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Leveraging Technology to Enable Mobility and Transform Health

Going beyond motivation! A framework for the design of technology for supporting physical activity where mobility is restricted.

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Abstract

Body movement sensing and feedback technology is increasingly seen as a means of facilitating self-directed physical rehabilitation outside the clinic for long-term chronic conditions. Such technology can make self-directed physical therapy more effective by providing easy and continuous access and personalisation options. Current models used to design such technology are mainly based on physiotherapist-led exercise sessions and novelties introduced by technology predominantly focus on providing fun and tracking physical progress. Unfortunately, such models do not reflect physical rehabilitation in chronic conditions. For example, multidisciplinary outpatient programmes for chronic condition management take a much broader perspective where: (1) psychological and personal needs are as important to physical rehabilitation as physical needs; (2) physical rehabilitation does not occur only in exercise sessions but is fully embedded in everyday life and contexts; and (3) the person is responsible for self-directing and managing physical rehabilitation, as access to healthcare providers is limited. To address these gaps, we propose a new framework for the design of body-aware physical rehabilitation technology, which puts emotional and personal needs at the forefront of rehabilitation in chronic conditions where mobility is restricted. Our proposed framework is an initial attempt to provide technology designers with systematic support for the identification and translation of needs, aims and barriers to managing self-directed physical activity in populations with chronic conditions; it encourages consideration of the variety of factors and contexts that are critical to adherence and effectiveness of a program of physical rehabilitation using technology. We built this framework on lessons learnt from 5 years of work in the context of chronic pain physical rehabilitation and refined it by: (1) conducting a human computer interaction (HCI) literature review on physical rehabilitation technologies in other chronic conditions and (2) running a workshop with two designers working in this area to discuss the framework's application. Through this work, we aim to stimulate a critical discussion on the important considerations for the design of technologies for physical rehabilitation in chronic conditions including the models, theories and methods used to design them.

Introduction

Everyday physical rehabilitation is important in chronic conditions to maintain/improve mobility and quality of life. Technology can provide a means to support people with long-term chronic conditions in doing physical activity and rehabilitation (Morton et al. 2017). This is especially true now as the number of people with chronic conditions is increasing and the UK National Health Service (NHS) is under increased strain.

Taking a Human-Computer Interaction (HCI) perspective, in this paper, we argue that the current approach to designing technology to support physical rehabilitation in long-term conditions is very narrow. It is mainly based on the model of dedicated physiotherapist-led physical rehabilitation sessions and considers physical limitations and lack of motivation as the only, or the main, barriers. Firstly, many recent studies have shown that self-directed physical rehabilitation goes beyond dedicated physiotherapy-like sessions in the home and can take various forms (Bagalkot et al. 2012; Balaam et al. 2011; Singh et al. 2014, 2016). Second, there are other psychological, social and contextual factors beyond physical progress and motivation that need to be addressed by technology for physical rehabilitation in chronic conditions, such as chronic pain (CP) (Singh et al. 2014; Duggan et al. 2014), stroke (Morris 2016; Nicholson et al. 2013), Parkinson's (PD) (McNaney et al. 2015) and Multiple Sclerosis (MS) (Ayobi et al. 2017; Octavia & Coninx 2015).

Psychological progress in people with chronic illness does not only concern motivation to do an activity. It requires overcoming fear, anxiety and depression, as well as gaining the confidence to self-direct o self-manage physical rehabilitation (e.g., confidence in increasing demand or progressing to a new challenge) and functional activity (e.g., confidence in loading a washing machine). The social context (e.g., home or work) where rehabilitation takes place, and social roles of people in such contexts, are important factors for physical rehabilitation. Indeed, learning to engage with rehabilitation requires both physical and psychological progress, and thus both these should be considered in the design of rehabilitation technology to be embedded in people's everyday life.

To support the needs of people with chronic conditions in long-term self-managed physical rehabilitation, multidisciplinary healthcare programs have been created; these target psychological, physical, personal and social factors and are effective in supporting people to become more active (Seale et al. 2010; Chriki et al. 2006; Kristensen et al. 2016). However, they cannot be continuously provided for everyone with chronic conditions in the long-term. While technology is seen as a way to provide self-management support (Rosser et al. 2009), we have identified three challenges that need to be addressed for the design of successful rehabilitation technology delivered outside of the clinic:

1. Clinical outcomes are prioritised: Technology designers view clinical improvements as the most important aspect of the rehabilitation with less consideration towards the long-term and broader aims. Moreover, they tend to translate solutions from one chronic condition to another without working with healthcare practitioners, who can help to identify clinically focused requirements, or with people living with the targeted conditions, who can highlight needs and barriers encountered when engaging in self-directed physical rehabilitation outside the clinic. Existing design frameworks for rehabilitation technologies mainly focus on computational aspects and software architectures to develop the technology (Egglestone et al. 2009; Saini et al. 2012).

2. Evaluations are primarily conducted in the presence of clinicians/clinical settings: Many physical rehabilitation technologies for self-management are evaluated in contexts where clinical staff are present, either due to the study design, or because such technology is assessed in the initial period post-diagnosis (e.g., intensive physical rehabilitation post-stroke). In such situations (e.g., Schönauer et al. 2011), the importance of the psychological factors is underestimated because psychological barriers (e.g., fear that the exercise cause more injury) are overcome by the clinician's presence (either physical or virtual).

3. Behaviour change theories neglect the emotional barriers to physical rehabilitation in chronic conditions: While the importance of emotion is acknowledged in theories/ frameworks of behaviour change (e.g., the Behaviour Change Wheel - Michie et al. 2011), persuasive technology (e.g., Oinas-Kukkonen 2012; Mohr et al. 2014; Fogg 2009) and motivation (e.g., self-determination theory - Deci and Ryan, 1985), the role of emotions as barriers in adopting particular behaviours is underexplored. In modelling the relationship between emotion and motivation, studies using these theories focus on emotion as mainly an outcome of motivation but it can be an antecedent as well (Seo *et al.*, 2009). For example, technology designers use gamification (Saini *et al,.* 2012; Charles & McDonough 2014) and shift-of-attention mechanisms (Holden 2005; Lewis & Rosie 2012) to target fun and motivation through rewards and thus facilitate adherence. However, in self-directed physical rehabilitation contexts, emotions such as fear in response to the perceived risks of the activity, can lead a person to avoiding the activity altogether (Rainville et al. 2011) despite being motivated to engage in such activity and committed to the goal. Our studies with people with chronic pain (CP) (e.g., Singh *et al.*, 2014; Felipe *et al.*, 2015) demonstrate, for example, that self-setting targets and goals in the presence of pain is psychologically challenging due to low self-efficacy associated with catastrophic predictions associated with negative mood and past failure, among other emotional states (Olugbade *et al.*, *in press*). Other studies suggest the same is true in other chronic conditions such as stroke and Multiple Sclerosis (Chriki et al. 2006; McNaney et al. 2015). As such, approaches built on these health behaviour theories fail to address emotional barriers that exist independently of motivational factors.

To address these gaps, we propose a framework to guide researchers and designers through different considerations when designing/evaluating technology to support physical activity rehabilitation for people with chronic conditions, delivered outside of the clinical context and without the (physical or virtual) presence of physiotherapists and clinicians.

Method

An initial version of the framework was proposed based on findings from five years of research on the design of physical rehabilitation technology for people with CP (Singh et al. 2014, 2016, 2017; Olugbade et al. – *in press*). As the literature on self-managed rehabilitation programmes for many other long-term conditions suggests similar needs to those we found in our studies with CP (Jordan & Osborne 2007; Holman & Lorig 2004), we reviewed the HCI and Computer Science literature to understand whether the questions raised by the rehabilitation programmes and our framework were addressed and to what extent. Findings from the review were incorporated in the framework; the framework was further refined through a workshop conducted with two researchers with expertise in this area. Below, we discuss the methods used in the literature search and expert workshop.

Literature search

An electronic literature search was conducted using the ACM Digital Library database in April 2017. The search comprised articles published since 2011, which included the term “physical rehabilitation” in any field and did not use the term “assistive” as author keyword.

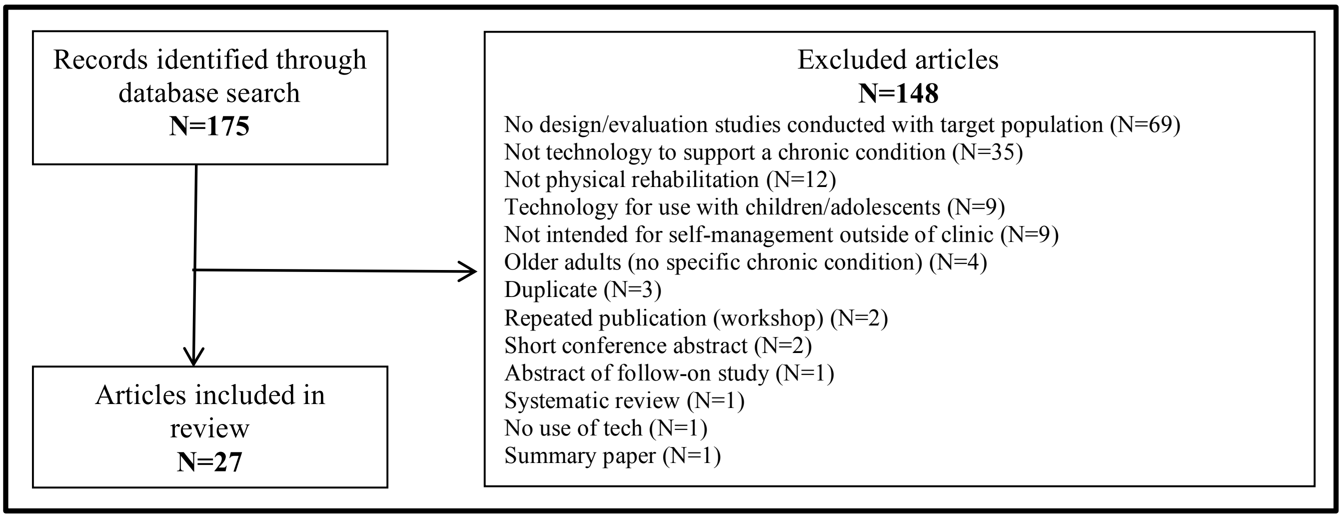
Study selection

Eligible studies included papers written in English which: (i) referred to the physical rehabilitation of a chronic condition with a focus on recovering/maintaining physical abilities; (ii) were related to the design and/or evaluation phase of a technology; (iii) had as participants those people who had the chronic condition of interest and/or their therapists/clinicians; and (iv) the technology was aimed to be used outside the clinic for shared/self-management. Studies conducted in clinic but which indicated in the paper that they were intended for future use outside the clinic were included. Excluded studies were those that focused on post-operative rehabilitation, acute injuries, assistive technologies, technologies for use with children/adolescents or purely technical papers. Studies focusing on physical rehabilitation for older adults with no specific chronic condition were excluded. Figure 1 depicts a flow diagram of the study selection process and reasons for excluding studies. The search identified 175 results, of which 27 were included in the final review.

Data extraction

Abstracts of 175 search results were reviewed; information was extracted for included studies regarding author(s), chronic condition, type of technology/modality, type of feedback, sample size, study methods, results, theoretical/conceptual frameworks used. We also used the components from the original proposed framework (based on our research in CP) to extract information about how the studies included in the review addressed these components and to what extent. In this paper, we mainly report aspects of the review directly applicable to the framework and its refinement, due to space constraints. We are currently expanding this review with another keyword: activities of daily living, in the context of rehabilitation.

Figure 1: Flow diagram of study selection process



Workshop

Next, we conducted a workshop with two researchers, specialising in HCI and physiotherapy, who have worked in interdisciplinary settings (7-12 years) designing rehabilitation technology, both within and beyond clinical contexts, for people with spinal cord injuries (across a variety of conditions). The workshop was audio-recorded and insights were used to provide more depth to elements of the framework. Figure 2 shows a researcher at the workshop exploring the framework.

Figure 2: Working on different aspects of the framework during the workshop

Next, we present the refined framework which includes discussion of findings from our own work with CP, along with results of the literature review and the expert workshop.

Rehabilitation framework for technology (RaFT)

We propose a Rehabilitation Framework for Technology design (RaFT) composed of three components: (i) a *Person* component formed by physical, psychological and personal factors (henceforth referred to as ***P*^3**); (ii) a Physical Rehabilitation component comprising the "what, when, who, where" of the physical rehabilitation contexts and processes (henceforth referred to as **W^4**); and (iii) a *Social* component (henceforth referred to as ***S***) that further defines and affects how physical rehabilitation is carried out (e.g., the with/around/for/despite whom).

Through this framework, we attempt to provide systematic support for the identification and translation of needs and aims for physical activity rehabilitation into effective rehabilitation technology. Our aim is not to address all the requirements for physical rehabilitation in any condition, but to facilitate the identification and evaluation of the critical factors for effective rehabilitation of a targeted condition. We envisage the use of the framework throughout the lifecycle of developing technologies for rehabilitation from conception and design to evaluation and implementation. This will enable a broader range of factors to be considered in studies conducted through this process, beyond issues such as usability, likeability and a broad view of motivation and engagement. Next, we discuss components of the RaFT framework considering our studies with people with CP and our findings from the literature review of other chronic conditions and workshop.

The *Person* component (henceforth referred to as P^3)

P^3 highlights that people's needs from rehabilitation are not just *physical* but also *psychological*. Further, since rehabilitation needs to be integrated into people's everyday lives, there is a *personal* element that cannot be ignored when designing technology (Table 1). Table 1 also includes corresponding strategies to overcome barriers and measures of progress for each of the P^3 factors for the condition.

*Table 1: RaFT framework for physical rehabilitation technology. P^3 refers to **P**hysical, **P**sychological & **P**ersonal components*

	RAFT: P^3		
LEVELS: P^3	**NEEDS**	**STRATEGIES**	**PROGRESS**
1. Physical	Physical needs, capabilities, resources of the person: e.g., how constrained are the movements, how altered is the proprioceptive system, etc.	Strategies used by people or recommended by physiotherapists to overcome barriers and address needs.	The set of metrics that define progress towards goals over each of the **P^3** components.
2. Psychological	Emotional, cognitive, social resources and barriers to physical activity		
3. Personal	Personal aims, preferences, roles, goals (incl. social roles) to either recover and/or maintain capabilities.		

Physical factors

The physical component is the primary focus of the literature surrounding rehabilitation technologies and includes aspects such as tracking and measuring movement; it was the most encountered in our literature review. People need to be supported while doing physical activity, not only to maximise performance (such as number of repetitions, range of movement, pace of movement, balance) but also to learn ways of using their bodies. Compensatory behaviours due to limited capabilities (e.g., one handed dressing following stroke)(Cirstea & Levin 2000) or protective behaviours associated with fear and pain (e.g., moving stiffly, guarding, limping) (Aung et al. 2013; Sullivan 2008) can be the cause of further pain and damage. It is important to gain awareness of these physical behaviours that can become habitual or automatic, and to change them since they can be incompatible with physical goals such as increasing speed, power, and endurance or physical activity. Protective behaviours, aside from our work in CP, have not been acknowledged in the existing HCI literature even though this is commonly observed in many other chronic conditions. Differently from compensatory movements, both physical and psychological needs must be considered to reduce protective behaviour.

Psychological factors

Our studies with people with CP (Singh et al., 2014, 2016) indicate that psychological and emotional needs are equally important to physical needs for rehabilitation. Common psychological barriers in CP exist in relation to performing movement (e.g., fear, anxiety, low confidence), accepting the limitations of the condition (e.g., anger, frustration, low mood) and the social impact of living with CP (e.g., embarrassment, feeling stigmatised, loneliness). Similar psychological concerns in other chronic conditions are well-known (e.g., embarrassment, loss of confidence in stroke (Saunders et al. 2014), and fear of falls in Parkinson's disease (PD) (Jankovic 2008)). Our literature review findings show that, in the HCI or Computer Science literature, while authors do acknowledge these psychological factors, indicating their importance, they are rarely explicitly addressed/evaluated in the studies (see Table 2).

Table 2: Psychological barriers to rehabilitation raised in the literature review.

Psychological factors	**Conditions**	**Papers that raise the factors**	**Papers that address/ evaluate the factors**
Fatigue	PD, Stroke, Arthritis, CP, MS	McNaney et al., 2015; Vandermaesen et al., 2016; Kirk et al., 2016	Vandermaesen et al., 2016; Kirk et al., 2016)
Pain	CP, PD, Stroke, Arthritis	Dekker-van Weering and Vollenbroek-Hutten, 2015; Bagalkot et al. 2012; Costa et al., 2013; Song et al., 2014; Pompeu et al., 2015; Newbold et al., 2016; Singh et al., 2014, 2016, 2017	Singh et al., 2014, 2016, 2017.
Social Stigma (embarrassment)	PD, CP	McNaney et al., 2015; Ananthanarayan et al., 2014; Singh et al. 2016, 2017	McNaney et al., 2015; Singh et al. 2017
Anxiety	CP, Chronic Obstructive Pulmonary Disease (COPD)	McNaney et al., 2015; Newbold et al., 2016; Taylor et al., 2011; Singh et al. 2014, 2016, 2017	Singh et al. 2014, 2016, 2017
Perceived effort, competence	Stroke, CP	Singh et al. 2014, 2016	Jacobs et al., 2013; Vandermaesen et al., 2016; Singh et al. 2016.
Fear	CP, PD	McNaney et al., 2015; Newbold et al., 2016; Singh et al. 2014, 2016, 2017	Newbold et al., 2016; Singh et al. 2014, 2016, 2017
Motivation (includes presence of and loss of motivation due to slow progress/ degenerative disease)	Stroke, Spinal cord injury, MS, PD, CP	McNaney et al., 2015; Newbold et al., 2016; Octavia and Coninx, 2015; Jacobs et al., 2013; Vandermaesen et al., 2013, 2016; Wang, 2016; Matos, 2014; Singh et al. 2014, 2016, 2017	Newbold et al., 2016; Octavia and Coninx, 2015; Vandermaesen et al., 2013, 2016; Matos, 2014; Huang et al., 2014; Singh et al. 2014, 2016, 2017
Loss of confidence	Stroke, CP	Newbold et al., 2016; Jacobs et al., 2013; Singh et al. 2014, 2016, 2017	Newbold et al., 2016; Singh et al. 2014, 2016, 2017
Lack of ability to generalise to other movements due to fear	Stroke, CP	Jacobs et al., 2013; Singh et al. 2017	Singh et al. 2017
Boredom (lack of variability, challenge)	Stroke, CP	Jacobs et al., 2013; Singh et al. 2014	
Engagement (enjoyment, fun)	Stroke, CP, MS	Newbold et al., 2016; Octavia & Coninx, 2015; Jacobs et al., 2013; Vandermaesen et al., 2016; Tadayon et al., 2016	Newbold et al., 2016; Octavia & Coninx, 2015; Jacobs et al., 2013; Vandermaesen 2016
Depression	PD, CP	McNaney et al., 2015; Song et al., 2014; Taylor et al., 2011; Singh et al. 2014	
Good/bad days; on/ off days; variable ability; tendency to overdo	PD, CP	McNaney et al., 2015; Newbold et al., 2016; Singh et al. 2014, 2017	Newbold et al. 2016; Singh et al. 2014, 2017

Personal factors

Technology design needs to align with users' daily lives, interests and goals, in addition to the physical aims of the rehabilitation. Our literature review suggests that technologies designed for rehabilitation neglect individuals' goals within the context of their lives. Instead, most approaches tend to focus on fun (e.g., Schönauer et al. 2011; Jansen-Kosterink et al. 2013), or exercise sessions in front of a camera (e.g., Tang et al. 2015). Evidence is lacking for the potential of such systems to encourage people to self-manage their activity outside the clinic, particularly for functional improvement over time. Indeed, most of the systems are evaluated simply in terms of physical capability progress (e.g., range of movement of the leg, strength of grip) with respect to the exercise but without exploring if their capability to function has improved (beyond the use of questionnaires) (Huang et al. 2012). In Singh et al. (2014), we reported that people struggle to transfer gains from exercise to everyday activity. Thus, while people's physical capability may have improved (increased number of movement repetitions/steps taken) those metrics do not directly translate into confidence in doing the activity. Our studies with people with CP (Singh et al, 2017) and other studies from the wider literature (e.g., Zheng et al. 2010 for CP, stroke) suggest the importance of a more personalised approach towards achieving functional goals, reprising social roles or developing new ones – see Table 3.

Table 3: Personal barriers to rehabilitation based on the literature.

Personal factors	**Conditions**	**Related barriers**	**Papers that raise the factors**	**Papers that evaluate the factors**
Reconnecting with lost activities.	PD, CP, Stroke	Lack of time for home rehabilitation. Fear of losing habit of exercising.	McNaney *et al.*, 2015; Singh et al., 2017	Singh et al. 2017
Reducing dependency in daily life	MS, Paraplegia, CP	Cost of living, quality of life, cost of treatment. Difficulty in activities of daily living.	Vandermaesen et al., 2013; Wang, 2016; Singh et al., 2017	Singh et al. 2017
Interact and socialise with others	Stroke, PD, MS	Engage with community, others.	McNaney et al., 2015; Octavia & Coninx, 2015; Wang, 2016	McNaney et al., 2015; Octavia & Coninx, 2015; Wang, 2016

The *Physical Rehabilitation* component (henceforth referred to as W^4)

The ***W^4*** component of the framework (Table 8) encourage a broader consideration of the factors that define physical rehabilitation itself. The first overarching W^4 factor suggests establishing "*What*" the aims of physical rehabilitation are. The other three factors further help to understand these aims and the process to achieve them by understanding: (i) "When" the physical rehabilitation activities take place, (ii) "Who" directs or support the physical rehabilitation (generally not the clinician outside the clinic), and (iii) "Where" (the physical context) rehabilitation takes place. We present and discuss each W^4 factor here based on the findings from our own CP work and our literature review and workshop.

*1. **What*** are the aims of physical rehabilitation?

We identified three aims: (i) improve/maintain progress or reduce decline in physical capabilities, (ii) psychological/personal progress towards psychological/personal aims or goals, and (iii) gaining the skills to self-direct/self-manage activities for rehabilitation. Each activity can have a clear and different purpose. For example, people may choose to do tasks where the 'what' might be to increase or maintain physical capability (e.g., range of motion, number of repetitions, balance capabilities, muscle control and strength) and work towards achieving targets and goals indicating physical progress (e.g., gradual increase in control and range of motion when lifting arm). Physical improvement is the type of 'What' that is generally addressed in the literature concerning other chronic conditions and is the driving factor in the design of technology for rehabilitation. Less addressed by the literature are the other two aspects of the *What* (see Table 4). Psychological progress is critical to both engaging in a movement during physical rehabilitation and to acceptance of one's condition and its therapy. Hence, the different psychological factors identified in P^3 could or should be considered when designing for the *What* not only as barriers to it but as aspects of where progress is fundamental to its success.

An even less considered but very important aim of physical rehabilitation is to learn skills to self-direct/self-manage rehabilitation such as appropriately pacing activities. In our CP studies (Singh et al., 2014, 2016), physiotherapists emphasised that during pain management programmes, their role is not to direct the rehabilitation session, but to help the patient to learn the skills and confidence to self-direct activity, select goals, set an appropriate pace and decide when to progress to the next level. Indeed, they felt that patients who have not learned such skills, report difficulties in rehabilitation without clinical support.

Table 4 lists the aims of physical rehabilitation or *Whats?* from our review.

Table 4: The Whats or Aims of Physical Rehabilitation from the Literature Review

Physical Activity factors	**Types**	**Conditions**	**Papers (see Table 6 for Reference details for the numbers).**
What *(are the aims of physical rehabilitation)?*	(i) Improve/maintain progress or reduce decline in physical capabilities	PD, CP, MS	McNaney *et al.*, 2015; Huang et al., 2014; Newbold *et al.*, 2016; Octavia & Coninx, 2015; Song *et al.*, 2014; Pompeu *et al.*, 2015; de Paula Oliveira *et al.*, 2015; Tadayon *et al.*, 2016; Matos et al., 2014; Singh et al. 2014, 2016
	(ii) Psychological/ personal progress towards psychological/personal aims or goals	CP, MS	Newbold *et al.*, 2016; Octavia & Coninx, 2015; Singh et al. 2014, 2016, 2017
	(iii) Gaining the skills to self-direct/self-manage activities	CP	Newbold *et al.*, 2016, Singh et al. 2017

2. WHEN does physical rehabilitation take place?

Our studies (Singh et al., 2016; Singh et al., 2017) show that rehabilitation takes place in various contexts of a person's life, each associated with specific needs. We identified four physical rehabilitation situations: (i) typical dedicated exercise sessions, (ii) everyday function, (iii) function as a source of exercise and (iv) transferring skills from exercise to function. These "*Whens*" can be connected or dependent on each other, and this synergy can be leveraged by technology to achieve rehabilitation aims (e.g., doing a dedicated exercise can increase confidence in achieving functional tasks). However, these types of rehabilitation pose different challenges for technology design and it is therefore important to investigate them separately as well. We describe the four situations here in detail.

(i) Typical dedicated exercise sessions

Dedicated exercise sessions are typically used to increase, recover or maintain physical capability. They generally take place at fixed locations, focus on repetitive movements and are traditionally used by most rehabilitation technologies where people exercise in front of a television screen or Microsoft Kinect/ Nintendo Wii. For example, in our literature review, serious games were used for PD (McNaney et al. 2015; Pompeu et al. 2015), orthopaedic rehabilitation (Costa et al. 2013) and others. Most studies up to now have developed technology specifically designed to sense and provide feedback about the specifics of the movement to be trained. The selection of the exercise and the design of technology is generally driven by an in-depth understanding of the biomechanics of the movement, people's physical capabilities and the integration of physical measures and parameters to personalise the training. Games commonly target typical emotional barriers such as frustration and lack of motivation (McNaney et al. 2015; Octavia & Coninx 2015; Wang 2016; Matos et al. 2014) to make the repetitive rehabilitation activity more engaging.

(ii) Everyday functioning

In our CP studies (Singh et al. 2017), people considered functional tasks as rehabilitative exercise (e.g., loading a dishwasher involves bending and reaching), demonstrating that facilitating ubiquitous functional activity in everyday life can boost confidence and address low mood by providing a sense of progress and control. Studies in our literature review alluded to the importance of designing to facilitate everyday functional tasks (McNaney et al. 2015). Functional tasks are increasingly important for self-managed rehabilitation as often they may be the only source of activity. They can be supported by technology, but need different strategies to dedicated exercise sessions as there is no model movement to follow and the movement range is not predefined by the user's ability but by the activity (e.g., height of shelves which the user needs to reach). Thus, people may need to go beyond optimal targets set in accordance with their ability for a typical exercise session and to facilitate this movement they need to identify supportive strategies (either physical or environmental). Technology should consider how the targets differ from the capability of the person and compensate or tailor feedback accordingly. For example, while loading a dishwasher, body and movement awareness can be enhanced through tracking and feedback (real-time or retrospective); and technology can be used to support strategies, such as pacing activities (e.g., identifying when the person needs a break), relaxing (e.g., focus on breathing) or stretching (e.g., when feeling tense). In this sense, technology can be used to raise awareness of one’s body during functional tasks where people may be focussed more on the task, rather than their body’s needs.

(iii) Function as a source of exercise

In our CP studies (Singh et al. 2014, 2017), we reported how people incorporated further challenges, exercise/stretches into their daily tasks and routines. For example, some participants put objects higher up so they were forced to reach further. (e.g., reaching towards a book in a bookshelf). These tasks could be used as goals and to measure achievements and progress. Such embedding of rehabilitation in ubiquitous functional activity is also seen in other conditions in our literature review (e.g., Bagalkot & Sokoler 2011). The aim is to perform the specific rehabilitation exercises but within a functional situation that can be variable and complex. People may try to do this because while they may not have the time or motivation to exercise, they do tend to do functional tasks and this can lead to better adherence (Singh et al. 2014). Thus, there is a clear focus on building capabilities, not just in executing a functional task. Technology can be used in this context to exploit functional tasks to set goals to increase physical capabilities and confidence.

(iv) Transferring skills from exercise to functioning

Transfer of gains between rehabilitation exercises and function is important and was highlighted in our studies with CP (Singh *et al.* 2014, 2016). and in other conditions according to our literature review (Vandermaesen et al. 2016; Kirk et al. 2016; de Gouvêa et al. 2015). To achieve functional recovery, movement training needs to be meaningful to the person and what s/he wants to achieve (Takeuchi & Izumi 2013). Transferring is not typically addressed by technology in traditional rehabilitation models and when transferring skills is addressed using technology, this tends to be limited to simulated real-life activities in games or virtual reality environments (Paraskevopoulos et al., 2014). These environments neglect the complexities of mapping capabilities and extrapolating confidence from controlled exercise to everyday activity. While this approach appears effective in motivating physical performance in certain conditions, the simulated environment can fall short of modelling the complex real world, especially when psychological factors are a barrier to function. Technology can be designed to go beyond exercise and act as a bridge to function; for example, Vandermaesen *et al.*, 2016 used tangible daily use objects with sensor feedback for people with MS to practise functional hand grips. Technology can also raise awareness of capabilities during task performance by setting targets from the real world to exercise as in Newbold et al. 2016.

Table 5 lists the *Whens?* from our studies and literature review.

Table 5: The 'Whens' from the literature on physical rehabilitation

W	Types	Conditions	Papers (see Table 6 for Reference details for the numbers).
When?	Dedicated exercise sessions	PD, Stroke, CP, Spinal injury, MS	McNaney *et al.*, 2015; Huang et al., 2014; Newbold *et al.*, 2016; Octavia and Coninx, 2015; Song *et al.*, 2014; Pompeu *et al.*, 2015; de Paula Oliveira *et al.*, 2015; Tadayon *et al.*, 2016; Kirk *et al.*, 2016; Matos et al., 2014; Singh et al. 2014, 2016, 2017
	Everyday functional activities (activities of daily living)	PD, CP	McNaney *et al.*, 2015, Singh et al. 2014, 2016, 2017
	Function as a source of exercise	CP	Singh et al. 2014, 2017
	Transferring skills from exercise to functioning	Stroke, CP	de Gouvêa *et al.*, 2015; Kirk *et al.*, 2016; Vandermaesen *et al.*, 2016; Singh et al. 2017.

3. WHO directs (or co-directs) the rehabilitation? Who supports it? Who decides?

We identified two possibilities for this component of the framework: (i) the clinician, or technology as supervisor; and (ii) the person as self-supervisor supported by technology.

(i) The clinician or the technology as a supervisor

The most common approach in the literature involves the clinician deciding the rehabilitation exercises and corresponding parameters (movement type, range, duration). Technology is set up for clinicians to set exercise plans and assess physical progress; it serves to improve the objective measures of such assessment; and supports clinicians to personalize and optimise plans (de Paula Oliveira et al. 2015; Pompeu et al. 2015; McNaney et al. 2015). Some technology emulates the clinician by integrating models tuned by clinicians for continuous personalization (e.g., Matos et al., 2014). In this context, technology as a ‘who’ provides activity tracking, rewards for activity and supervision to ensure movement is correct (e.g., Duggan et al. 2014). Such an approach is however explored only in the context of exercise and not during functioning (or very limited in this context) as shown in Table 6.

(ii) The person as self-supervisor supported by technology

In chronic conditions, people are expected to self-direct their rehabilitation or share this role with a clinician/carer. Based on where people are in this journey towards self-management and the amount of support they need, two different roles for 'who' emerged for technology: (a) a (co-) supervisor to share control where technology can provide reassurance, co-supervise use of resources, guide attention to important information for activity and even free cognitive resources when needed (such as a physiotherapist, friend or partner); and (b) a self-representation that emerges through technology and increases peoples' awareness of their own capabilities (e.g., through feedback to enhance perception of body movement in Newbold et al., 2016, Singh et al. 2016, 2017). The self-representation is created through multi-sensory feedback such as visual and auditory feedback that provides extra information about the body's capabilities. Further, this representation is within the functional and personal context allowing people to appraise their performance leading to increased confidence and the ability to develop strategies for self-directed functioning.

Table 6 lists the *Whos?* as they emerged from other studies in our literature review.

Table 6: The 'Whos' from the literature on physical rehabilitation

W	**Types**	**Conditions**	**Papers (see Table 6 for Reference details for the numbers).**
Who?	The clinician or the technology as a substitute clinician	PD, CP, Stroke, MS	Huang et al., 2014; Octavia and Coninx, 2015; Song *et al.*, 2014; Pompeu *et al.*, 2015; de Paula Oliveira *et al.*, 2015; Tadayon *et al.*, 2016; Matos et al., 2014
	The person as self-supervisor supported by technology	CP	McNaney *et al.*, 2015; Newbold *et al.*, 2016; Singh et al. 2016, 2017

4. WHERE is the activity performed?

Whilst most of the literature considers physical rehabilitation as situated and that specific space will be made available in the home to complete the exercises, some studies have highlighted that rehabilitation space is influenced by other factors. Each context such as home or other public place has different characteristics and requires different support from technology. This question encourages an exploration of the rehabilitation context. Different factors characterising the 'Where' include:

(i) ubiquitous/improvised vs situated/ dedicated spaces

Many technologies for rehabilitation are designed to be used in situated spaces mainly for dedicated exercise (e.g., Chang et al. 2011). However, this is not the only kind of rehabilitation activity that people do. For example, this does not support functional activity (Bagalkot & Sokoler 2012). Our studies (Singh et al. 2014, 2017) and others from the literature review (e.g., McNaney et al. 2015) highlight the need for technology to be flexible for use in different locations and contexts. For example, in Bagalkot & Sokoler (2012), one of the rehabilitees used the portable technology on the stairs to exercise.

(ii) reconfigurable vs static spaces (i.e., level of control on reconfiguration)

The level of customisation of the environment possible (for activity) depends on its context and the level of control the rehabilitee has on changing it. For example, the home can be adapted to the needs of activity but a public place cannot. In Singh et al. (2017), people rearranged their home to better use their limited resources. Even in situations of greater control such as the home, our studies and those within the published literature (e.g., McNaney et al. 2015, Axelrod et al. 2009) revealed that rehabilitation can be affected by space available for activity and this needs consideration by technology designers.

(iii) social vs personal spaces

Technology can also be used outside the home, for example, as a reminder to stretch or take breaks, especially in social situations where people are busy or distracted. For example, in Singh et al. (2017) people with CP used technology to pace their activities and remind them to take breaks in social spaces. From these studies, it emerged that technology needed to be discreet yet able to attract users' attention. In Geurts et al. (2016), the authors refer to the need for technology design to consider social as well as personal spaces. Even in personal spaces, factors such as space available in people's homes, and attributes of the space in terms of light, temperature and social use by others in the home affect rehabilitation (Singh et al. 2014, 2017). People might also prefer to do activity at certain times of the day or to fit in with routines (Singh et al. 2014). For example, some people do exercise in the bedroom before work, others do it socially in the living room with their children. Such motivations need to be accounted by technology for rehabilitation in the home or other environments (e.g., in the park), differently from hospital or clinic.

Table 7 lists the *Wheres?* from our studies and review.

Table 7: The 'Wheres? from the literature on physical rehabilitation

W	Types	Conditions	Papers (see Table 6 for Reference details for the numbers).
Where?	Ubiquitous space	CP	Huang et al., 2014; Newbold *et al.*, 2016; Singh et al. 2014, 206, 2017
	Situated space	CP, Stroke, MS, PD	Octavia and Coninx, 2015; Song et al., 2014; Pompeu et al., 2015; de Paula Oliveira et al., 2015; Tadayon et al., 2016
	Personal (individual) space	CP	Newbold et al., 2016; Singh et al. 2014, 2016, 2017.
	Social space	CP	Geurts et al., 2016; Singh et al. 2017
	Static space		Oliveira et al., 2015
	Reconfigurable space	PD, Stroke, CP, Spinal injury, MS	McNaney et al., 2015; Huang et al., 2014; Newbold et al., 2016; Octavia and Coninx, 2015; Song et al., 2014; de Paula Oliveira et al., 2015; Kirk et al., 2016; Matos et al., 2014; Singh et al. 2017.

The *Social* component (henceforth referred to as S)

In the current literature, physical rehabilitation is considered an individual activity or carried out in the presence of known peers. However, the social scope of physical rehabilitation is wider and could also be in the presence of others (including strangers) e.g., when exercising outdoors, swimming or cycling (Geurts et al. 2016). These situations have their own set of constraints. When activity is performed socially, the psychological and personal factors may differ, depending on who it is performed with (Singh et al. 2017). Therefore, we introduced the social level in the RaFT framework, which refers to '*with whom is the activity performed?*' or '*in what social environment/ context is the activity performed?*' The important aspects of the social component that emerged from our studies and those included in the literature review suggest acknowledging whether the person engaging in rehabilitation is (i) within a familiar context, such as with friends/family (McNaney et al. 2015; Singh et al. 2014; Octavia & Coninx 2015; Bagalkot & Sokoler 2012), (ii) with other people with the same condition (Singh et al. 2014; Wang 2016), or (iii) as part of an unfamiliar group (Felipe et al. 2015; Taylor et al. 2011). Various physical, psychological, and personal factors affect this component depending on who the rehabilitation is performed with. These factors include feeling embarrassed or uncomfortable when accompanied by people who do not understand the chronic condition (Felipe et al. 2015; Geurts *et al.*, 2016), or feeling encouraged by seeing others with the same condition complete certain activities (McNaney et al. 2015; Singh et al. 2014). Studies from the exergaming literature have used balancing approaches (e.g., Gerling et al. 2014) to enable people with varying skill levels to play together more equally by taking account of each individual's skill level. Similar approaches were implemented in studies in our literature review (Octavia & Coninx 2015) and are considered *desirable* (Wang 2016; McNaney et al. 2015). The aim is to provide enjoyable social experiences, increase self-esteem and encourage appropriate rehabilitation matched to the users' capabilities.

In Singh et al. (2017), we reported that in social contexts with unfamiliar others (e.g., working, shopping), people may not practise pain management skills due psychological factors such as embarrassment about they are perceived, feelings of stigma if they have to take extra breaks during work to complete rehabilitation tasks. Most rehabilitation technologies are designed to be used *in situ* and do not address such situations. Hence, there is a need to design for, and assess how, the presence of others affects physical rehabilitation and how this can change depending on who those others are.

Discussion: consolidating the framework

In the previous section, we discussed the P^3, W^4 and S factors of the framework separately. However, all these component factors are interlinked and should be analysed together when designing, gathering user needs or evaluating rehabilitation technologies. Table 8 shows how the aspects of the framework relate to each other. The framework can be used to gain an in-depth understanding of the design space and to better inform the design of technology. In addition, it can also be used to set more 'fit for purpose' evaluation criteria grounded in the problem the technology is trying to overcome.

In our studies with people with CP (Singh et al. 2014, 2016, 2017; Olugbade et al. *in press*), we identified a larger set of emotional needs that need to be addressed (especially in the absence of clinicians), such as fear, anxiety, depression, pain, and psychological (not just physical) setbacks. The physical capability of a person might not improve in long-term conditions but often fluctuates (e.g., CP itself is a condition but is also observed with other conditions such as stroke) or deteriorates (e.g., MS). In our studies (Olugbade et al., *in press*), we have investigated how despite high motivation, each of the different affective states interferes with physical rehabilitation differently and needs to be specifically targeted. For example, on days when the level of pain is low and people feel good, they may tend to overexert themselves which can lead to setbacks. In other studies, such needs may not emerge either because of the presence of a clinician during evaluation that can alleviate anxiety (e.g., Doyle et al., 2010; Jansen-Kosterink et al. 2013), because biomedical outcomes are used to measure effectiveness or because the evaluation studies have focused mainly on the usability and general experience of the technology (Donker et al. 2015; Costa et al. 2013). A few HCI studies highlight emotional states such as the ones mentioned above but they are not addressed in the design/evaluation as shown in Table 2. In addition, physical needs of the condition under rehabilitation also need to be considered. For example, physiotherapists in Singh *et al.* (2014) focused on encouraging any activity in people with CP while raising awareness of protective behaviour but in other conditions, such as stroke or rehabilitation following knee replacement surgery (Ayoade & Baillie, 2014), more emphasis was reported on performing movements correctly.

Table 8: RaFT framework for physical rehabilitation technology: physical activity environment component

LEVEL: W^3	**SCOPE of W**	**P3 Requirements**	**P3 Strategies**	**Social context**
W^1: *WHAT* are the Aims of Physical Rehabilitation? Gain or maintain P^3 capabilities or slow down their deterioration;	**(i)** physical progress/maintenance/slowing deterioration **(ii)** psychological or personal progress (iii) Skills to direct the physical activity	P^3 factors that can act as facilitators or barriers? P^3 components targeted/operated on, and/or rewarded?	Tailoring of P^3 strategies according to the context of rehabilitation	With whom/ for whom/ in the presence of whom is activity performed? **Aim**: to identify the social context of the activity (not in a coaching role): e.g., exercising with family/ friends, doing tasks with colleagues, socializing with friends, riding a bus with strangers. What should be shared? With whom? How will data be used?
W^2: ***When?*** In what context is the physical rehabilitation activity performed?	**(i)** Typical dedicated exercise sessions (ii) Everyday functioning (iii) Function as a source of exercise **(iv)** Transferring skills from exercise to functioning	How do P^3 barriers and resources change between the when of physical activities?		
W^3 : *Who directs?* Who (co-) directs or facilitates the different rehabilitation aims	(i) The clinicians and the technology to simulate or supporting the clinician (ii) The person and the technology to support the person (co-supervisors The family/friend/carer	What P^3 components support or act as barrier: - to self-direct the activity - to trust the coach (his/her understanding of one's body state and need) Who should have access to the P^3 components?		
W^4: W*here?* Where is the activity performed? This question aims to understand the environment and the level of control on it	(i) dedicated vs improvised spaces (ii) ubiquitous vs situated spaces (iii) reconfigurable vs static spaces (i.e., level of control on reconfiguration) (iv) social vs personal spaces	How P^3 components affect (e.g., choice of place) or are affected (e.g., lack of control on environment) by the *where*. E.g., (organisation of the home; weather, time of the day)?		

Conclusions

Here, we presented a framework for the investigation, design and evaluation of rehabilitation technologies (RaFT). The framework emerged from our studies spanning over 5-years on designing technology for CP physical rehabilitation, from an associated literature review assessing other long-term conditions where physical rehabilitation is important and a workshop with experts. While our studies investigated needs in CP, our findings are relevant in rehabilitation for other chronic conditions where people face psychological and personal barriers and where rehabilitation is integrated into people's everyday lives.

Our framework provides technology designers with a tool to systematically assess the design space for physical rehabilitation in chronic conditions. Through appropriate assessment of its three components - P^3 (Person), W^4 (Physical rehabilitation), S (social context) - the RaFT framework can assist designers and developers of rehabilitation technology to formalise their intentions with respect to each design consideration, and to clarify implementation mechanisms that are important for achieving the aims of the technology. The P^3 part of the framework aims to help the designers to go beyond physical issues and build an understanding of the psychological and personal needs and barriers to rehabilitation. However, what changes for each specific rehabilitation condition is how the framework is tailored to the condition. The W^4 component aims to support designers in understanding the wider scope of physical rehabilitation beyond exercise sessions, including skills to self-manage, taking responsibility and the various factors that characterise the context in which physical rehabilitation is carried out. Finally, the S component reminds designers that physical rehabilitation does not occur in isolated dedicated spaces, but occurs in people's lives, which is also inhabited by others (known or unknown to the person).

In future research, experimental work is needed to demonstrate the framework's suitability and effectiveness in real-life situations for different rehabilitation conditions and contexts. Indeed, this is an initial proposal of a framework based on our findings and refined by an initial literature review and one workshop. We will be running more workshops to test and refine the framework. Finally, the framework is not intended as a replacement for design processes, such as user-centred design. Design processes that integrate information on the needs, desires, and limitations of users into the development process are critical to ensuring that technologies are usable and useful and are needed in addition to frameworks such as RaFT. We hope that this framework will help designers identify some of these needs throughout user studies and in formative qualitative work.

Summary of impact

The RaFT framework includes factors that technology designers should consider to address people's physical rehabilitation needs. The framework focuses on the interaction between the physical, psychological and personal needs that technology must address with the type of activity, where it is executed/ performed, who directs it, who participates in it, what are the rehabilitation aims and how can technology be used to achieve the goals of activity. While the framework was developed based on the needs of people with CP, we argue that it can be generalised to other conditions based on the literature (e.g., stroke) and we have done an initial literature review reported in this paper to this end.

The RaFT framework's contribution is that it provides a structure for designers to identify factors that need to be considered to support physical rehabilitation in people with CP and other conditions where mobility is restricted. Our aim is not to create a static resource but to use this framework as a dialogue that is enriched through use by researchers/ designers for the development/ expansion of novel rehabilitation technologies. We hope that, other researchers will build on the framework to provide a rich understanding of physical rehabilitation in everyday life.

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Ramón y Cajal Research Fellow, Departamento de Informática, Universidad Carlos III de Madrid, Leganés, Spain
Honorary Research Associate, UCL Interaction Centre, University College London, London, UK

Biography

Ana Tajadura-Jiménez studied Telecommunications Engineering at Universidad Politécnica de Madrid. She obtained an MSc degree in Digicom and a PhD degree (2008) in Applied Acoustics at Chalmers University of Technology, Sweden. Ana was post-doctoral researcher in the Lab of Action and Body at Royal Holloway, University of London. In 2012 she moved to University College London Interaction Centre (UCLIC) as an ESRC Future Research Leader and Principal Investigator of the project *The Hearing Body*. Since 2016 Ana is a Ramón y Cajal research fellow at Universidad Loyola Andalucía (ULA) and Honorary Research Associate at UCLIC. At ULA, she is part of the Human Neuroscience Laboratory and coordinates the research line called "Multisensory stimulation to alter the perception of body and space, emotion and motor behavior". Ana's research is empirical and multidisciplinary, combining perspectives of psychoacoustics, neuroscience and HCI.

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Anna Roberts

PhD candidate, UCL

Biography

Anna Roberts is an MRC funded PhD candidate based in the Department of Behavioural Science & Health at UCL. Anna's research aims to develop and evaluate a smartphone app to increase cancer survivors' participation in physical activity.

Her previous work included the evaluation of digital health interventions to promote physical activity among people with knee osteoarthritis at the University of Nottingham, where she also completed her BSc in Psychology and MSc in Health Psychology.

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Nadia Bianchi-Berthouze

Professor, UCL Interaction Centre, University College London, London, UK

Biography

Nadia Bianchi-Berthouze is a Full Professor in Affective Computing and Interaction at the Interaction Centre of the University College London (UCL). She received her PhD in Computer Science for Biomedicine from the University of the Studies of Milan, Italy. Her research focuses on designing technology that can sense the affective state of its users and use that information to tailor the interaction process.

She has pioneered the field of Affective Computing investigating body movement and more recently touch behaviour as means to recognize and measure the quality of the user experience in full-body computer games, physical rehabilitation and textile design. She also studies how full-body technology and body sensory feedback can be used to modulate people's perception of themselves and of their capabilities to improve self-efficacy and coping capabilities.

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Amanda CdeC Williams

Reader in the Psychology & Language Sciences Division of UCL.

Biography

Amanda Williams is a Clinical Psychologist with an interest in chronic pain, behavior associated with pain, psychologically based treatment and evaluation. She worked clinically and in research and audit in a charity for torture survivors, and is now developing research and policy work with colleagues in the field. She is involved in several systematic reviews and meta-analyses on pain treatments, and in writing UK and European guidelines on best practice in managing pain; she is also pursuing experimental work concerning expression of pain and its (mis)understanding by others.

Amanda was a founding member of a special interest group in pain from torture, organised violence, and war in the International Association for the Study of Pain, and has spoken at several national pain conferences about recognition and treatment of pain in survivors of torture. Dr Williams has written over 120 papers and chapters on aspects of pain and psychology, presents at national and international pain meetings, and is on the editorial boards of several major pain journals.

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