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Tailoring real-time physical activity coaching systems: a literature survey and model

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Abstract Technology mediated healthcare services designed to stimulate patients' self-efficacy are widely regarded as a promising paradigm to reduce the burden on the healthcare system. The promotion of healthy, active living is a topic of growing interest in research and business. Recent advances in wireless sensor technology and the widespread availability of smartphones have made it possible to monitor and coach users continuously during daily life activities. Physical activity monitoring systems are frequently designed for use over long periods of time placing usability, acceptance and effectiveness in terms of compliance high on the list of design priorities to achieve sustainable behavioral change. Tailoring, or the process of adjusting the system's behavior to individuals in a specific context, is an emerging topic of interest within the field. In this article we report a survey of tailoring techniques currently employed in state of the art real time physical activity coaching systems. We present a survey of state of the art activity coaching systems as well as a conceptual framework which identifies seven important tailoring concepts that are currently in use and how they relate to each other. A detailed analysis of current use of tailoring techniques in real time physical activity coaching applications is presented. According to the literature, tailoring is currently used only sparsely in this field. We underline the need to increase adoption of

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tailoring methods that are based on available theories, and call for innovative evaluation methods to demonstrate the effectiveness of individual tailoring approaches.

Keywords Tailoring · Personalization · Physical activity · Real time coaching · eHealth · Telemedicine

1 Introduction

The prevalence of chronic diseases is increasing world wide, largely due to demographic changes. The growing demand on healthcare services calls for cost-effective treatments that reduce the demands on healthcare professionals. Provision of eHealth and telemedicine services, in particular technology mediated services which stimulate and support patient's self-efficacy, is a fast growing field of research (Ekeland et al. 2010) and is widely regarded as a promising paradigm to reduce the burden on the healthcare system. An important factor in prevention and treatment of chronic disease and supporting healthy ageing is maintaining a healthy lifestyle in terms of regular physical activity. The American College of Sports Medicine recommends that the majority of adults perform moderate-intensity cardio respiratory exercise training for at least thirty minutes each day (Garber et al. 2011). Monitoring of physical activity and development of eHealth and telemedicine systems to motivate individuals to reach personal activity targets is a large and growing field of research and development in its own right.

1.1 Physical activity monitoring

Research into accurate assessment of physical activity levels has been conducted for many decades. Kohl et al. (2000) reviews various assessment techniques, citing articles dating back to 1971, and classifies techniques into six categories, including *self-report* (Sallis and Saelens 2000), *direct observation* (McKenzie 2002), *indirect-, and direct calorimetry* (Bailey et al. 1995), *doubly labeled water* (Speakman 1998) and *electronic or mechanical monitoring* using e.g. pedometers (Saris and Binkhorst 1977; Lutes and Steinbaugh 2010) and accelerometry (Bouten et al. 1997; Plasqui et al. 2013). Activity monitoring tools in this last category have seen a surge in recent years due to their low cost and unobtrusive applicability.

The popularity of low-cost, accelerometer based activity monitoring tools becomes apparent when looking at the wide range of commercially available systems and services (Table 1). These commercial fitness applications, designed for use throughout the day, measure physical activity and provide feedback on performance and/or progress to the user in various ways. The products vary mainly on two points: the location where the sensor is worn, and how measured activity data is fed back to the user. This feedback is either visualized on the sensor, smartphone, web portal, or PC application. A number of commercially available accelerometry-based activity monitoring and feedback applications are shown in Table 1.[1]

[1] This selection (gathered in June, 2012) does not represent an exhaustive list but serves as a representative sample to illustrate the range of available commercial products.

Table 1 Representative sample of commercially available accelerometry based activity monitoring systems

#	Name	Worn	SE	SP	WP	PC	Website
1	Polar Active	W	+		+		www.polarusa.com
2	ActivPal	H			+	+	www.paltech.plus.com
3	GENEActive	W	+			+	www.geneactiv.co.uk
4	MoveMonitor	H				+	www.mcroberts.nl
5	APDM	H A W C				+	www.apdm.com
6	ActiGraph	H A W C				+	www.theactigraph.com
7	Philips DirectLife	H C P	+		+		www.directlife.philips.com
8	FitBit	H P C W	+	+	+		www.fitbit.com
9	Acti Smile	H C	+				www.actismile.ch
10	BodyBugg	U	+	+	+		www.bodybugg.com
11	BodyMedia FIT	W		+		+	www.bodymedia.com
12	Jawbone UP	W		+			www.jawbone.com/up/
13	Nike+ Fuelband	W	+	+	+		www.nikeplus.nike.com

The 'Worn' column indicates where the sensor can be worn: on the Ankle (A), Chest (C), Hip (H), Upper arm (U), Wrist (W) or in the Pocket (P). The remaining columns indicate whether the product gives feedback on the sensor (SE), smartphone (SP), web portal (WP) or through a PC program (PC)

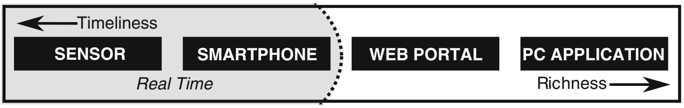

Fig. 1 Timeliness versus richness of feedback modalities. Modalities to the left are increasingly readily available, while modalities to the right are increasingly rich in their capabilities of providing feedback. Sensor and smartphone are real time feedback modalities

The feedback modalities used differ in terms of timeliness and richness as visualized in Fig. 1, with feedback on the sensor being the fastest and least rich, and PC applications capable of the richest, but slowest, feedback. Sensors capable of displaying feedback can do so without any significant delay, however the feedback is simplistic due to the limitations of a small display and low processing power. Smartphones offer more possibilities in terms of screen size and processing, and if a sensor is connected (wirelessly) to a phone (e.g. *Nike + Fuelband*) feedback via the phone can be presented in real-time. Web portals introduce a delay in feedback since they operate on synchronized data over the internet, however they offer a potentially richer experience due to the ability to provide full-screen data visualization. Furthermore they can be accessed from any location. Currently available PC applications usually require the sensor to be physically near a specific computer running specific software. This approach offers the least timely modality for providing feedback. However, the available processing power and screen size make it potentially the richest way of doing so, enabling for example the use of realistically rendered virtual human avatars.

1.2 Background

A vast range of systems for daily activity monitoring are available; a complete review of these is not the purpose of this article. Rather we focus on the techniques employed in these systems which aim to motivate the user to reach personal activity related goals. We have already shown the diversity in the way different systems provide feedback to the user, ranging from real-time approaches through a display on the sensor or a direct connection to a smartphone, to *offline* methods using e.g. web portals or PC applications. However feedback is only one of the possible ways of stimulating the user to change his activity behavior through generating awareness of current behavior. There are other motivational strategies and different ways of ensuring that the system's goal of changing the user's behavior is understood and followed by the user. Since each individual is different, an intervention should preferably use an approach which matches the individual user. This is better known as *tailoring*, and it is the topic of this survey.

The field of tailoring—also referred to as personalization, or individualization—is broad, even when limited to behaviour change interventions. Long before the emergence of eHealth and telemedicine, tailoring techniques were applied to print-based health behavior change interventions. These 'tailored' interventions could range from a simple leaflet that is addressed to an individual by name—i.e. personalized generic communication (Kreuter et al. 1999), a message developed specifically for a certain target group to messages targeted at the individual user. The effects of tailoring in such print-based interventions have been well documented, and the overall merit of this approach is clear (see e.g. Noar et al. 2007 for a meta-review on tailored print).

The use of printed material however, severely limits the ability to effectively target individual users, a shortcoming that is alleviated by the application of web-based interventions. In a study to promote a healthy lifestyle, targeted at families, Colineau and Paris (2011) used an online webportal to provide family-based goals and tailored feedback to encourage families to submit ideas for improving the family's lifestyle. The feedback messages provided by this online platform are tailored specifically to the situation of the family, or of individual family members through an automatic message composition system. The use of such computerized interventions allows more advanced tailoring, providing more personal and varied motivational messages to the user.

Morandi and Serafin (2007) use various parameters such as stage of change, day of the week, and specific user preferences to tailor motivational messages to the user. Others use more advanced models based on e.g. ontologies (Erriquez and Grasso 2008) possibly in combination with user clustering (Cortellese et al. 2009). A method for clustering users of a health-related persuasive gaming application is discussed in Orji et al. (2014) in this issue, showing which design strategies fit best to which gamer type. To facilitate personal communication with the user, the field of tailored behavior change interventions is highly related to and benefits greatly from the work done on user modeling, a field that addresses the issue of communicating the *right* thing at the *right* time in the *right* way for each individual user of a system (Fischer 2001). In particular, smartphone based user modeling frameworks such as described in Gerber et al. (2010) offer promising benefits for real time tailored coaching applications, as smartphones offer the best potential for providing rich, real-time coaching (see Fig. 1).

1.3 Scope and goals

The body of literature on tailoring, as well as on activity monitoring and coaching is extensive, and as stated earlier beyond the scope of this survey. We focus here on the following two key aspects:

1. *Physical activity coaching* we include only applications which aim to motivate users to change their activity behaviour by means of a coaching element.
2. *Real time tailoring* we include only those systems that offer real-time coaching, and use some form of tailoring to adjust the application's communication to individual users.

The goals of this article are twofold: (*I*) to provide a comprehensive survey of the literature that describes tools and techniques currently used for tailoring in real-time coaching applications for physical activity; (*II*) to define a conceptual framework of these techniques, extending current models of tailoring, that can help guide the design of new tools and applications in this field.

This article is not a systematic review in the sense that we do not aim to derive statistical evidence or conclusions from existing literature. Due to the scoping of the article it is also clear that we neither capture the full body of work on tailoring, nor on physical activity promoting applications. Instead we aim to provide an exploratory and more detailed analysis of the more narrow cross-section between these two fields. Emerging ubiquitous technology brings the promise of continuous coaching that goes beyond e.g. daily or weekly summaries of performance. Smartphones and other intelligent devices have the ability to reach their users at opportune moments throughout the day, and as such are able to provide intensive coaching. This ability has great merit for behaviour change systems and as such we add a specific focus on such emerging technologies that offer *real-time* tailored activity coaching.

Various reviews, complementary to the current work, have been published in recent years and will be discussed in Sect. 2. The literature search process is described in Sect. 3, after which an overview of included papers is given in Sect. 4. We then present our model of tailoring (Sect. 5) before providing an analysis of the tailoring concepts (Sect. 6), finishing with a discussion (Sect. 7) and conclusions (Sect. 8).

2 Related work

In recent years, a number of scientific review papers were published on various topics related to the theme of tailored real-time coaching for physical activity. In 2008, Lustria et al. (2008) reviewed 30 computer-tailored health interventions delivered over the web, seven of which in the domain of physical activity. Although the modalities (or delivery methods) used for the interventions were not real time, there were some interesting findings in the various tailoring mechanisms adopted. The authors distinguish between three types of tailoring: personalization, feedback, and adaptation (or 'content matching’). These types originate from a 2008 paper by Hawkins et al. (2008) who systematically defined the constructs that encompass tailoring. A detailed description of tailoring concepts, including the ones defined by Hawkins is given in Sect. 5.2. All of the included physical activity interventions in Lustria’s review adopted a combination of two or all of these tailoring mechanisms. Overall, the authors conclude that computer-tailored online interventions vary greatly in their strategies to provide users with tailored messages, but also in their delivery mode and -timing, and overall levels of sophistication.

A systematic review published in 2009 by Fry and Neff (2009) focuses specifically on periodic prompts that encourage healthy behavior (including physical activity) and shows the effectiveness of daily, weekly, or monthly messages, reminders or brief feedback in limited contact interventions. The review includes 19 articles, published between 1988 and 2008, 13 of which used email as the medium for sending prompts, and 14 of which employed some form of message tailoring. One of the aspects evaluated was the timing of messages. Most of the included studies used weekly prompts to encourage healthy behavior change, and in one of the studies it was shown that weekly (telephone) prompts performed significantly better in encouraging physical activity than prompts sent every 3 weeks (Lombard et al. 1995). The authors state that the question remains how prompts issued every day (a situation that would better approach the real-time feedback that we are interested in) would affect behavior change, because such a frequency was not found in any of the included studies.

A review by Enwald and Huotari (2010) on second generation tailored health communication for the prevention of obesity conclude on this regard that “*mobile devices can help to achieve ‘kairos’, that is, the opportune moment to persuade...*”. Real-time feedback through the use of mobile phones thus seems to be a promising, but underexplored field of research. In general, Enwald and Huotari (2010) found in their review of 23 studies, from which seven targeted physical activity, negative or mixed results regarding the effectiveness of tailoring, which according to the authors, is in line with previous studies. A particular focus of interest in their review is the use of theories and models of health behavior change to guide intervention design. Out of the included 23 studies, 14 used Prochaska’s Transtheoretical-, or Stages of Change (TTM/SoC) model, including five of the seven physical activity related studies. The SoC model claims that people attempting to change can be categorized as being in one of five stages of the change process: precontemplation, contemplation, preparation, action, and maintenance (Prochaska and Velicer 1997). The theory is often used in physical activity interventions as one of the tailoring criteria, e.g. people in different stages need different motivation or prompts, but the effectiveness of using this model in physical activity interventions is contested (Adams and White 2005). The ‘controversy’ of using the TTM in the domain of physical activity promotion is again underpinned by a review on tailored print communication by Short et al. (2011) who state that their findings support earlier claims that studies using Social Cognitive Theory (Bandura 1986) or The Theory of Planned Behavior (Ajzen 1991) demonstrate more positive effects in increasing physical activity levels than those applying the theories of the TTM.

The reviews mentioned earlier are relevant to the current work insofar that they deal with tailoring for healthy behavior, including physical activity, but none of them

Table 2 Search terms used in the systematic literature search phase

Topic	Terms
Personalized	Personalized OR personalised OR personalization OR personalisation OR individualized OR individualised OR individualization OR individualisation OR tailored OR tailoring
Activity	Physical activity OR daily activity OR **walking** OR **exercise** OR **exercising** OR **Activities of daily living**
Coaching	Coach OR coaching OR feedback OR motivate OR motivation OR stimulate OR stimulation OR promote OR promotion
Application	**Application** OR **system** OR **device**

Target literature has to contain at least one of the listed terms from each of the three topics. The bold-underlined terms were added in the second literature search phase

have a focus on (or even mention) real-time technologies. In contrast, a review by Kennedy et al. (2012) deals specifically with what the authors call "active assistance technology", defined as "*any technology involving automated processing of health or behavior change information that is ongoing as the user interacts with the technology*". One of the four technology roles selected for inclusion of articles is defined as "*dynamic adaptive tailoring of messages depending on context*", which has potential overlap with the topic of real-time, tailored feedback. The authors found widespread use of dialog systems as active technology (19 out of 41 included studies), out of which eight employed embodied conversational agents as interface to the user. Overall they found that dynamic tailoring was not a major topic in most included studies and concluded that the potential of active technologies for dynamic information processing is currently not fully exploited. The authors stress the need for interdisciplinary collaboration between behavior change researchers and researchers from computer science and cognitive science, but do not provide clear recommendations on the use of dynamic tailoring.

3 Search strategy, inclusion-, and exclusion criteria

The systematic literature search was carried out in two phases. An initial systematic search was done in July 2012 (phase one). Due to the limited amount of included articles, a second phase search was performed in August 2013 (phase two).

To capture the literature relevant for the scope and goals (Sect. 1.3) of this survey we formulated our search query to find articles related to "[*personalized*] [*activity*] [*coaching*]". The search terms used can be found in Table 2, where all **bold-underlined** terms were added only for the second phase. In order to cover both the health- and technology domains, we performed the initial search on PubMed (www.pubmed.com, 582 results) as well as the ACM Digital Library (www.dl.acm.org, 623 results). Additionally we included a total of 116 results from a manual search through Google Scholar (www.scholar.google.com) and our personal libraries, obtaining a total initial set of 1.321 papers. We performed an initial filtering of results by removing duplicates and by looking at titles and abstracts, eliminating all papers that were not primarily about

Table 3 Listing of the inclusion- and exclusion criteria as used for the selection of final papers in phase one and two of the systematic search process

Topic	In./Ex.	Criteria
Activity	In.	Describes an application targeting promotion of everyday physical activities including e.g. walking or jogging preferably to be used throughout the day
	Ex.	Targeted at specific (rehabilitation) exercises, exergames, or specific training of functions/skills
Real-time	In.	Applications that are able to communicate constantly with the user and can give immediate feedback on measured performance
	Ex.	Web-based applications (where users can only be targeted after login) or applications that do not have a direct connection between sensor and feedback device
Tailoring	In.	Applications that use some form of tailoring/personalization
	Ex.	Applications that do not change their behaviour or usage for different individual- or groups of users

everyday physical activity, novel coaching tools or applications, or methods regarding motivational coaching. This first filtering resulted in a set of 320 papers for which full text articles were retrieved. When analyzing the full-text articles, we excluded any work that did not describe an application containing real-time communication with its user. Also, papers that targeted very specific physical activities—(e.g. gaming, exercises) instead of regular daily activities—were excluded. The specific inclusion-, and exclusion criteria are listed in Table 3. We found a total of *13 papers*, describing *11 applications* to be included in the survey. We also found a total of *40* "*background papers*" describing relevant (real-time) tailoring techniques that did not describe its use in a specific application. These papers are used throughout the survey to serve as examples or background literature where relevant.

For the second phase literature search we modified our search query in two ways. First we extended our definition of [*activity*], and second—based on the experience from the first phase of literature search—we limited our search to [*application*] oriented papers. The extended search terms are presented in **<u>bold-underlined</u>** in Table 2. The second phase search was carried out in August 2013. The systematic search was carried out on the PubMed and the ACM digital library archives. From these two sources we found a combined total of 986 results, out of which 361 were new compared to the phase one search results. By examining the titles and abstracts we filtered out any articles that were either not written in English, review articles, and articles not targeted at daily physical activity—resulting in a set of 85 potentially relevant new articles. We performed the same filtering on the archives of the User Modeling and User-Adapted Interaction Journal as well as the proceedings of the past conferences on User Modeling, Adaptation and Personalization (UMAP 2009–2012), resulting in an additional 42 articles. For the 127 potentially relevant titles, full-text articles were retrieved and the inclusion of papers was again based on the inclusion-, and exclusion criteria as described in Table 3. From the second phase search, an additional *two papers*, describing *two applications* were included. In addition, we added *10 "background papers"* to the body of literature to be used as reference material.

Table 4 Listing of the 12 included applications and their corresponding papers that were found during the literature search. The order is in ascending year of publication and author name

Sect.	Application	Reference (s)
4.1	The mobile personal trainer	Buttussi et al. (2006)
		Buttussi and Chittaro (2008)
4.2	MPTrain and TripleBeat	Oliver and Flores-Mangas (2006)
		de Oliveira and Oliver (2008)
4.3	UbiFit Garden	Consolvo et al. (2008)
4.4	NEAT-o-Games	Fujiki et al. (2008)
4.5	The mobile fitness companion	Ståhl et al. (2008)
4.6	Handheld exercise agent	Bickmore et al. (2009)
4.7	Haptic personal trainer	Qian et al. (2010)
		Qian et al. (2011)
4.8	Everywhere run	Mulas et al. (2011)
4.9	Move2Play	Bielik et al. (2012)
4.10	ActivMON	Burns et al. (2012)
4.11	BeWell+	Lin et al. (2012)
4.12	Analytic, social, affect	King et al. (2013)

In total, we included *12 applications*, described by 15 different papers found in the literature search. In order to adequately analyze and describe these applications, we performed an additional search targeting the selected applications by searching for the application *name* as well as for additional publications by the authors. This search yielded an additional 36 papers that are used to summarize the works in Sect. 4 below.

4 Descriptions of included applications

In this section we will present an overview and summaries of the 12 included applications (see Table 4). The summaries focus on (1) functionalities, (2) theoretical foundations, (3) employed tailoring concepts, and (4) algorithmic approaches. For each of the applications we address these four topics where sufficient details are provided from the literature. The analysis of these papers and the creation of the tailoring model described later was done in an iterative way. On the one hand, the concepts and model have been derived from the analysis of the literature, while on the other hand the same literature is later described using the model as framework for structured analysis. After the overview of papers presented here, we will first describe the key concepts and our model of tailoring in Sect. 5. Then, in Sect. 6, we give a detailed analysis of the various tailoring concepts by looking at how they are employed in included applications.

4.1 The mobile personal trainer

The mobile personal trainer (MOPET) described in Buttussi et al. (2006) and Buttussi and Chittaro (2008) is an embodied virtual trainer that can guide users through outdoor

Fig. 2 Example screenshots of four different real time physical activity coaching applications: **a** the MOPET system by Buttussi et al. (2006), **b** the UbiFit Garden by Consolvo et al. (2008), **c** the BeWell+ application by Lin et al. (2012) and **d** the socially framed application as described in King et al. (2013)

fitness trails (see Fig. 2a at the end of this section). The embodied coach, Evita, runs on a smartphone and provides audio navigation, audio and graphical feedback about performance and animated 3D demonstrations of exercises along the trail. The system uses GPS to track the user's position and encourages users to keep up with certain speeds at regular checkpoints using speech synthesis. The 2008 update of the MOPET system describes additional tailoring approaches like context-aware and user-targeting features. The system integrates a user model containing gender, age, weight, height, physiological parameters derived from a guided auto-test, as well as historical information regarding previously completed trails and exercises. The sensed context (location, speed) combined with information from the user model is used to recommend exercises and provide alerts regarding e.g. speed of jogging.

The MOPET user model is initialized at the application's first launch by requiring the user to manually input gender, age, weight and height. Subsequently the user is asked to perform the guided auto-test which consists of stepping on and off a step. The autotest implements an algorithm that estimates the user's maximum volume of oxygen uptake per minute (VO_2Max) based on the user's *Power*, heart rate and some gender/age specific constants. The user's Power calculation starts when the user's heart rate is within a predefined (age-specific) range and is based on weight, the height of the step (as indicated by the user) and the time taken per step. Additional user model information is obtained by storing the number of times a user has completed a certain exercise within-, above- or below the user's heart rate thresholds as well as the number of times the exercise was abandoned prematurely.

The Power and VO_2Max values can be updated by performing subsequent auto-tests, but are currently only used as an indication of the user's physical condition, and not for further tailoring of the system. Instead, the user's calculated heart rate thresholds and recorded previous experiences are used by the exercise recommender module. When recommending a strengthening exercise, the module keeps track of the current *level* of performance, starting at the beginner's level (fewer repetitions, slower pace). After each completion of an exercise the user model is updated with the performance, and subsequent recommendations of the same exercise can take this history into account by recommending increased repetitions or pace.

As future tailoring capabilities of the system, the authors mention the option of setting specific goals related to e.g. weight loss, cardiovascular training or muscle strength to further guide the recommendations of exercises. In a separate paper, the authors describe the automatic creation of a user generated fitness trail database that can be used in the MOPET system (Buttussi et al. 2009). By storing user-preferences in the trail database, collaborative filtering based algorithms can be used to recommend fitness trails to users of the MOPET system based on personal preferences as well as physical ability. The literature regarding the MOPET system does not give any details on whether any specific theories of behavior change are used as a basis of the tailoring features.

4.2 MPTrain and TripleBeat

The MPTrain system described in Oliver and Flores-Mangas (2006) is a mobile phone based system that uses automatic music selection to encourage the user to reach his/her exercise goals. The system consists of a set of physiological sensors (accelerometer, ECG) connected wirelessly to a mobile phone. The system implements a learning algorithm that automatically determines a mapping between musical features (volume, beat and energy), the user's current exercise level and the user's heart-rate response. While jogging, before the end of the current song, the algorithm determines whether the user needs to speed up, slow down or keep his pace, based on the user's current heartbeat compared to a predefined goal. MPTrain will then select the next song whose tempo is similar, faster or slower than the current song according to the difference between the actual and desired heart rates. The authors have chosen music as a feedback modality based on the theory that music improves gait regularity due to the beat helping individuals to anticipate the rate of movement, and as such causing the body and the music to get synchronized.

An update to the MPTrain system is presented in de Oliveira and Oliver (2008), dubbed TripleBeat. The TripleBeat system adds two important tailoring approaches: a virtual competition with other runners and a glanceable real-time user interface. The authors aim to increase the motivational effect of the system based on the behaviour change theories described in Fogg (2003) as well as on empirical demonstrations from related research. The authors specifically mention four persuasive strategies, taken from Fogg (2003), as motivation for their work: (1) providing *personal awareness* through feedback on current physiological and activity data—for which there are many examples; (2) leveraging *social factors* through providing real-time information about the performance of other users based on the work of Maitland et al. (2006), O'Brien and Mueller (2007) and Sohn and Lee (2007); (3) providing *enjoyable interaction* by e.g. the use of an appealing 3D virtual trainer as in the MOPET system (see Sect. 4.1) or through the use of virtual game environments (Mokka et al. 2003); and (4) *unobtrusive/intuitive notification*, stressing the need to provide relevant information without interrupting or disturbing the user.

In TripleBeat these persuasive strategies are implemented as follows. The *personal awareness* is created by allowing users to monitor heart rate and pace in real-time, as well as by providing real-time feedback on how to achieve specific workout goals. A more interesting and defining feature is the TripleBeat's implementation of *social factors*. Users can hold a virtual race with virtual runners—other runners who have previously completed a run or the user himself. In order to promote fair competition, the system can automatically match the user with a competitor based on similarity in how well they achieve their goals. This is done using a variation of the k-nearest neighbour algorithm on the *score-vectors* of the user and his potential opponents. In order to provide a challenge, there will always be at least one opponent whose score is higher than that of the user. The *enjoyable interaction* of Triplebeat is 'inherently' delivered through its musical feedback; and its *unobtrusive notifications* are provided through a glanceable user interface that provides simple and clear feedback on current performance. Additional information regarding the basis of the MPTrain/TripleBeat system—the automatic generation of music playlists—can be found in Oliver and Kreger-stickles (2006b), and details regarding the evaluations of the system can be found in Oliver and Kreger-Stickles (2006a).

4.3 UbiFit Garden

Consolvo et al. (2008) describe the UbiFit Garden, a mobile phone application that uses a glanceable display of a flowering garden to create awareness of and stimulate regular physical activity (see Fig. 2b). The system includes a separate sensor for measuring physical activity. The 'Mobile Sensing Platform' activity sensor takes data from a 3D accelerometer and a barometer and uses boosted decision stump classifiers to distinguish between various types of activities (e.g. walking, running, cycling) four times per second—described in more detail in Choudhury et al. (2008). This data is sent to the mobile phone over bluetooth where a smoothing algorithm is used to identify longer bouts of activities. In the case that performed activities are not recognized correctly, the user has the option of adding, editing or removing activities in a manual journal feature.

The defining feature of the UbiFit system is its glanceable mobile phone display. The display is implemented as a background image of the phone and represents the user's activity as a flowering garden. Each of the various types of detected activities are represented as a different type/color of flower. These different types of flowers represent different types of activities as recommended by the ACSM for a balanced physically active lifestyle: cardio, resistance training, flexibility, and walking. A specific tailoring approach that is implemented is a feature that allows users to set their own weekly goals in terms of activity types. Upon reaching their weekly goals, a large yellow butterfly appears on the glanceable display. Initial evaluations focused mainly on the activity detection component of the system, but a follow up three-month experiment was conducted later (Klasnja et al. 2009).

In Consolvo et al. (2008) the authors mention that the UbiFit garden application is targeted specifically at users in the contemplation, preparation and action stages of change of the transtheoretical model (Prochaska and DiClemente 1986), although it is unclear which specific design decisions were made based on this consideration. The application does not seem to use the user's current stage of change to tailor any specific form of motivational support. In Consolvo et al. (2009), the authors give background on some of the behaviour change theories behind the UbiFit garden system. For example, the ability for users to set their own goal is based on the Goal-Setting Theory by Locke and Latham (2002), with the specific reason for self-setting of goals being that *...the individual needs to have decided that the goal is important to her... rather than being assigned to her with no rationale*. More details regarding the goal setting design decisions can be found in Consolvo et al. (2009). Furthermore, the authors draw especially from two major psychological works: *Presentation of Self in Everyday Life* (Goffmann 1959) and *Cognitive Dissonance Theory* (Festinger 1957). A detailed description of how these theories can be applied in the design of systems supporting behavioral change can be found in (Consolvo et al. 2009).

4.4 NEAT-o-Games

Similar to the TripleBeat's virtual competition system described above, the NEAT-o-Games system by Fujiki et al. (2008) implements a virtual race as motivator for physical activity. The system's main purpose is to stimulate NEAT—*non-exercise activity thermogenesis*—or daily physical activity, by turning daily life into a game. An activity sensor measures daily physical activity and sends data to a smartphone over Bluetooth. An algorithm on the phone derives "activity points" from the measured movements, which propels the user forward in a virtual race with a networked buddy list, where a winner is declared every day.

The work is motivated by the idea that *strong motivation* and *ubiquity* are the two key drivers for everyday activity behavior change. The motivational aspect is tackled by opting for a gaming approach, while the ubiquity issue is dealt with by not requiring the full attention of the 'player' all the time. In principle, the user is playing throughout the day, by having all of his movements captured and transformed into "activity points". Primarily, these activity points are used to propel players forward in a virtual race with other players, while points can also be spent on hints in a cognitive game (Sudoku). The authors mention a set of four design principles used in the development of the system: *simple*, *informative*, *discreet*, and *motivating*. However, other than background on serious gaming for promoting physical activity, the authors do not seem to draw on any scientific theories of behavior change or tailoring approaches. The distinctive feature of the NEAT-o-Games system is the virtual race to provide motivation through competition. In an earlier pilot study it was shown that the addition of a computerized avatar increased mean activity of the user, and the further addition of a real human opponent increased activity even further (Fujiki et al. 2007). The system does not allow for automatic selection of opponents and requires a manual partnering with a buddy.

The system was evaluated in a short pilot study with eight participants, as well as a four-week field trial with ten included participants. The authors state that the gaming paradigm employed appeared to be effective as the participants who were classified as 'consistent users' reported higher activity levels than other participants.

4.5 The mobile fitness companion

The mobile fitness companion described in Ståhl et al. (2008) consist of a conversational agent running on a smartphone and a stationary system in the user's home in the form of a Nabaztag rabbit. The mobile interface shows an image of the same rabbit to create a feeling of persistence. The focus of this work is on the creation of a 'companion' as well as a natural language interface using automatic speech recognition (ASR) and text-to-speech (TTS).

The context of the work is the execution of fitness tasks. The system uses GPS to track the user throughout the day, deriving distance, pace, duration and calories burned during physical activities. The companion can keep track of a personal user plan and can suggest tasks for the user to perform based on the time of day and the user's current location (determined by GPS). The user can accept the suggestion or initiate a dialogue with the system to suggest a different exercise (e.g. walking). The technical details of the mobile fitness companion mostly concern the implementation of the ASR and TTS algorithms and functionalities through a client (mobile) and server architecture. As such, the authors do not provide any background regarding theories of behavior change or tailoring aspects (goal setting and context awareness) employed in the system. Details on the evaluation strategies can be found in Benyon et al. (2008) and further details including evaluation results are presented in Turunen et al. (2011).

4.6 Handheld exercise agent

In order to promote physical activity Bickmore et al. (2009) describes the handheld exercise agent. The authors developed a "general purpose health counseling agent interface" for use on smartphones. The interface consists of an animated agent that can display nonverbal conversational behaviors and produce text balloon output that is synchronized with lip movements. This embodied conversational agent (ECA) does not produce auditory speech due to privacy concerns. The article focuses on a pilot study to assess social bonding between user and agent in the application domain of exercise promotion. The study consists of two conditions: the AWARE condition, in which the agent automatically recognizes walking activities and the NON-AWARE condition in which the user has to explicitly tell the system when walking activities were performed. The agent would provide positive reinforcement after walking bouts of 10 min or longer, or provide neutral comments after shorter activity bouts. Also, in the AWARE condition, the user could request the total number of steps walked since midnight as additional feedback. The user interactions in the system are limited to multiple-choice options, and possible interactions are scripted in an XML-based hierarchical state-transition network. The scripts consist of agent utterances in plain text as well as specifications for transitions to different states based on user selection or sensed information (physical activity). Scripts are pre-processed using a text-to-embodied-speech engine as well as a viseme (visual phoneme) generator before being installed on the mobile device.

As a motivation for the work on embodied agents, the authors highlight the need for effective health behavior change interventions to deliver tailored motivational and informational messages based on the context of the user and his user characteristics such as motivational readiness (i.e. stage of change), past behavior, ethnicity and age. The complexity and nuance required to deliver this type of communication is perhaps most effectively delivered through technologies that come closest to the "gold standard" of one-on-one face-to-face counseling. The authors also highlight, from the literature, the importance of health provider empathy and the quality of the provider-patient working relationship in improving patient satisfaction, adherence and health outcomes. Context awareness is another important factor, as it provides the agent with the ability to proactively intervene in certain circumstances, increasing also perceptions of familiarity, common ground, solidarity and intimacy. However, the only "context aware" information currently employed in the system is the detection of bouts of walking. Overall it is hard to discover how certain design decisions are specifically motivated by (behavior change) theories. The system also does not use any specific tailoring approaches, other than that the use of an avatar should give a *personal* experience.

The author's focus is on the (embodied) conversational agents and provide much more background regarding this topic in e.g. Bickmore and Picard (2005) and Bickmore et al. (2005). More recently, the author's further explored the use of conversational agents to promote—amongst others—physical activity in Bickmore et al. (2013).

4.7 Haptic personal trainer

The work described in Qian et al. (2010) and Qian et al. (2011) takes a low-level approach to feedback on walking behavior for older adults. The solution is a smartphone based application that measures steps taken using the built in accelerometer and provides haptic feedback (vibrations) to the user to stimulate walking faster or slower. The author's argue that haptic feedback is ideal because it removes the need to consult the visual interface of the phone while in motion. Besides this relatively simple assumption, the work does not seem to be based on any specific theories of behavior change or persuasive technologies. The system also doesn't implement any specific tailoring approaches other than providing feedback to the user.

The work is implemented as a phone application (Nokia N95) including a step-counting algorithm that uses the phone's internal accelerometers. The haptic feedback consist of structured vibration pulses with varying durations that are composed into rhythmic units which are detectable by the user. A large focus of the work is on the development of these perceivable tactile icons (so-called 'tactons') that can aid in non-visual interaction between the system and the user. To find an optimal way of using the tactile channel for feedback, several experiments were conducted that are explained in more detail in Qian et al. (2011).

In a second version of the system, the haptic feedback was augmented with auditory feedback and additional work was done in amplifying the vibration signals of the phone. Sixteen older adults participated in an experiment to evaluate the effectiveness of the feedback modalities. For each participant a baseline pace (steps/minute) was recorded, and based on this lower- and upper limits of their ideal desired pace were calculated. During the experiment, participants were asked to walk for 90 s in four different feedback conditions (no feedback, audio-, tactile-, and audio + tactile feedback). Results showed that best performance—in terms of additional steps walked per minute—was achieved in a multimodal feedback scenario using both haptic and audio cues.

4.8 Everywhere run

The everywhere run smartphone application described by Mulas et al. (2011) is designed to motivate and support users during running activities. The main goal of the application is to foster social interaction between runners and real personal trainers so that runners can receive personal training plans. The main motivation behind the work is that one of the biggest barriers for beginning runners is the issue of creating a proper workout schedule; and social interaction can help motivate users to exercise. Other than this general assumption there is no reference to theoretical background on e.g. goal setting theory. In the everywhere run application, workout plans can be created on the Android based smartphone application, but more importantly they can be sent to the application via email. This way of interaction allows professional trainers to design a personalized, detailed workout plan for the users and send it to the user. When the user starts a session, the application functions as a virtual trainer by making sure the user adheres to his training plan. The application's screen serves as a glanceable user interface, while audio cues guide the user through the workout session. The application promotes social interaction by enabling users to share their workout schedules with others. With the focus on social interaction and setting of exercise goals, the system does not include any other tailoring functionalities.

A 2012 "updated version" of the system, dubbed *Everywhere Race!* is presented in Mulas et al. (2012). This version focuses on the issue of finding opponents for a virtual

Table 5 The 10 design principles based on literature review from social features and game design principles in fitness applications from Bielik et al. (2012)

#	Design principle
1	Give the user proper credit for activity
2	Provide personal awareness of activity level
3	Ensure fair play
4	Provide a variety of motivational tools
5	Provide feedback on activities done
6	Consider the practical constraints of users' lifestyles
7	Provide both short-term and long-term motivation
8	Support social influence
9	Provide possibility of integration with existing solutions
10	Protect users' privacy

race by implementing an integration with the popular social network *Facebook*. The application allows the sharing of created virtual races through Facebook, and allows users to search for and join existing races. The everywhere race system does not specify the implementation of algorithms for automatic matching of competitors. The system was evaluated with 35 users over a period of 30 days and results in terms of motivation and physical activity seem to be positive.

4.9 Move2Play

The Move2Play system described in Bielik et al. (2012) is a conceptual design of an innovative platform to stimulate healthy living and improve quality of life. A key aspect of the system's design is the integration of different motivational facilities (intrinsic and extrinsic) delivered in a non-obtrusive manner, taking into account the current context of the user. To guide the system's design, the authors first describe a set of ten design requirements for successful implementation of physical activity encouragement tools, listed in Table 5. These design principles are based on literature review regarding social features for wellness applications (Ahtinen et al. 2009) as well as game design principles for fitness and exercise applications (Campbell et al. 2008; Yim and Graham 2007). In their motivation and background the authors refer mostly to similar existing solutions and do not touch upon any behavior change theories.

The authors describe a design that encompasses the full scope of their own design requirements, resulting in a conceptual system that includes many different tailoring approaches and technological innovations related to activity monitoring and coaching. The authors propose to increase the accuracy of activity assessment by combining accelerometers with location information provided by wireless networks. Activity data is fed back to the user via a number of different visualization options, and incorporates goal setting and group feedback. Furthermore the system contains social encouragement through social network integration, gamification techniques such as achievements, badges and unlock-able content, as well as an animated motivational agent to foster natural communication with the user. Although the envisioned design is innovative, for the most part the system appears to be conceptual. Besides a very high-level modular architecture, no technical implementation or algorithmic details are given. From the described modules some specifics are given regarding the features of a user- and domain model that are used for inferring optimal activity recommendations. However, from the description of the evaluation it appears that only minor parts of the described functionality are implemented.

4.10 ActivMON

The work in Burns et al. (2012) focuses on a low-complexity Ambient Light display as feedback device for representing the user's level of physical activity. The paper describes a wrist-worn device that notifies the user of his progress towards his daily activity goal. The device contains a 3D accelerometer and a multicolor LED. The ambient light lights up red at the start of the day, and progressively turns to yellow and green as the user reaches a predefined activity goal—a more recent paper describes in detail the use of a color gradient as feedback modality (Burns et al. 2013). Activity is measured using a 3d accelerometer, where thresholding of the magnitude of acceleration is used to increment an activity counter. Furthermore, the device can connect to a smartphone to enable data synchronization with a server. This connects the user to a social group of users which allows the device to show in near real-time when group members are physically active. The system was evaluated with a group of five colleagues. After a baseline week of measuring, each group member received a target activity goal set to 105 % of their baseline activity. Although the device had some usability problems, four of the five users averaged higher activity levels than their personal goals at the end of the second week.

The system targets users with attitudes and behaviors described as "less motivated", and argue that these users are less willing to commit time and effort to monitor detailed information regarding their physical activity performance. This is the motivation for using a less complex interface that is simpler to engage with, such as the ambient display. The decision to include a group-component is based on the recommendations from Consolvo et al. (2006) of supporting social influence. Additional details regarding the ActivMON application are presented in Burns et al. (2011). Most notably this work describes an interesting tailoring approach in the form of an *Adaptive Goal Setting* algorithm. The device will automatically calculate an average activity level of the first week of use and set a personal goal to 105 % of this value. In subsequent weeks, if the user reaches his goal, it is automatically raised by another 5 %; if the user fails to reach the goal it is left unchanged. Through the use of a web interface, users can influence the goal-setting behavior using simple "decrease/increase" buttons to alter the given goal. Although the authors do not mention it as motivation, this implementation is a good example of using the principles of the Goal Setting Theory (Locke and Latham 2002) by providing challenging, achievable goals as well as providing a mechanism for users to commit to those goals.

4.11 BeWell+

The BeWell+ application described in Lin et al. (2012) combines physical activity with sleep- and social interaction monitoring and provides feedback along those three dimensions using an ambient display on a smartphone's wallpaper (see Fig. 2c). The article focuses on two specific tailoring approaches that aim to improve a previous version of the system, both of these are aimed at tailoring the experience better to individual users. The theoretical background of the work mostly consists of a comparison to earlier work as well as similar existing applications, and includes no mention of specific behavior change theories that are consulted or used to drive any specific design decisions.

The first improvement in this new version of the system is the use of *community adaptive well being feedback*. The idea is that the performance of individual users is compared to other users of the system in terms of their well being scores. Through the use of an algorithm that automatically groups similar users, a more realistic assessment of an individual user's performance is possible. This is achieved by calculating how well he did compared to his peers, instead of comparing with an ideal situation (which may be unachievable). The system effectively matches the user with *positive role models*, users who are similar in behavior, but perform slightly better. The similarity matching is done using a *behavioral similarity network*, a weighted graph structure in which the nodes represent users, and the edge-weight is defined by the similarity between users. This similarity is based on mobility- (measured through GPS tracking), temporal-, and activity patterns (measured by activity inference). Details regarding the lifestyle similarity calculations can be found in Lane et al. (2011). By repeating the matching progress as new data is available the system constantly adapts these groupings.

The second aspect of the paper focuses on *well being adaptive energy allocation*. As a way of saving battery on the smartphone, the authors developed a system that prioritizes resource allocation to those sensors and modules of the system that are most relevant. For example, if the user has a normal sleep pattern but low physical activity, the system would shift its sensing priorities from sleep to physical activity. Specifically, the system can adapt the frequency of sensor sampling, feature extraction, and activity inference; as well as the frequency of communicating with the back-end cloud infrastructure to send data or collect revised well being scores from the adaptive well being feedback component.

4.12 Analytic, social, affect

Three variations of a daily physical activity coaching tool are described in King et al. (2013): an *analytically* framed version, a *socially* framed version, and an *affectively* framed version. All three applications work on a smartphone that measures daily physical activity patterns and provides a glanceable display for providing feedback of the current level of activity. The work forgoes technical implementations or descriptions of algorithms for discussion on theoretical background and evaluation.

The analytic application distinguishes itself by adding user-specific goal setting, set by the user himself every week, which was also added to the feedback on the smartphone's display. Users are provided with goal options of increasing difficulty, with the idea that graded goals increases self-efficacy while "nudging" individuals towards their goals (Thaler and Sunstein 2008). When weekly goals were not met, the system provides a "trouble shooting" mechanism that helps users in setting more attainable goals, and also provides additional informational tips on reaching the weekly goal. This version of the application is heavily based on behavior change theories related to self-efficacy and goal setting. The social application focuses on group-feedback displayed by a series of avatars on the smartphone's wallpaper, representing the user and other group members. Each avatar's posture changes based on the activity level of its corresponding user to indicate coarse performance about individuals in the group. In addition, physical activity feedback was presented in relation to the group performance, as well as the performance of a second "competing" group. In order to provide a 'positive role model', each group contained a virtual participant that inhibits healthy activity behavior. The affectively framed version of the application focuses on the use of a virtual avatar, a bird, that changes posture, position, and movements based on the level of physical activity performed by the user (see Fig. 2d). Similar to the UbiFit garden system (Consolvo et al. 2008), this visually appealing representation of physical activity becomes more attractive if more physical activity is performed.

5 Definition of concepts

The overview of related work given in Sect. 2 already touches upon the issue of definitions in the field of tailoring. The process of our literature search made it even more clear that for example terms like 'personalization', 'tailoring' and 'individualization' are used rather interchangeably throughout the literature. The article by Hawkins et al. (2008) provides some clear definitions, by coining 'tailoring' as an overall umbrella term for various sub concepts defined as "feedback", "personalization" (we use *user targeting*), and "content-matching" (we use *adaptation*).[2] Unfortunately, Hawkins' use of the term 'personalization' to define a very specific tailoring strategy is rather confusing. Therefore we opted to use the term *user targeting*—a term taken from the field of advertising (see e.g. Wang et al. 2011).

In this section we expand upon Hawkins' concepts by defining an extended model of tailoring. In Sect. 6 the model is used as a framework for the analysis of the papers included in this survey, while at the same time validating the definitions given below.

One of the reasons why Hawkins et al.'s (2008) definitions of tailoring fall short for this survey, is the introduction of recent advanced tailoring techniques such as *context awareness* and *self learning* that are not adequately covered. Subsequently we feel that the concept of *goal setting* does not fit the model of Hawkins and should be treated separately. Thirdly, where Hawkins et al. (2008) shortly treat interaction between users in their description of comparative feedback (comparing results with that of a peer or group of peers), we will elaborate on the idea of *inter-human interaction* as a separate concept. Finally, it is worth noting that the presented model can be seen as a detailed elaboration on part of the persuasive system design methodologies as defined by Oinas-Kukkonen and Harjumaa (2009), who in turn attempt to develop solid design

[2] The term "adaptation" is taken from Lustria et al. (2008) as an alternative to "content-matching".

methods for persuasive technology based on the fundamentals that have been laid out by Fogg (2003).

5.1 Tailoring and communication

Before defining the various aforementioned tailoring concepts we will provide a working definition of *tailoring* itself. When talking about *tailoring*, we use the word as a transitive verb, meaning we are tailoring *something* to *someone*. In our context of physical activity coaching systems, the *someone* is the user of the system who wants to (or has to) change his or her physical activity behavior. The *something* is in our case a more complex concept, namely *communication*. In short, *we tailor communication to the user*.

We first need to define ‘communication’ in the context of physical activity coaching. Communication (from the Latin word “communis”, meaning to share) is a process of sharing information between two or more participants. In our context, we are talking mostly about a computer agent sharing information with a human user in order to e.g. motivate, or inform. Every communication instance can be seen as having four distinct properties: *timing*, *intention*, *content*, and *representation*. As an example, consider the following hypothetical message from a physical activity coaching system to its user:

> *You haven’t been active enough today. Maintaining a healthy level of physical activity can drastically reduce the chances of cardiovascular disease. In order to achieve your daily goal, you need to walk for at least another 18 minutes or perform 12 minutes of vigorous exercise.*

In this example, the *timing* of this communication would be the moment at which the system would present it to the user. The communication instance has three different *intentions*: (1) to provide information on the user’s current progress (i.e. feedback), (2) to inform about the benefits of physical activity, and (3) to give a suggestion on an activity to perform. The *content* of the communication is the factual information presented (e.g. the fact that you haven’t been active enough), and the *representation* is in this case a rather long-winded natural language text.

Now consider the second example in Fig. 3: a screenshot of the web portal of the commercially available Nike + Fuelband activity coach system. Although very different from the natural language example above, in this form of communication we can also identify *timing* (in this case the timing is user initiated as the time when he or she chooses to visit the web portal), *intention* (to provide feedback), *content* (activity values and goals for seven days, expressed in Nike Fuel points, the total amount of Nike Fuel earned, and the number of days the goal was reached), and *representation* (a bar graph with goal lines).

Looking at these communication instances, the goal of any form of tailoring would be to increase the likelihood that the system successfully conveys its intention to the user by matching each of the communication properties in some way to the user and/or his context.

From the literature, we have identified seven tailoring concepts with varying levels of complexity: *Feedback* (FB), *Inter-Human Interaction* (IHI), *Adaptation* (Ad), *User*

Fig. 3 Screenshot of the Nike+ Fuelband web portal displaying a 7-day overview of activity counts (expressed in Nike Fuel points) and daily goals. Source: http://www.pocket-lint.com/news/114706-7-days-with-nike-fuel-band (August 2013)

Targeting (UT), *Goal Setting* (GS), *Context Awareness* (CA), and *Self Learning* (SL). These concepts will be defined in Sect. 5.2 below. Then in Sect. 5.3 the connections between the various concepts will be defined and explained with examples.

5.2 Tailoring concepts

The seven tailoring concepts and their relationships to the communication properties—timing, intention, content and representation—are explained below.

Feedback Feedback involves presenting individuals with information about themselves, obtained during assessment or elsewhere. To give feedback is a strategy for achieving the intention of motivating the user to change a behavior (another strategy could be e.g. to inform about the advantages of physical activity). Broadly speaking, three forms of feedback can be distinguished: descriptive, comparative and evaluative. Descriptive feedback *reports what is known about the recipient based upon his or her data*, comparative feedback *contrasts what is known about the recipient with what is known about others* and evaluative feedback *makes interpretations or judgments based on what is known about the recipient* (Hawkins et al. 2008). From these three forms of feedback, we treat comparative feedback as part of the broader tailoring concept "inter-human interaction" described below. Feedback is a tailoring concept that can exist on it's own, i.e. a communication can consist of solely a feedback message.

Inter-human interaction We define inter-human interaction as the support for any form of interaction with other real human beings. Inter-human interaction is for example any type of built in support to contact professionals or peers, share information about performance or progress to selected individuals or any built in support for professionals or peers to contact the user to provide support or advice on physical activity. Inter-human interaction can provide additional motivation (peer pressure) or can provide a feeling of safety in case of a connection with a healthcare professional.

Adaptation Adaptation "attempts to direct messages to individuals' status on key theoretical determinants (knowledge, outcome expectations, normative beliefs, efficacy and/or skills) of the behavior of interest" (Hawkins et al. 2008). For example, someone that wants to be more active in order to lose weight would receive different messages from the system than someone who wants to be more active to prevent exacerbation of a disease like COPD, since the motivation in both cases is different. Similarly, a user in the precontemplation phase of the stages of change model could receive motivation as to why being active is good for you, while such information would not be appropriate for someone in the action phase.

User targeting User targeting attempts to increase attention or motivation to process messages by conveying, explicitly or implicitly, that the communication is designed specifically for 'you' (Hawkins et al. 2008)[3]. When tailoring communication, user targeting is a technique that attempts to fit the representation to the individual. Hawkins et al. (2008) defines the three most common tactics as follows. *Identification* attempts to target the individual by identifying the recipient by name (see Dijkstra 2014 in this issue), using pictures of the recipient, or recognizing the recipient's birthday. *Raising expectation* through mentioning explicitly that an advice was specifically designed for the recipient—a form of 'placebo tailoring'. And finally *contextualization* by e.g. matching the content of messages to the recipient's age, sex, culture, or other user parameters.

Goal Setting According to the Goal-Setting Theory, people are more likely to change behavior the higher the specificity and (achievable) difficulty of a goal (Locke and Latham 2002). Goal setting is a technique used to present the user with short-term, as well as long-term goals that can instill a feeling of progress over the course of an intervention or the day. Goal setting is a tailoring concept that can only be used in combination with feedback.

Context awareness For context awareness we adopt the definition from Dey and Abowd (1999): "*A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task*". In the area of physical activity coaching, we deal not so much with tasks, but with 'needs' or 'goals'; but the critical part of this definition is the notion of *context*. We define context as any information, *non-critical to the application's main functioning*, that can be used to characterize the situation of a user or the system (i.e. not including user characteristics). Context awareness is a tailoring concept that can be used in various ways to tailor timing, content and/or representation of communication instances.

Self learning Tailoring techniques such as adaptation and user targeting aim to adapt communication to a user, while context aware systems aim to adapt to a user in a particular context. But the 'user' is a very dynamic entity. Any application that employs tailoring techniques has an intrinsic user model, which is never perfectly accurate or complete. A self-learning application is able to update its internal model of the user by recording and learning from the various interactions the user has with the application. Within an intervention that aims to achieve behavior change, the user is almost by definition something that changes over time. The intervention could (and should) for example move the user forward through the stages of change. This means that an intervention or behavioral change tool that

[3] Note that Hawkins uses the term 'personalization', which we changed to avoid confusion.

uses adaptation to tailor communication intent to a specific stage of change should change with the user throughout his use of the application. This ability of a tool to change with the user is defined as *self learning*. A system can be self learning in the way it employs other tailoring techniques such as adaptation, context awareness, goal setting or user targeting.

5.3 The tailoring model

Figure 4 shows the seven tailoring concepts and the ways in which they can interact with each other. The graph includes an extra node for *Motivational Messages* (MM) that is not a tailoring concept in itself, but a common technique used in physical activity promotion applications that can be enhanced through various ways of tailoring. This node is encircled, depicting that it is a possible end-node in the graph. The graph should be read as follows. Any path through the graph represents a possible combination of one or more tailoring techniques that should end at one of the two end-nodes (FB or MM). For example, the path CA→FB represents "context aware feedback", e.g. tailoring the timing of feedback based on the user's location, the time, or weather as in (op den Akker et al. 2010). Designers of physical activity promotion systems can use this to find various paths of tailoring. By starting at an end node (FB or MM), following edges back through the graph will lead to ever more complex forms of tailoring. The self learning (SL) nodes in the graph are special in that self learning can only be used in combination with other tailoring concepts.

The following list gives examples for each of the links defined in Fig. 4. For those links directed to an end-node the relation to the communication model properties of *timing*, *intention*, *content*, and *representation* is given—indicating which of these communication properties it can affect.

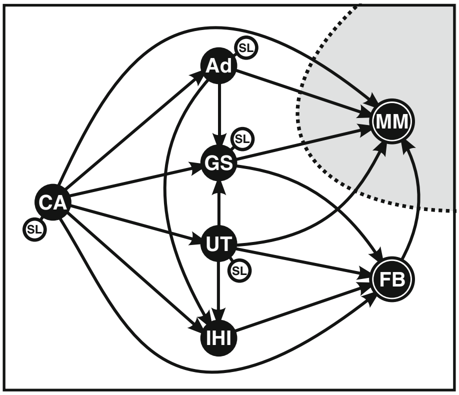

Fig. 4 The tailoring model, showing the various tailoring concepts and how they can be combined to form various motivational communication through feedback (FB) or motivational messages (MM)—which is not a tailoring concept in itself. The other non-end nodes represent context awareness (CA), goal setting (GS), inter-human interaction (IHI), Adaptation (Ad), and user targeting (UT). Self learning (SL) can be used to further augment various other tailoring concepts. Starting at one of the end nodes, designers of physical activity coaching tools can work their way back through the graph to find ways in which to tailor their communication to the user

CA→FB	Tailor the feedback based on the user's context. E.g. use a different modality based on the user's location such as audio feedback in private settings, and text-based feedback in public settings (*timing*, *content*, *representation*).
GS→FB	Improve the effectiveness of feedback by also providing daily, weekly or monthly goals, e.g.: "You did 8,472 out of 10,000 steps today!" (*content*).
UT→FB	Change the wording of a feedback message by adding user targeting, e.g.: "Mr. Johnson, you have done 7,000 steps so far today!" (*representation*).
IHI→FB	Receiving group based feedback (*timing*, *intention*, *content*, *representation*).
FB→MM	Add feedback to a general motivational message, e.g. "*You have done 7,384 steps today. Keep it up!*".
CA→MM	Provide a general motivational message based on user context, e.g. when the weather is nice: "It's perfect weather to go for a walk!" (*timing*, *content*, *representation*).
GS→MM	Simply stating the daily goal, or informing about an automated change in goals (*content*).
IHI→MM	Receiving a (motivational) message from a user in a peer-group (or friend) through the application (*timing*, *intention*, *content*, *representation*).
Ad→MM	If the subject is in the precontemplation stage of change, inform him about the benefits of physical activity (*intention*, *content*).
UT→MM	Provide the subject with a general motivational message, enhanced with user targeting, e.g.: "Mrs. Johnson, maybe you can take a lunch walk today" (*representation*).
CA→GS	Tailor a user's goals for different days of the week, based on e.g. the user's agenda.
CA→UT	Combine user information (likes, dislikes) with current context, e.g. recommending a cycling route nearby if the user likes cycling.
Ad→GS	Set goals based on psychological constructs, e.g. set an easily attainable goal for someone with low Self Efficacy.
Ad→IHI	Place a subject in a group of peers based on similarity in psychological constructs (e.g. same Stage of Change).
UT→GS	Set a specific user goal based on a user parameter such as BMI.
UT→IHI	Place a subject in a group of peers based on similarity in user preferences, e.g. likes, dislikes, age, gender.
CA→IHI	Place a subject in a group of peers based on his current location (e.g. users in the same city).

6 Survey of real-time, tailored coaching systems

A total of 15 papers were included in the survey. We have analyzed each of the described systems regarding the use of the seven tailoring concepts defined previously. Table 6 lists all the included papers, and indicates whether the application makes use of these tailoring techniques. The table is split into three parts, the first part contains

Table 6 Overview of papers included in the literature study

Article	Tailoring						
	FB	IHI	UT	Ad	GS	CA	SL
Real-time systems—daily life activities							
Bickmore et al. (2009)	✓	–	–	–	–	–	–
Bielik et al. (2012)	✓	✓	✓	–	✓	✓	✓
Lin et al. (2012)	✓	✓	–	–	✓	–	✓
Burns et al. (2012)	✓	✓	–	–	✓	–	–
Fujiki et al. (2008)	✓	✓	–	–	✓	–	–
King et al. (2013)	✓	✓	–	–	✓	–	–
Consolvo et al. (2008)	✓	–	–	–	✓	–	–
Qian et al. (2010)	✓	–	–	–	–	–	–
Qian et al. (2011)	✓	–	–	–	–	–	–
Real-time systems—excercise based							
Mulas et al. (2011)	✓	✓	–	–	✓	–	–
Buttussi et al. (2006)	✓	–	–	–	–	–	–
Buttussi and Chittaro (2008)	✓	–	✓	–	–	–	–
Ståhl et al. (2008)	✓	–	–	–	✓	✓	-
de Oliveira and Oliver (2008)	✓	✓	–	–	–	–	–
Oliver and Flores-Mangas (2006)	✓	–	–	–	✓	–	–
Non real-time systems—excluded							
Arteaga et al. (2010)	✓	✓	–	✓	–	–	–
Saini and Lacroix (2009)	✓	✓	–	–	✓	–	–

The first group of nine articles deal with daily life (DL) activities, the second group of six are mostly exercise based systems. The final two papers are excluded because the systems are not real-time (RT), they do however serve as useful examples in the discussions below. The last columns mark the use of feedback (FB), inter-human interaction (IHI), user targeting (UT), adaptation (Ad), goal setting (GS), context awareness (CA), and self learning (SL)

real time applications that deal with daily life activities, the second part with real time applications that are more related to exercises, and the third part contains two excluded papers that serve as useful examples throughout the analysis below. The columns indicate the use of feedback (FB), inter-human-interaction (IHI), user targeting (UT), adaptation (Ad), goal setting (GS), context awareness (CA), and self learning (SL).

In the seven subsections below we will explain for each of these aspects of tailoring how it is currently applied in the literature, and how these methods are justified by underlying theories.

6.1 Feedback

The use of feedback is the most obvious form of tailoring, and it is applied in all of the real-time physical activity coaching system we have reviewed. Because it is such a common motivational tool, it is worth to have a more detailed look at its internal mechanisms and relevant (sub) properties. Feedback on physical activity is simply presenting the measured amount of activity performed to the user. It is almost impossible to imagine a real-time coaching system that does not employ this form of tailoring, but the ways of doing so are diverse. We will discuss the ways in which feedback communication instances can vary in their *timing*, *content*, and *representation*.

6.1.1 Timing

We define the timing of feedback as the moment at which users are able to request their current performance level, or are given a report of their performance by the system. The timing aspect of feedback is such a distinctive and widely varying parameter, that this survey already focuses on a subset of these type of systems—those that are able to provide feedback in real-time. An example of a system that, based on this criteria, was excluded from this survey is the Philips DirectLife system described in Saini and Lacroix (2009). The system requires the user to physically dock an activity sensor to a PC in order to upload data to a central server before being able to receive feedback through regular emails or by visiting a website.

The timing of feedback can vary between e.g. receiving weekly emails, all the way through continuous feedback as for example in the music-based personal trainers, MPTrain (Oliver and Flores-Mangas 2006) and TripleBeat (de Oliveira and Oliver 2008) that automatically adjust the music that is playing while exercising in order to match your current gait and heart rate goals. This type of music-based feedback is however meant for exercise-based physical activity coaching and is not suitable for use in daily life. The UbiFit Garden described by Consolvo et al. (2008) is designed for coaching on daily life activities, and presents a ubiquitous method of providing feedback by using a glanceable mobile phone wallpaper to provide subtle feedback to the user whenever and wherever the phone is used. This way, whenever the user wants to receive feedback he is able to see his own performance quickly on the display, and even if the user has to perform a different task on his phone, he is subtly reminded of his activity progress.

The initiative is however with the user, which means that opportune moments for behavior influencing may go by unused. The literature provides two ways of overcoming this issue. One is to simply provide feedback that is always visible as in the ActivMON system presented by Burns et al. (2012). The ActivMON is a wrist worn sensor incorporating a multicolor LED that slowly changes color from red to green as the user reaches his daily activity goal. The second and more obvious strategy is to let the system decide when to provide feedback. For example, Qian et al. (2010, 2011) employ continuous feedback where the initiative is with the system itself. The system, developed for a Nokia N95 mobile phone, tracks the user's pace (steps/minute) and produces vibrations to indicate the user to walk faster or slower than their own baseline, or comfortable speed. Similarly, but in a more realistic activity coaching setting, the system developed by Bickmore et al. (2009) provides system-initiated positive reinforcement after the detection of a 10 min bout of physical activity. Their system supports a flexible way of dealing with users who fail to respond, as well as a flexible way of defining a protocol for timing of user notification based on various state transitions and events.

With this last feature the authors touch upon a question that is in our view critical, and currently unanswered in the literature: what would this ideal protocol be? When examining the timing of feedback, there seem to be three dimensions that play an important role. Initially there is the choice whether the *initiative* for providing feedback lies with the user of the system, or with the system itself. Subsequently, when the system takes the initiative, the question remains what the right *moment* and *frequency* of feedback is. Lastly there is the issue of making sure that the user actually notices and responds to feedback at the moment it is provided.

6.1.2 Content

Besides the question of when to give feedback, there is the question of what to communicate to the user. Arteaga et al. (2010) performed detailed focus-group based user studies for the design of their system to motivate teenagers' physical activity, and one of the aspects included in their studies is personality theory. Based on the idea of similarity attraction, proposed by Byrne and Nelson (1965), the authors state that the set of motivational phrases included in the system should be matched to the users' personality traits. After presenting a set of motivational phrases to five focus group participants, some phrases were however unanimously preferred or disliked, regardless of personality. Whether or not this finding contradicts the idea that phrases should be matched to personality is unclear. It does show however, that carefully choosing the content of a feedback communication matters. There are other examples in the literature of natural language feedback messages in which special attention is given to phrasing. The wording of the feedback presented by the MOPET system by Buttussi et al. (2006) was deliberately chosen to be gentle ("You are walking regularly. If you are not tired, try to increase your speed."), because, as the authors state, the more aggressive inciting of the Philips Virtual Coach (Ijsselsteijn et al. 2004) did not work as well as expected. More complex approaches of matching motivational messages to the user have been proposed, as for example in Di Tullio and Grasso (2012), who propose an abstract argumentation framework—the values system—for automatically generating motivational arguments based on a matching between system- and user's beliefs. The system is based on a logical inference of arguments to influence the conversational partner's values (beliefs) system.

It is clear that in the design of some systems, the importance of content is recognized. However, in most of the included papers, either no special attention is given to the content, or the content is visual, music based or tactile (feedback representation will be discussed below). As such it is hard to draw firm conclusions regarding content. Intuitively it seems relevant, and Byrne and Nelson's similarity attraction suggests that content of feedback is ideally matched to individuals. However, further research is needed in order to provide clear recommendations on how to tackle content in a tailored physical activity coach.

6.1.3 Representation

Natural language text is not the only form of representation in which physical activity coaching can take place. The chosen representation for interacting with the user is the most diverse aspect of feedback in the included articles in this survey. It ranges from spoken dialogue (Bickmore et al. 2009; Mulas et al. 2011; Buttussi et al. 2006; Buttussi and Chittaro 2008; Arteaga et al. 2010) and music (de Oliveira and Oliver 2008; Oliver and Flores-Mangas 2006) to more graphical displays (Fujiki et al. 2008; Consolvo et al. 2008) or even tactile (Qian et al. 2010, 2011) or using simple ambient light (Burns et al. 2012). The choice of representation seems to be mostly based on the expected use of the application as well as its target audience. For example, all of the systems that are focused on exercise based physical activity employ either spoken dialogue or music as feedback modality, as the user would be too occupied with performing exercise to use the visual display of a coaching device. As it is difficult to give detailed feedback on performance through the audio channel, these modalities are always combined with a more graphical display, such as a graphical representation of a virtual race in e.g. Mulas et al. (2011).

The concept of exercise based feedback through a multimodal graphical/audio interface is not exactly new, and there are many free applications for smartphones available on the market, such as RunKeeper[4] or SportyPal[5], that offer exactly this. Those applications that aim to support physical activity during daily life show a more diversified use of feedback representation. Qian et al. (2010, 2011) describe the development of a mobile phone based application that can provide haptic feedback on walking behavior for older adults. The application uses the phone's internal accelerometer to count steps, and provides vibration signals for real-time feedback to the user: move faster, or move slower. The author's state that vibration signals are an ideal modality for feedback because it reduces the need to consult the visual interface whilst in motion. There is however an obvious limitation in richness for this type of feedback. Similar problem of richness are obvious in the ActivMON system envisioned by Burns et al. (2012), who developed an ambient display that is worn on the wrist that uses a light-emitting diode to indicate the user's activity, as well as the activity of peers in the user's social group.

The effectiveness of using such simple modalities for providing feedback is unclear, as it has not been evaluated in much detail. The intensity of coaching is low, and we expect that at least some people require much more in terms of persuasion and motivation. As Bickmore et al. (2009) suggest, "...perhaps the most effective technologies are those which come closest to the 'gold standard' of one-on-one, face-to-face counseling with an expert health provider". They, and other authors (Bielik et al. 2012; Fujiki et al. 2008; Buttussi et al. 2006; Buttussi and Chittaro 2008; Ståhl et al. 2008; Arteaga et al. 2010) employ embodied agents to interact with the user in order to achieve a heightened level of social bonding and trust between the user and the system. A downside of presenting a human avatar to the user is that, as Bickmore et al. (2009) conclude, the perception of agent reliability is a pre-requisite for effective health outcomes as well as for relational bonding.

4 http://www.runkeeper.com/.

5 http://www.sportypal.com/.

6.1.4 In summary

We described how feedback, or presenting individuals with information about themselves, is implemented in greatly varying ways across the different studies. We described the complex issue of feedback through the three properties of a communication instance: its *timing*, *content* and *representation*, and showed the diversity of use in each aspect. All of the included papers describe systems that are in the conceptual, or prototype phase, and have undergone only small scale evaluations at best. This, and the fact that for example *timing* of feedback is usually only a very small part of a larger complex activity coaching system, it is hard to draw firm conclusions on the effectiveness of the various employed strategies.

6.2 Inter-human interaction

The second tailoring technique is in a way quite different from feedback, as with inter-human interaction, it is not the system that does the coaching directly, but merely enables the user's peers to coach him or her. The inter-human interaction strategy is used in seven out of the 15 included papers. In the virtual running application 'Everywhere Run' by Mulas et al. (2011) users are guided through a running workout by a coaching application on their smartphone. The system allows users to download a workout plan from other users or from a paid personal (real life) coach. A system that can connect with professional healthcare personnel or coaches can provide a feeling of safety and comfort to the user, as he can rely on the professionally trained coach to design a workout schedule that matches the user's capabilities. Another IHI technique in a mobile phone based exercise coach is the inclusion of virtual competition as presented by Fujiki et al. (2008) and de Oliveira and Oliver (2008). The coaching system described by de Oliveira and Oliver (2008) supports virtual competitions in which the user can run against a fictional runner, the user himself on previous runs, or real runners that have previously run with the system. The competition is set up in such a way that it does not award faster running, or burning more calories, but awards those runners that achieve their own exercise goals in a healthy manner. The system allows users to choose their own competitor from a database of registered users, or to let the system automatically select a competitor based on performance similarity metrics. An evaluation study with 10 subjects showed no significant increase in performance between the system with competition and an earlier version of the system that did not include the competition aspect. Although from a subjective evaluation, five out of 10 subjects indicated that the competition element was the main reason for enjoying the system.

Other methods of supporting IHI are presented by Bielik et al. (2012), who envision embedding social network capabilities in their coaching system, allowing users of the system to connect, share, and communicate with each other through the application. Sharing your physical activity results, and particularly seeing the results of other users could work in a motivating way, similar to the virtual competitions described above. Such techniques are already widespread in commercial fitness tracking applications such as RunKeeper or SportyPal. Social influence can be a strong motivating element, and being able to connect to your friends or family through an activity coaching system could increase the connectedness that you experience with the system and foster long-term enjoyment in using the system.

6.3 Adaptation

Adaptation, or the process of tailoring message content to individuals' status on key theoretical determinants, was not found to be applied in any of the real-time physical activity coaching systems included in the study. We did however find one article describing the application of adaptation techniques in a physical activity coach by Arteaga et al. (2010), but the system did not adhere to the "real-time" criteria. Nevertheless, the system shows an interesting application of adaptation, which could have been implemented in real time. Arteaga et al. describe a smartphone application that uses physical activity games to motivate teenagers to be more active in order to prevent obesity. A core component of the system is that it assesses the user's personality profile through the use of a questionnaire that has to be filled out when starting the application. The personality profile defines the individual on the level of personality traits such as 'extraversion', or 'openness', for which the authors showed correlation to the results of a self-developed questionnaire consisting of physical activity-, personality-, and mobile phone related questions. The system then uses the personality traits to define a set of games that are specifically relevant to the user's personality. The system was evaluated in a small trial with five users, in which there was no comparison with a system that did not use the personality trait based adaptation step, so it is unfortunately not possible to comment on the effects of the authors' approach.

Adaptation seems to be a useful tailoring technique. The example given in the definition (Sect.5) about not telling a user in the action stage of change what the benefits of physical activity are seems obviously useful and technically easy to implement. Unfortunately, the current state of the art of real time physical activity coaching systems is such, that these methods are simply not being employed.

6.4 Goal setting

Goal setting is a tailoring form that can mostly be seen as an extension of feedback. Where feedback presents users with information about their performance (e.g. doing 7,000 steps), goal setting adds a certain value to the presented information (e.g. reaching 7,000 out of 10,000 daily steps). According to the Goal-Setting Theory (Locke and Latham 2002), people are more likely to change behavior the higher the specificity and (achievable) difficulty of a goal. Many of the included articles describe a form of goal setting for their applications (nine out of 15). Broadly speaking, two levels of complexity within goal setting strategies can be identified: simple numerical methods, and methods based on more complex tasks or schedules.

Similar to the example given, many of the applications that focus on daily life activities include a simple numerical goal, representing e.g. the amount of steps to take, or minutes of daily activity to perform. The variations in these applications relate to (1) the associated time scale of the goals—Bielik et al. (2012) allows users to set both short-term and long-term goals—and (2) the representation of the goals—Consolvo et al. (2008) shows a large butterfly on the glanceable display when the goal is met.

Another more complex way of goal setting is used in the exercise based systems described in Oliver and Flores-Mangas (2006); Ståhl et al. (2008); Mulas et al. (2011). These applications rely on the definition of an exercise schedule either by the user himself (Oliver and Flores-Mangas 2006) or by an expert through a connection with an inter-human interaction component (Mulas et al. 2011). Such schedules can be based on e.g. time spent in a specific heart-rate zone, user's running speed/duration, the performance of specific activities such as shopping (Ståhl et al. 2008), or a combination thereof. Currently none of the reviewed papers include a form of automatic generation of complex goals in the form of task-schedules.

6.5 User targeting

User targeting is the simplest form of tailoring in terms of technical complexity, but it is a technique not often used in the literature. Out of the 15 included papers, only two employ some form of user targeting. Buttussi and Chittaro (2008) require the user of their fitness coach to enter personal information—weight, height, gender and age—into the system before first use. From this information, using a so called auto-test, the maximum oxygen uptake is calculated based on a physical test and the user's gender and age. During use of the system, the user is given information on the amount of calories burnt which is calculated for the individual based on his/her weight. The user's gender and age are also taken into account when deciding when to give alerts or speed/intensity advices while performing exercises. This type of user targeting falls under the category of 'contextualization'. The second paper that describes some form of user targeting is by Bielik et al. (2012). In order to provide tailored motivation, the authors describe the use of a *user model* containing preferred activities for each individual. The authors state that these preferred activities are derived automatically over time (see Sect.6.7: Self learning), but the details are unclear and it does not appear to be implemented. The idea however is that each individual receives recommendations about which physical activities could be performed in order to reach a daily goal, based on this set of preferred activities. This is another, clearly more advanced form of contextualization, that adapts the content of messages based on a user model. The authors also claim to take gender and age into account when determining an appropriate amount of activity, but it is again unclear how exactly this is done. Although it seems that these two methods of user targeting remain in the conceptual phase, the authors did perform an evaluation with another form of user targeting. Users, in this case children aged 12–13, would start the activity coach by choosing a nickname and were then able to customize a personal avatar that would be used later on for providing feedback. This technique, called *identification*, worked very intuitively for the children as it is common practice in online social services and games. Although its effects on physical activity performance was not evaluated, for the younger target populations, the ability to name and customize a personal avatar seems to be a logical and natural feature that could improve the connectedness between the user and the digital coach.

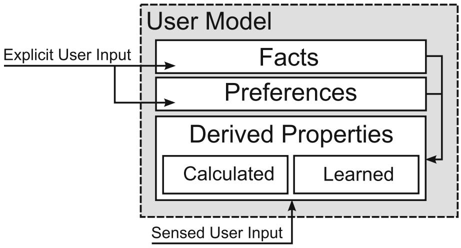

Fig. 5 An example high level architecture of a user model containing facts, preferences (obtained explicitly from the user) and derived properties (learned, or calculated from facts, preferences and or sensed user input)

An overall commonality between the two author's usages of user targeting is in the implementation of an internal user model to keep track of application relevant features of the user. Figure 5 shows an example of a high level *user model* architecture that covers the examples from Buttussi and Chittaro (2008) and Bielik et al. (2012). The model consists of three high level types of information: *facts*, *preferences*, and *derived properties*. Facts are properties queried directly from the user such as age, gender or height; preferences contains slightly more fluid properties such as a chosen nickname, or visual features of an avatar, that are also explicitly given by the user, but could be changed over time. Derived properties contain dynamic user properties that are derived from the facts and preferences, as well as from continuous user input. This type of information includes e.g. a fitness level that is calculated after a specific self-test has been performed, but it also includes e.g. a statistically learned preference for a certain category of outdoor activities.

These various properties of the user model can then be used in varying degrees of transparency to the user. If e.g. calories burnt per hour of walking are calculated based on the user's weight, this is a form of user targeting that improves the quality of feedback that is given to the user. But it is also very unlikely that the user will actually know that this form of user targeting is taking place (low transparency). This is basically the opposite of raising expectation or 'placebo-tailoring' (see Sect. 5) in which the system would mention explicitly that advice is specifically targeted to the user. An example of such tailoring, also known as *name mentioning* is discussed in Dijkstra (2014) in this issue, where it is shown that the effects of name mentioning in a smoking cessation application is dependent on the person's individual stance on health in general (health value). Figure 6 shows some examples of user targeting techniques with varying degrees of transparency.

6.6 Context awareness

Context Awareness is a tailoring technique used in two out of the 15 included studies. Ståhl et al. (2008) developed a fitness companion prototype system consisting of a mobile application and a home system. The mobile companion is developed as a spoken dialogue system, where the focus lies on spoken interaction with a virtual embodied agent (a 2D representation of a Nabaztag rabbit) that can be used during physical exercise such as running or walking. The mobile application is able to download a daily plan that is generated by the user's home system, consisting of various tasks like

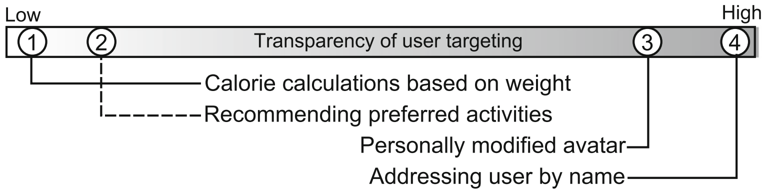

Fig. 6 Four examples of user targeting techniques with varying degrees of visibility (or transparency) to the user

shopping or physical exercise activities. The companion is context aware in the sense that it uses location and time to suggest a suitable task for the user to perform. It is unspecified how this is implemented exactly, but one can imagine that the system does not suggest to the user to go shopping at a time when supermarkets would be closed, or suggest a user to go vacuum cleaning when the user is not at home.

The system described by Bielik et al. (2012) also applies context-awareness in their contextual information recommendation algorithms. The system uses, besides the User Model as described in Sect. 6.5, a Domain Model, containing information about e.g. the day of week, the month, and the weather. As the article mostly seem to describe a conceptual system, again not much details about the actual use of this information is given. The example that the authors give is not related to activity coaching, but to nutritional advice, where the system could recommend different drinks on *colder as opposed to warmer days or different meals at noon or in the evening*. But it is not hard to imagine the usage of the same type of contextual information for physical activity recommendations, as for example a recommendation to perform outdoor activities is less suitable when it is raining outside. Similarly, the system could define a daily activity goal based on the day of the week, allowing for example office workers to be less active during workdays, and make up for it on the weekends.

Note that in the discussion on context-awareness we do not consider the 'navigational cues' and 'location aware exercise demonstrations' given by the MOPET system (Buttussi et al. 2006; Buttussi and Chittaro 2008) as context aware features, as the navigation of users through fitness trails is the core function of their system. Similarly the paper by Bickmore et al. (2009) is excluded; although the title of the paper contains the term "Context Awareness", the only information that is sensed and used in the feedback is the user's physical activity, which we consider to be the *core* information, not the context.

6.7 Self learning

Self Learning is a tailoring technique where the system does not merely adapt to the individual, but automatically adapts to the changing individual in changing contexts of use. Out of all the included papers, only Bielik et al. (2012) mention self-learning techniques. The authors describe the application of a User Model, containing user activity preferences, which is built incrementally as users use the system. They also describe the use of educational quizzes that are meant to teach children the benefits of a healthy lifestyle. The results of the quizzes are stored in the User Model, and on subsequent selections of quizzes, questions in those areas in which the user has low results are selected with higher probability. As mentioned before, the work described by Bielik et al. seems to be in a conceptual phase, as their system evaluation describes covers only a small set of features described in the paper. The self-learning aspect is not included in those evaluations.

Self learning techniques in real-time physical activity coaching systems are much more sophisticated than the other possible tailoring techniques and as such, these techniques are not so ubiquitously used in the literature yet. Self-Learning can be seen as an upgrade for any other type of tailoring mechanism. For example, as a first step of tailoring a physical activity coach to its users, a designer can add context-aware activity recommendations: e.g. advising the user to go for a stroll through a nearby park, or go to the vegetable market when there is one currently taking place. Then, as an improvement to such a system, the system could keep track of the user's responses to given advice, and learn for example that this particular user does not like to simply go for a walk, but prefers to do only purposeful activities, and act accordingly.

7 Discussion

Although the fields of physical activity monitoring and tailoring are both extensive and richly illustrated with example systems, the intersection between the two fields where real time tailoring is employed (the focus of this article) yields a somewhat sparser set of examples. We identified only 15 articles which met the scope and search constraints defined in Sect. 3 in which real time tailoring for physical activity is discussed, covering between them a total of 12 different applications. From these articles, four describe only the use of feedback—the most obvious form of tailoring—and another four describe the additional use of one other tailoring concept (e.g. *feedback* and *inter-human interaction*, see Table 6). The only paper that describes the use of six of the seven tailoring concepts is mostly conceptual in nature (Bielik et al. 2012). This indicates that tailoring in this domain is a novel but emerging research area. As this research area matures, we hope to see more applications emerging that incorporate a variety of tailoring concepts based on sound theoretical foundations into the application design.

There exists a considerable body of theoretical literature on behavior change theories such as the Stages of Change (Prochaska and Velicer 1997), Theory of Planned Behavior (Ajzen 1991), Goal-Setting Theory (Locke and Latham 2002) as well as literature on e.g. persuasive technologies (Fogg 2003) and tailoring (Hawkins et al. 2008). Such theories provide the basis for our definitions of the tailoring concepts in Sect. 5. Throughout the survey we have given examples of how these theories can be applied to tailor a real-time physical activity coaching system. However, in our study of the 12 applications detailed in Section 4, we found that many of the articles failed to clearly specify a theoretical foundation for specific design decisions. For example, the automatic goal setting functionality described in Burns et al. (2011) is a textbook example of implementing the Goal-Setting Theory, but no motivation or reference regarding that theory is given. Instead, the motivation for application design is often based on similar applications in the domain. The citing of similar applications, and indeed eachother among the reviewed articles, seems to be more common than refering to theory. We believe that this issue arises due to the highly multidisciplinary nature of the field, as the development of a tailored motivational health tool requires the input from technicians, medical staff as well as people with a background in psychology.

In principal there is no issue in developing tailored behavior change applications based on previously demonstrated methods instead of established theory. The problem is that the effectiveness of the methods referred to are often not proven by the evaluation studies performed. The tailoring concepts that are implemented in the various systems can in general be described as intuitive, and from a technological point of view, the solutions are often not very complex. For example, *user targeted* feedback is provided in Buttussi and Chittaro (2008) by using a simple formula, taking into account user's characteristics; or activity goals provided in Burns et al. (2011) are given by averaging the activity of previous days and multiplying by a factor of 1.05. Although such forms of tailoring seem intuitive, their effectiveness is not proven. A common method of evaluation is to simply test the effectiveness of the application as a whole, making it difficult to draw conclusions regarding the individual tailoring methods implemented. As such, there is a need to demonstrate the effectiveness of tailoring in a more structured and controlled manner.

As the ultimate goal of physical activity coaching systems is generally to promote long-term behavior change, it is clear that evaluations are not a trivial component of the research in this field. Demonstrating the effectiveness of a coaching application would require longitudinal studies, and given the large differences between individuals (the premise for research in tailoring) also requires a large numbers of participants. Whenever such large-scale, long-term trials are feasible within the scope of the research, it would be prudent to perform exhaustive analysis on the available data. Given the high costs of such trials, it is necessary to ensure that every aspect of the intervention is regarded, including e.g. an analysis of the user's active engagement with the system, as discussed elsewhere in this issue (Bouvier et al. 2014). Although the focus of this work is on physical activity coaching applications, we believe that the problem pertains to a broader context. Often the *tailoring component* is just a piece of the puzzle in the development of an innovative ICT service, while the focus of evaluation is on the service as a whole. We believe that this is a principal burden for progress in the field of tailoring. Therefore it is essential to develop innovative evaluation strategies that can quickly and decisively demonstrate the effectiveness of isolated tailoring approaches for which the result can be translated to the domain in which the tailoring is applied.

The staged approach to evaluation posed by DeChant et al. (1996) seems a promising framework for evaluation that can aid in overcoming these issues. The framework, developed in the context of evaluating telemedicine applications, consists of four stages of evaluation, from small scale experimental studies that demonstrate technical efficacy, to larger trials that demonstrate overall system validity. Translated to tailoring research, the goal would be to first perform small scale, experimental lab-studies to evaluate the effectiveness of isolated tailoring concepts. The goal here would be to demonstrate that users recognize and enjoy the tailored interaction and feel that it actually matches their personal needs or preferences. Then, the system can be evaluated on higher level constructs. In small scale pilot studies, evaluation should focus on whether or not the tailored system increases compliance, and whether or not this effect lasts after a period of use. Only then, the highest level outcome effects (e.g. increase in physical activity) should be evaluated in larger scale trials involving more participants.

Future work in the field of tailored physical activity coaching systems should aim to address the major topics discussed here. In order to arrive at innovative methods of tailoring, multidisciplinary research teams should make use of the knowledge available in theoretical literature instead of referring to existing applications in the field. Many different paths of tailoring are currently unexplored. The tailoring model in Fig. 4 points out many possible combinations of future tailoring approaches, and the discussion in Sect. 6 gives examples on all of the various tailoring concepts that can hopefully serve as a source of inspiration for future designers of these systems. There is especially room for the application of more advanced forms of tailoring such as context-awareness and self learning. Modern smartphones are able to collect a wealth of contextual information such as location, weather data and digital agenda's. They also contain the processing power necessary to perform powerful analysis using data mining or machine learning algorithms on the device itself. This combination gives the potential for a smartphone application to learn exactly how to deliver communication to the user in various contexts of use. Finally, innovative evaluation methods should be studied that can be used to quickly and cost-effectively demonstrate the merits of individual tailoring approaches.

8 Conclusion

In this work we have addressed the field of tailoring for real-time physical activity coaching systems. The survey was used to create a conceptual framework of tailoring. We identified seven key concepts: *feedback*, *inter-human interaction*, *adaptation*, *user targeting*, *goal setting*, *context awareness*, and *self learning*. Each of these concepts relate to each other, as well as to different properties of a *communication instance*. Earlier work that aimed to define the field of tailoring (Hawkins et al. 2008) has provided the basis for our framework, but lacked in covering emerging concepts like context awareness and self learning. The model we have developed (Fig. 4) can be used for designers of activity coaching systems. By following different paths through the graph, different combinations of tailoring can be explored. The analysis of the included applications based on the various tailoring concepts (Sect. 6) provides useful examples of how these concepts are currently being applied. We addressed the state of the art and point out future research directions as (1) applying available theoretical constructs to develop new forms of tailoring, (2) exploring new combinations of tailoring, with a focus on more advanced tailoring processes, and (3) developing innovative, fast and effective methods of evaluating the merits of individual tailoring approaches in the context of ICT services as a whole.

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