and challenges. Disabil Rehabil. 2015:1–9. [Epub ahead of print]. doi:10.3109/09638288.2015.1044035.
60. Brennan DM, Barker LM. Human factors in the development and implementation of telerehabilitation systems. J Telemed Telecare. 2008;14:55–58.
61. Lathan CE, Kinsella A, Rosen MJ, et al. Aspects of human factors engineering in home telemedicine and telerehabilitation systems. Telemed J. 1999;5:169–175.
62. Chu Y, Brown P, Harniss M, et al. Cognitive support technologies for people with TBI: current usage and challenges experienced. Disabil Rehabil Assist Technol. 2013;9:279–285.
63. Norman DA. Emotional design: why we love (or hate) everyday things. New York (NY): Basic Books; 2004.
64. Rooksby J, Rost M, Morrison A, et al. Personal tracking as lived informatics. Proceedings of SIGCHI Conference on Human Factors in Computing Systems; Toronto, Canada; 2014:1163–1172.
65. Bate P, Robert G. Experience-based design: from redesigning the system around the patient to co-designing services with the patient. Qual Saf Health Care. 2006; 15:307–310.
66. Vines J, Clarke R, Wright P, et al. Configuring participation: on how we involve people in design. Proc SIGCHI Conf Hum Factors Comput Systems. 2013:429–438.
67. Buxton B. Sketching user experiences: getting the design right and the right design. San Francisco (CA): Morgan Kaufmann; 2010.