Personalization in Real-Time Physical Activity Coaching Using Mobile Applications: A Scoping Review

Francisco Monteiro-Guerra, Octavio Rivera-Romero, Luis Fernandez-Luque, and Brian Caulfield

***Abstract*—Mobile monitoring for health and wellness is becoming more sophisticated and accurate, with an increased use of real-time personalization technologies that may improve the effectiveness of physical activity coaching systems. This study aimed to review real-time physical activity coaching applications that make use of personalization mechanisms. A scoping review, using the PRISMA-ScR checklist, was conducted on the literature published from July 2007 to July 2018. A data extraction tool was developed to analyze the systems on general characteristics, personalization, design foundations (behavior change and gamification) and evaluation methods. 28 papers describing 17 different mobile applications were included. The most used personalization concepts were Feedback (17/17), Goal Setting (15/17), User Targeting (9/17) and Inter-human Interaction (8/17), while the less commonly covered were Self-Learning (4/17), Context Awareness (3/17) and Adaptation (2/17). Few systems considered behavior change theories for design (6/17). A total of 42 instances of gamification-related elements were found across 15 systems, but only 6 explicitly mention its use. Most systems (15/17) were submitted to some type of evaluation. However, few assessed the effects of particular strategies or overall system effectiveness using randomized experimental designs (5/17). Although personalization is thought to improve user adherence in physical activity coaching applications, it is still far from reaching its full potential. We believe that future work should consider the theory and suggestions reported in prior work; leverage the needs of the target users for personalization; include behavior change foundations and explore gamification theory; and properly evaluate these systems.**

***Index Terms*—Mobile applications, mobile health, personalization, physical activity, persuasive technology, scoping review, tailoring.**

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I. Introduction

It IS well understood that we need innovative approaches to address the alarmingly low levels of engagement in physical activity (PA) among the general population. The use of wearable and mobile monitoring technologies for this purpose has exploded from a standing start in the last 10–12 years. In this line, there has been important progress on the use of these systems to increase adherence to PA [1], both for the healthy population as well as for prevention and management of chronic diseases [2]–[4]. In particular, PA coaching applications are defined as systems that aim to motivate the user to change their activity behaviour by means of a coaching element [5]. A common motivational strategy used in PA coaching is Feedback, which is a way to stimulate such change by generating awareness of the user current behaviour.

Despite an increase in number, complexity and accuracy, these systems face the underlying challenge of user abandonment, which has been highlighted in recent publications [6]–[8]. Studies report that users may stop using such technologies once they have gathered enough information about their routine activities [8], [9]. Also, when it comes to commercially available solutions, these often target young and active people [10], who do not require special recommendations nor motivation. For users who need to be persuaded to become active, effects seem promising in the short-term but users do not feel additional inducement to use the devices [10], [11].

In order for these persuasive technologies [12], [13], to make an impact on user's behavior, researchers have highlighted the importance of including a strong theoretical basis considering different aspects of behavior change. In particular, a meta-analysis from Fanning *et al.* shows that mobile-based PA interventions tend to be more effective when relying on behavior change theories (BCTs) and models [14]. Some of the most used are the Social Cognitive Theory [15], the Transtheoretical Model [16] and the Self-Determination Theory [17]. Yet, relatively few health apps explicitly rely on these theories [18]–[21]. Also, as brought up by Fogg *et al.* in [12], for the behavior change program to have a sustainable impact, it is essential that automated systems engage people. In that context, gamification, defined as "the use of game design elements in nongame contexts" [22], has recently emerged in the design of persuasive health technologies [23], [24] with particular uses in health and fitness apps [25]. The field has been on a rapid rise [26], with evidence suggesting its potential in creating pleasant experiences for the users of technology.

Overall, the high levels of user abandonment have been commonly associated with a low perceived personal relevance and a lack of engagement [11], [27], which highlights the importance of exploring additional motivators to adopt sustainable healthy behaviors. A key factor that may determine persuasiveness to behavior change is related to creating personalized, or tailored, experiences to each individual [28].

As stated in [10], each individual is unique, and dynamic, in a sense that a strategy that works for one, might not work for another. It is believed that mobile-based interventions that are closely tailored to the individual's convictions and motivations are more likely to be observed and remembered [29]. Therefore personalization, or tailoring, helps in increasing the intended effects of communication, which can contribute to overcome the lack of adherence and effectiveness of these systems [30]. Furthermore, with mobile technologies allowing for more accurate, usable and engaging real-time support, there is an increase in alternative forms of personalization that can potentially make a difference in the effectiveness of PA coaching applications.

Hawkins *et al.* in [30] defined tailoring as "any of a number of methods for creating communications individualized for their receivers …". Since 2008 a number of papers were published related to tailoring technology-based health interventions [31]–[33]. The most recent work in this area, by op den Akker *et al.*, deals specifically with real-time tailoring of PA coaching applications [5]. The authors report on a literature survey, with data collected until July 2013, and define a tailoring model relying on 7 different concepts: Feedback (FB) - presenting the measured amount of activity performed to the user (can vary in timing, content and representation); User Targeting (UT) - conveying that communication is designed specifically for the user; Goal Setting (GS) - creating and updating user-specific goals based on users' activity trends and patterns; Inter-human Interaction (IHI) - providing support by form of interaction with other humans; Adaptation (Ad) - directing information to individual's status on key behavioral factors; Context Awareness (CA) - using users' external context to provide relevant information; and Self Learning (SL) - learning reactions of the users' to previous communications. However, the authors highlighted the lack of systems exploring the full potential of smartphones and available contextual information for the design of more complex personalization; the lack in application of Ad, CA and SL; the lack of clear specification of theoretical foundation for specific design decisions; and the lack of work demonstrating the effectiveness of tailoring in a more structured and controlled manner.

The exponential increase in evidence related to mobile PA coaching technologies motivated this scoping review. The aim is to systematically map the most recent developments on techniques used in these real-time systems that aim to motivate users in reaching their personal activity related goals. The specific objectives are to: i) expand the knowledge on personalization in real-time PA coaching applications, by presenting current advances in the field, ii) understand if previously reported gaps have been addressed and identify opportunities for future work, and iii) to provide a comprehensive analysis of these applications considering general system characteristics, behavior change theoretical foundation, use of gamification and system evaluation. Due to the scope of this review, it is clear that it does not cover all the work done on tailoring/personalization nor on physical activity coaching systems. Instead it explores a narrow topic that sits in-between these two fields.

II. Methods

A methodological scoping review [34], [35] was conducted to study real-time personalization in PA coaching mobile applications, and was built upon a prior literature survey and model published by op den Akker *et al.* in 2014 [5]. The protocol was drafted using the PRISMA extension for scoping reviews (PRISMA-ScR) checklist and explanation [36]. This extension provides reporting guidance for this specific type of knowledge synthesis. The checklist contains 20 essential reporting items and 2 optional items, which detail how to conduct and report scoping reviews.

This article does not aim to derive statistical evidence or conclusions from existing literature, as this is not applicable for scoping reviews.

A. Search Approach

The search strategy, used to identify potentially relevant studies, was based on [5]. Two searches were performed, one on July 12th, 2017 and another, to update the previous results, on July 10th, 2018. For the first search, 7 databases were selected as the source of information: PubMed; Association for Computing Machinery (ACM); ScienceDirect; IEEEexplore; PsycINFO; CINAHL; UCDlibrary-onesearch. A second search was conducted in PubMed, ACM and IEEEexplore, to include relevant papers published since the first search (from July 12th, 2017 to July 10th, 2018). These 3 databases were used as they covered all the selected studies from the first iteration. The search strategy was based on the previous review in this specific topic [5], and was conducted as follows: (personalized OR personalised OR personalization OR personalisation OR individualized OR individualised OR individualization OR individualisation OR tailored OR tailoring) AND ("physical activity" OR "daily activity" OR walking OR exercise OR exercising OR "activities of daily living") AND (coach OR coaching OR feedback OR motivate OR motivation OR stimulate OR stimulation OR promote OR promotion) AND (app OR application OR system OR device). When offered the option, keywords were searched in the entire text of the article.

To be included, papers needed to: be written in English; be published in conferences or journals over the last 10 years (from January 1st, 2007 to July 12th, 2017, when the first search was performed); deal with PA coaching systems, including either promotion of daily activities (e.g.,: walking, running), in-session coaching, or prevention of sedentary behavior; describe systems with some kind of personalization to the user; describe real-time coaching systems; describe systems that are smartphone-based and make use of embedded and/or external sensors to measure PA. Studies were excluded if they were: exergame-based; targeted at disease rehabilitation; targeted at specific exercises (e.g.,: rehabilitation exercises or machine exercises); with no direct connection between sensor and smartphone (e.g.,: systems in which a server is an intermediary of data synchronization between sensor and smartphone were excluded); with no real-time communication with the user. Also, papers were excluded if the full paper was not available. The real-time definition used in this study was the same considered in [5]. Following this definition, a real-time system is one that has a direct connection between sensor and feedback device, and that is able to communicate constantly with the user and provide immediate feedback on measured performance. For such real-time purposes, the feedback device could be either the sensor itself or a mobile phone/smartphone. The focus was on the latter modality as it offers more opportunities for richer processing and visual display. Some systems included in the previous review [5] were found through manual search, which means they could be missed in our database search. In such case, these systems were also included for analysis. Additionally, the research team searched for other papers with further system details by scanning the reference list from the included papers and through manual search in google scholar. The manual search terms included the author names and the system name.

B. Study Selection Procedure

The study selection procedure was divided into four phases. The identification phase consisted of retrieving articles from the databases and was performed by one researcher (FMG). After removing the duplicates, resulting papers went through the screening phase, first by title and then by abstract, by two researchers (FMG and ORR). In case of doubt, the paper was included and reviewed again in later stages for final inclusion. Then, a full-paper review was conducted by the two researchers (FMG and ORR) for eligibility, considering the defined inclusion/exclusion criteria. The included papers were then assessed for data extraction. Discrepancies on study selection and data extraction were solved by consensus. Cohen kappa coefficient was calculated, to measure inter rater agreement, in the title review ($k = 0.734$ on a random sample of 38 papers) and in the abstract review ($k = 0.85$ on a random sample of 100 papers) [37], revealing a substantial agreement between the two reviewers.

C. Data Extraction

A data-charting form was constructed by two researchers (FMG and ORR) based on the suggested in [36]. Following an iterative process, the authors identified the most relevant categories related to the objectives of this study and they were included or updated in the form. Discrepancies were solved by consensus.

The data was abstracted regarding 4 main categories. The first one included general system details on: target population, target activity, main features, inclusion of human (coach)-in-the-loop, platform used and market availability. The second aspect addressed was personalization, which was based on the model and framework provided in [5], and covered: coaching mode (if the communication is provided during daily activities, during exercise sessions or during sedentary behaviors), personalization concepts and mechanisms, technical implementation, communication properties addressed and inclusion of user profiling. The third category regarded the persuasive design considerations, and addressed the use of theoretical foundation and the inclusion of gamification elements [23]. The fourth, and last, category was on evaluation methods and included information on: study design (based on the framework in [38]), study population, study/intervention description, outcome measures and persuasive strategies comparison.

Theoretical foundation was only extracted if theories were explicitly stated in the paper. The presence of gamification elements was extrapolated for all systems based on [23]. The systems were, however, distinguished based on explicit or implicit use of gamification. Explicit use was considered in papers that included gamification-related terms in the system description (e.g.,: “games”, “game-based”, “game-like”, “gamification”, …), while implicit use was attributed to those systems that include gamification-related elements without explicitly reporting to do so.

The details of the data-charting form for each of the included systems were independently extracted by two researchers (FMG, ORR). After data extraction, classification discrepancies were resolved by mutual agreement.

D. Data Analysis

Two researchers (FMG and ORR) went through the taxonomy table for all the included studies, in an attempt to find relevant insights to the research objectives posed for this review. Common patterns, contradictory results, and gaps were also analyzed for all studies.

III. Results

We retrieved 1274 results from the first database search from which 341 were duplicates. To the remaining results, 200 new papers (without duplicates found) were added from the second database search, summing a total of 1133 results for screening. 555 met the title review criteria and, from these, 154 met the inclusion criteria in the abstract review. From the full-text review, 18 out of the 138 were then selected for inclusion, to which we added 8 more papers with further description of the included systems and 2 more with a system included in the review of op den Akker *et al.* In total, we included 28 papers [39]–[66] that covered 17 different PA coaching applications that explore personalization strategies in their design. A flow diagram representing the full process is shown in Fig. 1.

16 out of the 28 included papers (some describing the same system) were new compared to the previous review, contributing with 10 new apps and 1 updated version of an already reported system. 5 of the systems found by their team were not retrieved in our database search, as these were probably identified through the manual search they have performed in Google Scholar and their personal libraries. From those 5 systems, we only included 1 (with 2 associate papers), which respected our criteria for being a mobile phone app. Therefore, a total of 17 systems

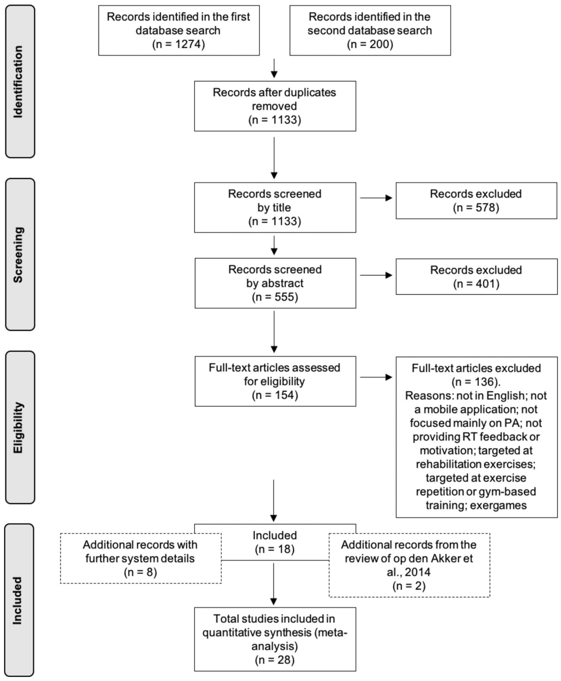

Fig. 1. Flow diagram of the search strategy.

were included in our study, and the analysis is presented in the following sections of this paper.

A. General System Characteristics

An overview of the systems' details is provided in Table I and includes a descriptive summary of the systems' objectives, main features, platform and market availability.

App screenshots of some of the included systems are presented in Fig. 2.

B. Personalization

The personalization concepts implemented in each app are discriminated in Table II, where the systems were categorized according to the coaching mode: over daily life activities (12 apps); during exercise sessions (3 apps); or to reduce sedentary behavior (2 apps). The most frequent used concepts were Feedback (used in all 17 apps), Goal Setting (15 apps), User Targeting (9 apps) and Inter-human Interaction (8 apps). The less frequent were Self Learning (4 apps), Context Awareness (3 apps) and Adaptation (2 apps). Move2Play and INTELiRun covered the highest number of personalization concepts, both with 6 instances, followed by Sweetch and AAFS with 5 instances.

The following subsections describe the different personalization concepts and mechanisms used by the systems.

1) Feedback: Feedback (FB) is the most obvious form of personalization and is used by all of the included apps.

Considering the intention of the FB, we can separate the included systems in two main categories, those that aim at promoting PA (daily activities or exercise) and those that aim at reducing sedentary behavior (SitCoach and B-Mobile). On11 and Analytic, Social, Affect feature both intentions. They monitor sedentary behavior and try to reduce it, but also monitor active periods and provide coaching to achieve certain activity goals.

In terms of timing, FB initiative can be with the user, when information is provided only if the user looks at a glanceable display (e.g.,: UbiFit Garden, BeWell), or with the system, when it provides cues for the user to walk/run faster or slower based on user's speed (e.g.,: Haptic Personal Trainer, u4fit). Another aspect of timing relates to the type of coaching, which can be during daily activities or during exercise sessions.

Considering the content of FB, only 2 papers seemed to address this property, reporting specifically on the phrasing of FB. The authors from the paper on the AAFS system, tested three types of messages: encouraging, neutral and discouraging. Also, in the SitCoach study, the authors tested motivational messages phrased using 4 different persuasive strategies based on the social influence theory.

Regarding FB representation, the simplest form is through text messages and/or text notifications. Most systems also make use of some kind of visual feedback, either through graphs or more complex visual displays such as avatars (e.g.,: Move2Play) or virtual ecosystems that change based on the user state (e.g.,: UbiFit Garden and BeWell). Audio feedback was explored in 3 systems, TripleBeat, Haptic Personal Trainer and SitCoach. These last two also explored tactile cues as a mechanism for providing feedback.

2) Goal Setting: Goal setting (GS) is used by most of the included applications (15 out of 17) and is a strategy commonly associated with FB.

Many of the applications, in particular the ones that provide coaching during life activities, include simple daily and/or weekly numerical goals such as number of steps, distance or activity duration. On the other hand, applications that provide coaching during a workout session can provide goals in the form of session routines that the user can follow step-by-step and that can be based on the type of activity, pace, duration, or time spent in a specific heart-rate range (e.g.,: TripleBeat and u4fit).

Some systems allow the user to choose from a set of high-level goals and then present more specific objectives or suggestions according to that goal choice. TripleBeat proposes a workout schedule based on a general goal, for example, to lose fewer calories but burn more fat, or to improve cardiovascular/ respiratory health. On11 allows the users to select from three types of goals: Keep Healthy, Lose Weight, or Burn Calories, and then suggests appropriate activities to help them achieve those goals. Regarding the creation of overall activity plans/calendars, only a few systems seem to implement this feature (e.g.,: CAMMInA and u4fit). In u4fit, for example, the schedule is composed of several sessions per week for several weeks. In general, most systems let the user set or review their goals. Only u4fit and AAFS allow the training goals or plans to be set or adapted by a professional (human-in-the-loop).

Several systems consider the user's characteristics (e.g.,: age, weight, preferences, physical activity level) in the definition of goals, combining GS and UT. iBurnCalorie provides a daily personalized caloric estimate that the user needs to expend,

TABLE I
GENERAL SYSTEM CHARACTERISTICS

Systems	Studies	Target Population	Target Activity	Summary	Platform	Market Availability
UbiFit Garden [a]	Consolvo et al. 2008 and 2009 [39], [40]	Adults	Walking, running or cycling	Encourages individuals to self-monitor their activity and incorporate regular and varied exercise into everyday life. Users' physical activity is presented through a graphic display with a "garden" metaphor, where a different type/color of flower represents a different activity and a butterfly shows up when the user reaches the weekly goals.	Mobile phone application (Nokia 5500 Sport). External sensors (accelerometer and barometer)	N
Haptic Personal Trainer [a]	Qian et al. 2010 and 2011 [41], [42]	Adults	Walking	Provides haptic feedback to the user to stimulate a change in the walking rate. The haptic feedback consists of structured vibration pulses with varying durations that are composed into rhythmic units which are detectable by the user. A second version of the system implements auditory feedback to be used in conjunction with the haptic feedback.	Mobile phone application (Nokia N95). Built-in accelerometer	N
BeWell [a] & BeWell+ [a]	Lane et al. 2011 and 2014 [43], [45] and Lin et al. 2012 [44].	Adults	General daily activities	Monitor users' health behavior across the dimensions of sleep, physical activity and social interaction. Feedback on those specific health dimensions is provided through an ambient display with an "aquatic ecosystem" on the smartphone's wallpaper, where each dimension is represented by different characters. The updated version BeWell+ includes a community adaptive feedback component, in which the performance of individual users is compared to positive role models. The system uses an algorithm that automatically groups similar users and a strategy to save the smartphone's battery.	Smartphone app (Android Nexus One). Built-in sensors (GPS, accelerometer and microphone)	N
Move2Play [a]	Bielik et al. 2012 [46]	Children and adults (2 versions)	General daily activities	Encourages an increase in activity through recommendations, in the form of personalized daily plans, and subsequent evaluation of the activity. Motivation component relies on 5 strategies - informational, social influence and network, gamification, rewards and the use of an avatar. Activity data is fed back to the user via a number of different visualization options and incorporates goal setting and group feedback. Includes personalized physical activity recommendation which is inferred based on a user model and a domain model.	Smartphone app. Built-in sensors (accelerometer, GPS and GSM)	N
CAMMInA	Rodriguez et al. 2013 [47]	Elders	General daily activities	An Ambient Information System (AIS). Allows users to set their goals. The system provides timed audible and textual notifications as triggers to encourage users to achieve their exercising goals: reminders for exercising and notifications while they are exercising. A virtual reward system is implemented as positive and playful reinforcement. The system provides a three-week representation of the compiled, current, and planned exercising goals through a calendar presented as a wallpaper on the mobile phone. The coins earned and user's social interactions are also presented in the calendar.	Smartphone app. No details on the monitoring sensors	N
Analytic, Social, Affect [a]	King et al. 2013 [48]	Adults	General daily activities of moderate-intensity and sedentary breaks	3 different apps constructed each based on different motivational frames (BCTs). An analytic app focused on goal setting, problem-solving and informational tips; a social app focused on interaction, competition and collaboration; and an affective app focused on avatars, game-like feedback and rewards. The 3 apps have in common the use of a glanceable display for just-in-time feedback; the use of ecological momentary assessment questions sent daily; and the type of PA.	Smartphone app. Built-in accelerometer	N
AAFS	Achterkamp et al. 2013 [49]	Adults	General daily activities	The user receives feedback on cumulative activity and goal through a graph. The system provides motivational cues to become more active or take a break based on deviations from the goal line. The new version explores personalized goal setting and tailored feedback messages in an attempt to increase adherence and effectiveness of the system. They are prompted with self-efficacy and stage of change questionnaires every 4 weeks and physical activity pattern is automatically detected so that the system adapts to the user's progress. Will integrate a user agenda to further personalize goal-setting.	Smartphone app. External accelerometer	N
It's Life!	van der Weegen et al. 2013, 2014 and 2015 [50]-[52]; Verwey et al. 2014 [53]	Patients with COPD or type-2 diabetes	Moderate to vigorous physical activity	Allows users to set their daily physical activity goals. Shows user's real-time activity results and history in minutes of moderate to vigorous activity on the mobile phone and Web app, showing an image of a sun as a subtle reward when the goal is reached. Users can enter information in individual sessions or read feedback messages generated by the system or the practitioners.	Smartphone and Web app. External accelerometer	N
StepbyStep	Zuckerman et al. 2014 [54]	Adults	Walking	The main functionalities of the app are real-time feedback on performance and goal-setting. Goals are automatically set, reflecting a 10% increase over this baseline level. Feedback is provided in the form of a progress bar showing progress toward the goal on the main screen of the application. A congratulatory pop-up message appears when the daily goal is reached. It has 2 versions: a quantified version, which offers continuous measurement of walking time, a daily goal, and real-time feedback; and a gamified version that provides virtual rewards and social comparison.	Smartphone app. Built-in accelerometer	N
On11	He et al. 2014 [55]	Adults	General daily activities (walking, running) and sedentary breaks	Allows the users to select from three types of goals, to Keep Healthy, Lose Weight, or Burn Calories, and then suggests appropriate activities to help achieve those goals. The main screen presents the weather dashboard and glanceable feedback on time spent sitting, walking and running; the calories spent; and the progress towards the personal goal. Also, if a user is inactive for a certain period, On11 will notify the user, through the LED, sound or vibration, and then recommends the user to stand up and take a walk. When the activity logger recognizes long periods of inactivity, the recommendation generator attempts to generate personalized suggestions: detours to their usual travel routes or mini-walks around their workplace. When the user clicks on a recommended activity the app displays a detour map.	Smartphone app. Built-in sensors (GPS and accelerometer)	N
iBurnCalorie	Khatri et al. 2016 [56]	Adults	Walking or biking	Uses simple personalized goal design and a social comparison feature, which takes a secondary role. The minimalist interface communicates the status of the personalized health goal (i.e., calories left to expend for the day), the bottom half of the screen communicates the user's status with respect to the group physical activity (presented in weekly or monthly views). The home screen shows an animation depicting the currently active mode. The driving screen carries a negative connotation by not having the calorie indicator and using a red graph instead of the green one, which shows up when doing an activity.	Smartphone app (iPhone). Built-in sensors (accelerometer and GPS)	iTunes App Store
Sweetch	Everett et al. 2018 [57]	Adults with prediabetes	General daily activities	Monitors users' life habits and, using machine learning based algorithms, presents them with personalized, contextual, just-in-time, recommendations to achieve their goals. Learns what types of messages result in better compliance for the specific user in a specific context. Implements goal-setting, feedback, and timely reinforcing features. Shows progress towards activity goals and provides actionable recommendations through personalized push notifications.	Smartphone app. Built-in sensors (not detailed). External sensor (Bluetooth enable digital scale)	GooglePlay and iTunes App Store
MPTrain [a] & TripleBeat [a]	Oliver & Flores-Mangas 2006 [58]; Oliveira & Oliver 2008 [59]	Adults	Jogging, walking or running	Assists users while exercising (jogging, walking or running) in achieving predefined exercise goals via musical feedback. Automatically determines the musical features (volume, beat and energy) to play that correspond to the users' exercise level and current heart-rate. The updated app makes use of a glanceable interface for increased personal awareness that provides cues on how to keep the heart-rate inside the proposed training zone. It also includes a proposed workout schedule, virtual competition and a novel score function with reward elements.	Mobile phone or PDA application. External sensors (ECG and accelerometer). A processing board and a Bluetooth transmitter	N
Everywhere Run [a] & Everywhere Race [a] & u4fit	Mulas et al. 2011 and 2012 [60], [61]; Boratto et al. 2017 [62]	Adults	Running	The objective is to foster interaction between users and personal trainers, and the main features are an intuitive glanceable interface that provides cues to slow down or speed up and the option to share the results with the community. Includes a "virtual personal trainer", which provides guidance and support in real time according to a workout plan (defined by users or a human coach) by means of visual and vocal cues. Optional coach-in-the-loop, where he/she can build complex user-tailored workout routines, monitor users' performance and motivate the user by means of an internal messaging system. The main screen of the "virtual personal trainer" presents the user with an indication of current activity being performed and the current goal, it also shows two widgets with the distance covered and speed (including indications to slow down or speed up the pace), and allows the user to choose among other activity statistics.	Smartphone and web app. Built-in GPS and external ECGs	GooglePlay and iTunes App Store
INTELiRun	Varadharajn et al. 2016 [63]	Adults	Running	Provides real-time feedback including quantitative information (average speed, total distance, etc.), emoticons representing emotions felt before and after exercise, and a map showing the path, of the current workout or history data. The app allows users to challenge their friends. It collects users' mood, personality, emotions before and after their exercises, and social media data. The collected information is analyzed for personalized recommendations.	Smartphone app. Built-in sensors (accelerometer, GPS, gyroscope and microphone)	N
SitCoach	van Dantzig et al. 2013 [64]	Adults	Sedentary breaks	Provides timely messages to encourage taking breaks from sitting. The app reminds users to take a break after a configurable number of inactive minutes, by means of visual, acoustic and tactile cues. Users can also set a goal in terms of the number of active minutes per day, and compare their results with peer users. The main screen shows when a user is moving, with a green icon if a running person, the number of total active minutes in the current day and the defined goal, and it also displays in red how many minutes are left until the next active break.	Smartphone app. Built-in accelerometer	N
B-Mobile	Bond et al. 2014 [65]; Thomas & Bond 2015 [66]	Adults with overweight/ obesity	Sedentary breaks	Uses an automobile dashboard metaphor to give them feedback. The dashboard includes a "fuel gauge" depicting the number of sedentary minutes remaining until the next physical activity break, and two odometers tracking the total number of sedentary minutes and activity minutes accumulated that day.	Smartphone app. Built-in accelerometer	N

[a]Systems also covered in the literature survey by op den Akker *et al.* in 2014 [5].

based on personal information provided during the registration process and daily requests. StepbyStep takes into account the user's baseline level of walking, then automatically sets a daily walking goal reflecting a 10% increase over the baseline level. The personal trainers from the u4fit system use information from the user's physical activity profile and his progress to adapt the plan provided. In the AAFS system, the goals are set based on a baseline of activity for each day of the week and are kept up to date based on the daily progress and the activity pattern throughout the day. Move2Play recommends the appropriate amount of activity based on characteristics present in user and domain models. Also, the Sweetch app

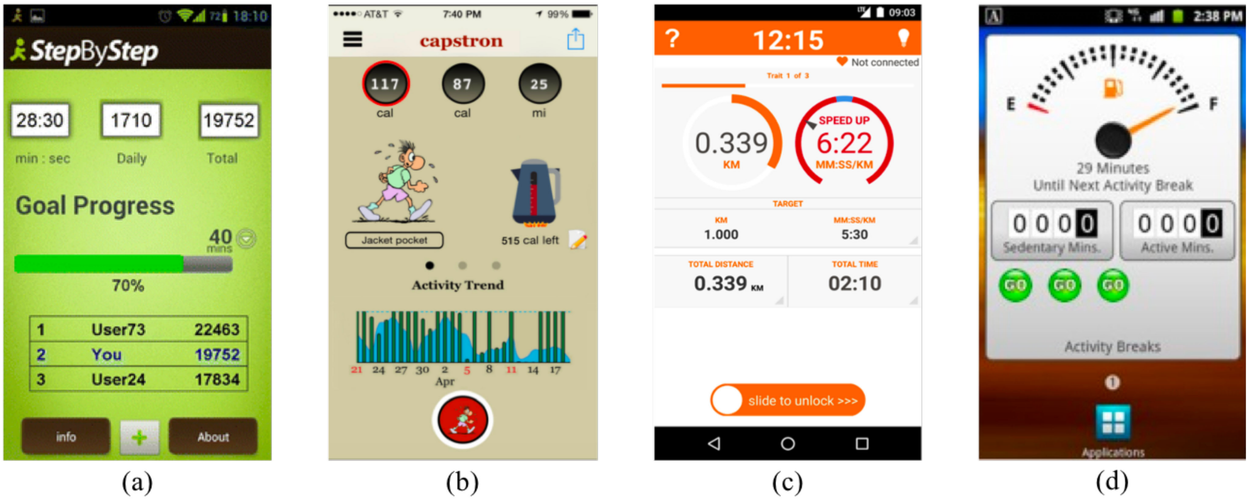

Fig. 2. Example screenshots of 4 real-time PA coaching applications. (a) StepByStep [54], (b) iBurnCalorie [56], (c) u4fit [62] and (d) B-Mobile [64].

continuously adapts goals based on the user's real-world behavior and weight.

BeWell+ is a particular case that uses community adaptive GS, adapting the goals based on the performance of the users compared to other similar users that perform slightly better.

In terms of representation of goals, most systems are making use of visual displays like progress bars, goal lines in graphs (see systems figures), or cues in virtual ecosystems, rather than relying solely on textual format.

3) User Targeting: A variety of forms of User Targeting (UT) are used by 9 of the included applications.

The most transparent way of implementing UT is implemented by Move2Play, SitCoach, Sweetch and iBurnCalorie apps, which include the users' names or nicknames in the main screen and/or in the textual feedback.

Other less transparent approaches involve adapting the information based on the user characteristics (e.g.,: age, weight, preferences, physical activity level). As described previously, this is mostly used in pair with GS strategies: the iBurnCalorie makes use of personal information provided during the registration process (age, gender, height, and weight during the registration process) and daily estimates of the users' mean caloric food intake per day; StepbyStep takes into account the user's baseline level of walking; u4fit system uses information from the user's physical activity profile and his progress; the AAFS system, uses the users' baseline of activity, daily progress and activity pattern throughout the day; Move2Play system adapts to the characteristics present in user and domain models (e.g., age, gender, physical activity fitness); the Sweetch app makes use of the user's real-world habits and weight data; and INTELiRun incorporates age, height, weight, heart rate and injury history. On11 is a system that combines UT with FB by providing estimations of burnt calories to the users based on personal information from the user profile interface (gender, age, height, and weight).

A less reported and detailed strategy of UT is to consider the users' preferences to provide personalized suggestions or recommendations. For example, Move2Play recommends the appropriate type activity, based on the user activity preferences, in a way that will lead to the fulfilment of the daily plan and that the user will enjoy. Also, On11 provides walking suggestions and recommends detours based on personal preferences.

4) Inter-Human Interaction: Inter-human Interaction (IHI) is used in 8 of the included systems and can also be covered through a variety of different strategies.

Social comparison is the most common form of IHI. The iBurnCalorie app makes use of a trending graph at the bottom of the home screen that provides an overview of the user's status (activity trend or driving trend) compared to the social trend. Also, Move2Play and StepbyStep include a feature that ranks users in a leaderboard according to their achieved results. Move2Play tries to ensure a fair competition by considering the relative effort from the users, based on their fitness and physical condition. A more complex strategy is implemented by TripleBeat, where the user can compete with other virtual or real users, or the actual user on past runs. This competition is defined by how well users achieve their predefined goals, not by who is faster or exercises longer, aiming to promote healthy goal achievement. In the paper, the authors detail the strategies used for this purpose and to create a fair competition, which are based on a novel performance score function and similar opponent selection. BeWell+ app implements social comparison but implicitly, in combination with GS and FB, by comparing the performance of individual users with other peers, but in this case with users that are similar in behavior and that perform slightly better (through similarity matching).

Some systems incite teamwork among the users. Such can be done either through group-based competition, as done in Move2play and the social version of the Analytic, Social, Affect system, or by simply allowing the users to create shared goals with others, which is also provided as an option in Move2Play app.

Another form of IHI relies on enabling sharing of results and providing support among a network of users. The social version of the Analytic, Social, Affect system includes an electronic message board where participants can post comments or suggestions to the other participants. In Move2Play users can connect with friends, see their progress and compare their

TABLE II
SUMMARY OF PERSONALIZATION, THEORETICAL FOUNDATION AND GAMIFICATION

Coaching Type	Systems	Personalization							Theoretical Foundation	Gamification									
		FB	GS	UT	IHI	Ad	CA	SL		Avatars	Challenges	Leader-boards	Levels	Progress	Rewards	Social Int.	Success Feedback	Theme	Descriptive details
Coaching Over Daily Life Activities	UbiFit Garden [a] [39],[40]	✓	✓	-	-	-	-	-	TTM [68], GST [67], Presentation of Self in Everyday Life [69] and CDT [70]	-	-	-	-	(✓)	(✓)	-	-	(✓)	Implicit. Rewards (butterflies for achieved goals), progress (number of flowers), theme (virtual garden)
	Haptic Personal Trainer [a] [41], [42]	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	BeWell [a] & BeWell+ [a] [43]-[45]	✓	✓	-	✓	-	-	✓	-	-	-	-	-	(✓)	(✓)	-	-	(✓)	Implicit. Rewards (wellbeing scores), progress (changes in the ecosystem - clown fish, school of fishes and lighting of ocean - and in the scores), theme (aquatic ecosystem)
	Move2Play [a] [46]	✓	✓	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	-	-	Explicit. Avatar (animated character), challenges (long-term achievements), leaderboards, levels, progress (progress bar and emotional level of avatar), rewards (points for virtual market or to use in external games, badges, unlockable features), social interaction (connect and compare with friends)
	CAMMInA [47]	✓	✓	-	✓	-	-	-	CDT (no reference)	-	-	-	✓	✓	✓	✓	✓	-	Explicit. Levels (based on level of motivation), progress (time exercising towards proposed goal), rewards (access time for playing games and virtual coins and virtual diamonds), social interaction, success feedback (audible notification and a gold coin)
	Analytic, Social, Affect [a] [48]	✓	✓	-	-	-	-	-	Analytic app: SCT [71] and self-regulatory principles of behavior change [73]. Social app: SIT [74]. Affective app: operant conditioning principles [75], [76]	-	-	-	✓	✓	✓	-	✓	✓	Explicit. Levels (of activity), progress (change of bird's posture, position, and movement; bird travelling), rewards (pictures of destinations), success feedback (bird giving a "thumbs up" with a melodious sound), theme (bird travelling to different destinations)
	AAFS [49]	✓	✓	✓	-	✓	-	✓	SCT (focus on Self-Efficacy) [72], TTM [16] and GST [67]	-	-	-	-	-	-	-	-	-	-
	It's Life! [50]-[53]	✓	✓	-	-	-	-	-	-	-	-	-	-	(✓)	-	-	-	-	Implicit. Progress (progress bars)
	StepbyStep [54]	✓	✓	✓	✓	-	-	-	SDT [77]	-	-	✓	-	✓	✓	-	-	-	Explicit. Leaderboard, progress (progress bar), rewards (points)
	On11 [55]	✓	✓	✓	-	-	✓		-	-	-	-	-	(✓)	-	-	-	-	Implicit. Progress (progress bars)
	iBurnCalorie [56]	✓	✓	✓	✓	-	-	-	GST [67]	-	-	-	-	(✓)	-	(✓)	-	-	Implicit. Progress (progress bar), social interaction (competition and comparison with social trend)
	Sweetch [57]	✓	✓	✓	-	-	✓	✓	-	-	-	-	-	-	(✓)	-	-	-	Implicit. Progress (progress bar and progress in weight loss program)
Coaching During Exercise Sessions	MPTrain [a] [58] & TripleBeat [a] [59]	✓	✓	-	✓	-	-	-	(refers to BCTs described in persuasive technology theory [12])	-	-	✓	-	✓	✓	✓	-	-	Explicit. Leaderboard, progress, rewards, social interaction (competition)
	Everywhere Run [a] [60] & Everywhere Race [a] [61] & u4fit [62]	✓	✓	✓	✓	-	-	-	-	-	-	-	-	(✓)	-	-	-	-	Implicit. Progress (progress bar)
	INTELiRun [63]	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	✓	-	-	Explicit. Social interaction (challenge friends)
Coaching to Reduce Sedentary Behavior	SitCoach [64]	✓	✓	✓	-	-	-	-	-	-	-	-	-	(✓)	-	-	-	-	Implicit. Progress (progress bar)
	B-Mobile [65], [66]	✓	-	-	-	-	-	-	-	-	-	-	-	(✓)	(✓)	-	(✓)	(✓)	Implicit. Progress, rewards (earn "go lights"), success feedback (prompt when goal is met), theme (automobile dashboard metaphor)

[a]Systems also covered in the literature survey by op den Akker *et al.* in 2014 [5].
FB - Feedback; GS - Goal Setting; UT - User Targeting; IHI - Inter-human Interaction; Ad - Adaptation; CA - Context Awareness; and SL – Self Learning. TTM - Transtheoretical Model; GST - Goal Setting Theory; SCT - Social Cognitive Theory; SDT - Self-Determination Theory; SIT - Social Influence Theory; CDT - Cognitive Dissonance Theory. The presence of gamification elements was classified with (√) – for implicit use - or √ - for explicit use.

results, and this is made easier with the integration with popular social networks. The u4fit application allows users to create, save, and share their workout session results on Facebook. INTELiRun also allows users to share their running data on multiple social media platforms, to send and receive challenges from others and to find similar fitness running mates (via a matching feature in the app).

A less frequent strategy of IHI is to include interactions with a human coach, which is one of u4fit's main features. In u4fit a coach (chosen by the user) creates a tailored workout plan, analyses the training data gathered from the app and has the option of modifying the plan and motivating the user by means of the internal messaging system.

5) Adaptation: Only 2 system covers the concept of Adaptation (Ad) as a personalization strategy.

The AAFS combines Ad with FB, by providing tailored messages based on the user's score on self-efficacy and stage of change questionnaires and also on the user's own baseline level of physical activity (UT). With that information users are identified as one of 8 personas and recommended one of six feedback strategies. The INTELiRun app also prompts the user with a personality questionnaire, and provides feedback specific to each personality type.

6) Context Awareness: Context Awareness (CA) is used in 3 out of the 17 included systems. However, the papers do not provide much details on its use and implementation, except for the one describing On11.

In Move2Play, they reported on a PA recommendation algorithm that takes into account a Domain Model, which holds stable facts/knowledge about how we generally exercise and what factors affect the amount of activity. The model integrates factors such as day of the week, the month or season and the weather. On11 encourages users to walk by adding detours into their usual travel routes, such as home-workplace route or routes to their frequently visited destinations, and suggesting mini-walks around their workplace such as walking to the coffee lounge. The implementation of the recommendation system is detailed in the paper and takes into consideration the user's current location, location history, date and time.

The Sweetch app is context aware in the sense that it notifies the user to do activity only when the user's calendar indicates available time and recommends specific activities based on the user's surrounding locations.

7) Self Learning: Self Learning (SL) is covered in 4 of the included systems.

The BeWell+ system uses SL in the way it implements the similarity matching algorithm for GS and FB, by repeating the matching process as new behavior data from the user is available. In that way, the system will incrementally set more challenging goals to the user, by selecting as frame of reference higher performing people that are still relatively similar to the user. Move2Play includes a user model (containing physical fitness, activity patterns and activity preferences) that is built incrementally with the use of the system. This model is fed into the rule-base system that provides recommendations on the amount and type of activity, hence combining SL with FB, UT and GS. As mentioned previously, the system seems to be partly in conceptual phase and no technical details are provided. The AAFS intends to be a continuously adapting system that takes into consideration the user's routine, for GS, and their progress through time regarding the psychological constructs, for Ad. The system uses a smart reference module that automatically plots in a graph self-adjusting goal lines for each individual based on their routine of activity. The goal lines provide information on the percentage of total activity that the user should achieve at different times of the day and are built based on the past user activity, on that day of the week and specific time of the day, but with a slight increment. Furthermore, users are prompted with self-efficacy and stage of change questionnaires that, combined with the classification of their activity pattern, allow the system to automatically select the best feedback strategies for each user. The Sweetch app uses machine learning to create insights about the individual's life habits (e.g.,: schedule, activity patterns, driving and walking routes, surroundings) and then, using advanced algorithms adapts the timing and content of FB, CA recommendations and GS. The system learns what types of messages result in better compliance for the specific user in terms of for example, day of the week, time, location and types of messages. However, no details are provided regarding its implementation.

C. Behavior Change Theories

Only 6 out of 17 analyzed systems explicitly included behavior change theoretical foundations (see Table II). All were classified into the category of "real-time coaching over daily life activities". The most reported BCT was the Goal-Setting Theory (GST) [67], used in 4 of the systems. Other included theories were the Transtheoretical Model (TTM) [16], [68], Presentation of Self in Everyday Life [69], Cognitive Dissonance Theory (CDT) [70], Social Cognitive Theory (SCT) [71], Self-Efficacy from SCT [72], Self-Regulatory Principles of Behavior Change [73], Social Influence Theory (SIT) [74], Operant Conditioning Principles [75], [76], and Self-Determination Theory (SDT) [77]. 3 systems used a combination of BCTs, all including the GST. The papers did not clearly report design decisions based on these theories.

D. Gamification

Only 6 out of the 17 systems explicitly mentioned the use of gamification. However, 10 included certain motivation features that could be associated with gamification. Game design elements included avatars (n = 1), challenges (n = 1), leaderboards (n = 3), levels (n = 3), progress (n = 14), rewards (n = 8), social interaction (n = 5), success feedback (n = 3) and theme (n = 4). A total of 42 instances of implemented gamification elements were found across the 17 systems (see Table II).

E. System Evaluation

The reviewed papers reported on the evaluation of 15 out of the 17 included systems (see Table III) [39]–[41], [44], [46]–[48], [51], [53]–[62], [64], [66], [78], [79]. 6 of these systems were evaluated in more than one separate study, with 4 being submitted to both nonexperimental and intervention studies. In total, 10 systems were submitted to nonexperimental studies (including user experience, system functionality, validation, usability and user acceptance). 9 systems were evaluated in terms of system effectiveness, 5 in randomized experiments, and 4 in quasi-experiments. None of the quasi-experimental studies included a control group. The quasi-experiment and randomized experiment studies, involved between 10 and 55 participants, and 27 and 199 participants, respectively. Regarding duration, the quasi-experiment studies lasted between 1 session and 3 months, and the randomized experiment studies between 10 days and 6 months. From all studies, only 4 compared the effects of different persuasive and/or personalization strategies.

IV. Discussion

In this scoping review we identified 28 studies, published between 2007 and 2018, describing 17 real-time PA coaching applications that used some form of personalization. The review contributed with the analysis of 10 new mobile applications and 1 updated version of an already reported system, compared to previous results reported by op den Akker *et al.* in 2014 [5]. Furthermore, we took a comprehensive approach, following the PRISMA-ScR, gathering detailed information on general system characteristics, personalization, behavior change foundation, gamification and system evaluation.

The global picture of having 17 personalized real-time PA coaching systems being published in the last 10–11 years reveals a considerable interest of the scientific community in this field of

TABLE III
SUMMARY OF SYSTEM EVALUATION METHODS

Systems	Evaluation Studies References	Study Design	Population	Study/Intervention Description	Outcome Measures	Persuasive Strategies Comp.
UbiFit Garden	Consolvo et al. 2008 [39]	Nonexperimental design	Sample Size: Total n=12; Population: regular mobile phone users who wanted to increase their PA; Age: 25 to 35; Male (%): 50; Country: -; Attrition rate (%): -	Study focus: user experience; Study participation involved 3 in-person sessions. In session 1, conducted at the start of week 1, participants were interviewed about PA, completed several questionnaires, chose a weekly PA goal and received the study phone and fitness device; in session 2 and 3, conducted approximately 7 and 21 days after the first interview, participants were interviewed about their experiences in the study. Duration: 3 weeks	Experiences with the sensing and activity inference capabilities and general reactions to the system. Tools: interviews	N
	Consolvo et al. 2008 [78] and Consolvo et al. 2009 [40]	Randomized experiment (P)	Sample size: Total n=30, (Full system) n=10, (No Fitness Device) n=9, (No Glanceable Display) n=9; Population: general public - regular mobile phone users; Age: 25-54; Male (%): 46.4%; Country: USA; Attrition rate (%): 6.67	Intervention focus: PA; Groups: (Full System) participants used glanceable display, interactive application, and fitness device; (No Fitness Device) participants used the glanceable display, and the interactive application; (No Glanceable Display) participants used the interactive application and fitness device. Duration: 3 months; Follow-up post baseline: week 1, 4, 12	The total weekly duration of cardio and walking activities (Activity Duration; the total number of weekly activities, including cardio, walking, flexibility, and strength training (Activity Count); and user experience. Tools: Mobile Sensing Platform (MSP) created for research purposes, interviews and questionnaires	N
Haptic Personal Trainer [a]	Qian et al. 2010 [41]	Nonexperimental design	Sample size: Total n=15; Population: -; Age: 18-25; Male (%): -; Country: -; Attrition rate (%): 0	Study focus: validation; Participants wore both N95 and pedometer and were asked to walk at three rates of pace: normal, slower than normal, and faster than normal. The order of the three rates was randomized and participants walked at each rate for two minutes, followed by an optional break. Finally, participants were asked to walk using a combination of the three rates (e.g. 90 seconds at a fast pace, 90 seconds at a slow pace, 90 seconds at their normal paces). Duration: 1 session	Step counting results from the mobile phone were compared to the values generated by a widely used commercial pedometer. Tools: Nokia N95 built-in accelerometer and Omron HJ-112	N
		Quasi-experiment (P)	Sample size: Total n=15; Population: older adults living independently; Age: over 60, Mean 69.81 (SD 7.02); Male (%): 46.7; Country: -; Attrition rate (%): 0	Intervention focus: effects of haptic cues on step pace; Groups: 1 group – the study was conducted with participants walking at varying speeds, both with and without the presence of assistive haptic feedback (HFB) from the prototype. Baseline: the participant's normal step rate was computed. Fast step rate was set 120% of baseline and desired slow step rate was 80% of baseline. Five conditions (order randomized): normal pace with HFB; faster than normal pace without HFB; faster than normal pace with HFB; slower than normal pace without HFB; slower than normal pace with HFB. Duration: 1 session	Average step rate (steps/min) after each condition and the ratio between the target pace and actual pace; and participants' comments regarding the usefulness of the system. Tools: Nokia N95 built in accelerometer	N
BeWell [a] & BeWell+ [a]	Lin et al. 2012 [44]	Randomized experiment (P)	Sample size: Total n=27, (Intervention) n=-, (Baseline) n= -; Population: faculty members, graduated students, researchers, and students; Age: 21-37; Male (%): 59.26; Country: -; Attrition rate (%): 0	Intervention focus: wellbeing - sleep, PA and social interaction; Groups: (intervention) participants had the core BeWell+ software installed, with the ambient display; (baseline) participants from the baseline group also had the software installed but did not have the ambient display and could only view collected information via a web portal. Duration: 19 days	Sleep (total quantity of the sleep for an individual over a 24-hour period), PA (daily activity) and social interactions (the total duration of ambient speech during a day); energy allocation (smartphone energy usage); user reactions to the display and attitudes and preferences to general use of the system. Tools: Nexus One built in accelerometer and microphone sensors, and interviews	N
Move2Play [a]	Bielik et al. 2012 [46]	Nonexperimental design	Sample Size: Total n=12; Population: children; Age: 12 to 13; Male (%): -; Country: Slovakia; Attrition rate (%): -	Study focus: user experience; Participants were given a mobile phone with the app installed and were asked to test the key app functionalities. Duration: 1 session	Perception of the overall concept and its key functionalities. Tools: task-based session	N
CAMMInA	Rodriguez et al. 2012 [47]	Nonexperimental design	Sample Size: Total n=15; Population: elders; Age: 63 to 86; Male (%): -; Country: Mexico; Attrition rate (%): -	Study focus: usability evaluation; Participants used the system for one day and were interviewed at the end Duration: 1 day	Experiences with the system. Tools: interviews	N
Analytic, Social, Affect [a]	King et al. 2013 [48]	Randomized experiment (P)	Sample size: Total n=68 (two waves), (Analytic) n=22, (Social) n=23, (Affect) n= 23; Population: community-dwelling adults insufficiently physically active (less than 60 min/week); Age: 45 to 81, Mean 59.1 (SD 9.2); Male (%): 26.5; Country: USA; Attrition rate (%): 1.5	Intervention focus: PA and sedentary behaviour; Groups: (1) participants using analytic app (2) participants using social app (3) participants using affect app. Participants wore a smartphone attached to their waist. First week was used as a baseline period during which time (only the activity-monitoring app without a behavior change app). At the end of this initial week, individuals were randomly assigned to use one of the three custom apps (Analytic, Social, or Affect). 12 participants enrolled in a post-intervention study (4 from each app group). Duration: 8 weeks	Mean brisk walking levels and MVPA minutes per week; mean daily hours of television viewing time; and satisfaction with apps. Tools: the CHAMPS Physical Activity Questionnaire; the Australian sedentary behavior questionnaire (referred to as the Measure of Older Adults' Sedentary Time [MOST]), and a usability survey	Y
AAFS	-	-	-	-	-	-
It's Life!	Van der Weegen et al. 2014 [51]	Nonexperimental design	Sample size: (Phase 1) n=6; (Phase 2) n=11, (Phase 3) n=20, (Phase 4) n=11; Population: (Phase 1) technology experts, (Phase 2-4) people with COPD or type 2 diabetes; Age: 40 to 70; Male (%): -; Country: Netherlands; Attrition rate (%): -	Study focus: usability; (Phase 1) heuristic evaluation by experts; (Phase 2) usability test in laboratory; (Phase 3) real-life pilot study (Baseline: 2 weeks; Study: 10 weeks); and (Phase 4) second usability test in lab	Heuristic evaluation based on Nielsen's usability principles. Error rate, task completion time, technical failures, defects, participants' comments, and satisfaction rating questionnaire. Tools: Annotations; Video Morae Recorder; Post-Study System Usability Questionnaire (PSSUQ); Software Usability Measurement Inventory (SUMI) Questionnaire; and Microsoft's Desirability toolkit	N
	Van der Weegen et al. 2015 [53]	Randomized experiment (P)	Sample size: Total n=199, (Group 1) n=65, (Group 2) n=66, (Group 3) n=68; Population: people with COPD or type 2 diabetes, not complying with the Dutch Norm for Healthy Exercise; Age: 40 to 70, (Group 1) Mean 57.5 (SD 7.0), (Group 2) Mean 56.9 (SD 8.3), (Group 3) Mean 59.2 (SD 7.5); Male (%): 47 to 54.4; Country: Netherlands; Attrition rate (%): 12.6	Intervention focus: PA (three-arm clustered randomized controlled trial); Groups: (Group 1) monitoring, Feedback, and Self-management Support Program (SSP); (Group 2) SSP; and (Group 3) care as usual. Duration: 6 months; Follow-ups: 4-6 months, 3 months after the end of the intervention	Minutes of physical activity per day, and general and exercise self-efficacy and quality of life. Tools: Personal Activity Monitor AM300, and questionnaires (Short Questionnaire to Assess Health-enhancing PA (SQUASH), SF-36, General Self-efficacy Scale, Exercise Self-efficacy Scale (ESS))	N
StepbyStep	Zuckerman & Gal-Oz 2014 [54]	Nonexperimental Design	Sample size: Total n=40; Population: owners of Android mobile devices; Age: 23 to 54; Mean (of participants that completed the study) 31.8 (SD 6.75); Male (% that completed the study): 63.3; Country: -; Attrition rate (%): 25	Study focus: user perceptions; First 3 days, the app collected walking time without engaging users (baseline); on day 4, the app set a personalized daily goal and became active. Duration: 2 weeks	Walking time and participants' perceptions of advantages and disadvantages of the app. Tools: Mobile app logs and questionnaires	N
		Randomized experiment (P)	Sample size: Total n=59, (Group 1) n=18, (Group 2) n=21, (Group 3) n=20; Population: undergraduate students; Age: 20 to 27; Mean: 23.39 (SD 1.40); Male (%): 25.4; Country: -; Attrition rate (%): -	Intervention focus: PA; Groups: (Group 1) participants used a 'quantified' version of StepByStep application; (Group 2) participants used a 'quantified and virtual reward' version of StepByStep application; (Group 3) participants used a 'quantified, virtual reward and leaderboard' version of StepByStep application. Duration: 10 days	Daily goal reached and daily walking time; daily number of times the application was accessed; and user experience and usability. Tools: Galaxy S mobile logs, System Usability Scale (SUS), and interviews	Y
On11	He et al. 2014 [55]	Nonexperimental design	Sample Size: Total n=9; Population: psychology students of the Worcester Polytechnic Institute; Age: -; Male (%): -; Country: UK; Attrition rate (%): 11.11	Study focus: user experience and functionality; Observational user experience study with 1 group. The study consisted of 3 parts: User Guide Tutorial; App Trial - participants used the system for 2 weeks; and a Post-Survey - participants were asked to answer a final questionnaire regarding their experience and changes in sedentary levels. Duration: 2 weeks	Experiences with the app. Tools: task-based session and survey	N
iBurnCalorie	Khatri et al. 2016 [56]	Nonexperimental design	Sample size: Total n=21, (Group 1) n=9, (Group 2) n=12; Population: habitual users of iBurnCalorie apps; Age: -; Male (%): -; Country: USA; Attrition rate (%): -	Study focus: comparison of 2 versions of an app; Retrospective observational study. Groups: (Group 1) competition app; and (Group 2) personalized goal app. Comparison of usage patterns of Group 1 vs Group 2. Duration: 48 days	Daily caloric goal completed and consecutive days of app usage before a break day. Tools: smartphone GPS and algorithm for caloric estimation	Y
Sweetch	Everett et al. 2018 [57]	Quasi-experiment (P)	Sample size: Total n=55, (Calibration) n=9, (Intervention) n=38; Population: adults with a diagnosis of prediabetes and body mass index between 24 kg/m2 and 40 kg/m2; Age: Mean 55.0 (SD 10.6); Male (%): 40; Country: USA; Attrition rate (%): 14	Intervention focus: PA; Groups: 1 group. (Calibration) earliest participants entered in a calibration cohort. Several refinements were made to the app during this period, which resulted in an enhanced version of the app; and (Intervention) any participants who received the enhanced version for 50% or more of their time in the trial were consider part of the intervention cohort, together with other recruited participants. The intervention consisted on a baseline session, where the participant would download and register for the Sweetch app. After 90 days of using the app and a DBWS the participant returned for a final visit for lab tests and to answer the questionnaires. Duration: 3 months	Study retention; acceptability (usability and satisfaction); change in physical activity (MET-hours per week); mean weight loss; median change in glycated hemoglobin (HbA1c); and change in blood glucose. Tools: system usability scale (SUS) and satisfaction questionnaire; digital body weight scale; participants' mobile phone accelerometers	N

(Table 3 continued.)

MPTrain [a] & TripleBeat [a]	Oliver & Flores-Mangas 2006 and [58] Oliver & Kreger-Stickles [79]	Quasi-experiment (P)	Sample size: Total n=20; Population: regular runners from several groups within a large corporation; Age: 24 to 63, Mean 36.0; Male (%): 65; Country: -; Attrition rate (%): 35	Intervention focus: how well user reaches predefined goal and user experience; Groups: 1 group - participants enrolled in 4 running sessions. The first session was without music; the second one with random music from the digital music library that is stored in the phone; the third one with the MPTrain system; and the fourth with a metronome. Duration: 4 running sessions on 4 separate days	Task performance (the percentage of time that the users' heart-rate, in beats/min, is within target zone) and users' perceptions with the app and workouts. Tools: ECG sensors in the AliveTec ECG monitor and questionnaires (enjoyment, perceived usefulness)	N
	Oliveira & Oliver 2014 [59]	Quasi-experiment (P)	Sample size: Total n=10, Group 1 n=2, Group 2 n=3, Group 3 n=2, Group 4 n=3; Population: healthy adults from several running groups of a big corporation; Age: 25 to 41, Mean 33 (SD -); Male (% that completed at least 3 sessions): 80; Country: -; Attrition rate (%): 50	Intervention focus: comparing success of 2 versions of the same system in keeping users' heart rate inside training zone; and evaluate competition feature vs no competition; Groups (based on sequence of sessions' conditions): (Group 1) C1, C2 and C3; (Group 2) C1, C3 and C2; (Group 3) C1, C3, C2, C4; (Group 4) C1, C2, C3 and C4. Session conditions: C1 - MPTrain Baseline; C2 - TripleBeat (no competition); C3 - TripleBeat (competition); and C4 - MPTrain Last Run. Duration: 3 to 4 running sessions	Success in keeping the users' heart rate inside the proposed training zone, through objective measures (the percentage of time spent running within the heart rate target zone) and through subjective measures (self-reported efficacy); and enjoyment through subjective evaluation. Tools: ECG sensors in the AliveTec ECG monitor and questionnaires	Y
Everywhere Run [a] & Everywhere Race [a] & u4fit	Mulas et al. 2011 [60]	Nonexperimental design	Sample Size: Total n=15, (usability) n=5, (software's capabilities survey) n=10; Population: runners; Age: -; Male (%): -; Country: -; Attrition rate (%): -	Study focus: usability and functionality; For the usability study, participants needed to interact with the application while being observed. To evaluate software's capabilities, participants used the software for a while and rated the app with regard to several characteristic. Duration: 1 session	Usability and software capabilities. Tools: observing interactions and survey to rate functionalities	N
	Mulas et al. 2012 [61]	Nonexperimental design	Sample Size: Total n=35; Population: volunteers that used Everywhere Race for 30 days; Age: 19 to 40; Male (%): 71.4; Country: -; Attrition rate (%): -	Study focus: preliminary evaluation on user motivation with the app; Participants used the app for 30 days and answered a subjective evaluation test. Duration: 30 days	App influence on users' motivation and on users' sports habits. Tools: exercise Motivation Inventory-2 (EMI-2) and an additional questionnaire	N
	Boratto et al. 2017 [62]	Nonexperimental design	Sample size: Total n=103; Population: users who subscribed to u4Fit training service for long subscription period; Age: -; Male (%): 41.3; Country: -; Attrition rate (%): 0	Study focus: PA; Retrospective observational study Dataset: April 1, 2015 - April 14, 2016	Total number of workout sessions completed by the user; total number of workout sessions related to a workout plan created with a specific type of coaching; number of weeks during which user completed task at least one workout session after her first subscription; number of weeks during which the user completed at least one workout session during her subscription period; number of workout sessions created for the user after her first subscription with a specific coaching type; and number of all the workout sessions completed by the user with a specific coaching type, which were created and completed after the user's first subscription. Tools: Dataset	N
INTELiRun	-	-	-	-	-	-
SitCoach	Van Dantzig et al. 2013 [64]	Nonexperimental design	Sample Size: Total n=8; Population: office workers; Age: -; Male (%): 50; Country: -; Attrition rate (%):	Study focus: usability and user acceptance; Participants were provided with an iPhone with the SitCoach application and invited to use the application throughout one day at the office. At the end of the day, a semi-structured interview was conducted to assess experiences with the system. Duration: 1 day	Acceptance of the app, usability and perceived locus of control (with respect to reducing sitting time). Tools: interviews, Attrakdiff 2 questionnaire and Locus of Control questionnaire	N
B-Mobile	Thomas et al. 2015 [66]	Quasi-experiment (P)	Sample size: Total n=30; Population: overweight/obese individuals; Age: 21 to 70, Mean 47.5 (SD 13.5); Male (%): 7; Country: USA; Attrition rate (%): 0	Intervention focus: sedentary behavior (SB); All participants tested 3 conditions presented in a randomized counterbalanced order: (1) participants received prompt for a 3-min walking break after 30 continuous SB min; (2) participants received prompt for a 6-min walking break after 60 continuous SB min; (3) participants received prompt for a 12-min walking break after 120 continuous SB min.7-day baseline and 3 weeks of intervention (7-day per condition). Duration: 4 weeks	Number of days and hours per day that smartphone was powered on and carried by the participant; daily number of walking prompts, number of walking prompts that resulted in a walking break of the prescribed duration, latency between the prompt and the start of the walking break; and total duration of the walking break. Tools: Smartphone onboard accelerometer	N

[a]Systems also covered in the literature survey by op den Akker *et al.* in 2014 [5].
(P) – Prospective.

research. However, we expected more contributions taking advantage of the current complexity and accuracy of smartphones and monitoring technologies in implementing more advanced real-time personalization. Prior work [5] has provided a clear conceptual framework for tailoring/personalization, and provided numerous ways to explore different tailoring mechanisms for the design of new and more complex systems. Yet, none of the reviewed papers referred to such work or any other personalization or tailoring theories. Hence, many gaps remain to be addressed in this field.

A. Personalization

Most systems made use of the more simple forms of personalization such as Feedback (17), Goal Setting (15), User Targeting (9) and Inter-human Interaction (8), while only a few systems covered the concepts of Adaptation (2), Context Awareness (3) or Self Learning (4).

In what concerns to Feedback (FB), further work is still needed to find the best way to communicate the information to the user, considering the different communication properties (intention, content, timing and representation). Such properties were implicit in most included studies, but few specifically explored this topic. Two new studies addressed the content of feedback messages, one compared encouraging, discouraging and neutral phrasing and the other compared different persuasive strategies based on a BCT. However, many aspects related to content and intention of the communication are still to be addressed, and can contribute to a better understanding of 'what' to communicate to the user. One possibility would be to study system variations with FB intended at promoting physical activity and/or sedentary breaks. Moreover, the variety in representation forms of FB, together with the need to address the timing (initiative, moment and frequency) of communication, provide numerous opportunities for tackling the lack of user engagement. All these aspects are related with the intensity of coaching provided, which also remains to be evaluated in detail.

Goal Setting (GS), normally used in pair with FB, was the second most used concept. The most common form of GS was through simple numerical goals or, in some cases, in the form of training sessions and routines. Compared to the previous review, there was a considerable number of new applications considering the user characteristics, however most only relied on information at the time of registration and only two considered the user's progress through time. Also, two new systems allowed a professional to adapt activity goals (human-in-the-loop), with one study addressing the effects of supervised coaching. Finally, there were only a couple of systems making use of PA plans or schedules and none adapting to the user's own schedule. The AAFS presented it conceptually in future work, suggesting the use of information on the users' schedule (sleep, travel, work and leisure time), tracked manually by the user or automatically using location data, to determine changes in activity goals.

User Targeting (UT) and Inter-Human Interaction (IHI) were used in more than half of the included systems, with UT being more predominant in the new applications (8/10) compared to

IHI (3/10). The instances of UT were, in some cases, in the form of including the user's name or nickname, but mostly in combination with GS, considering information on the user's characteristics (e.g.,: age, weight, height, PA level). Still few systems explored the progress in PA level. Besides Move2Play, which was included in the previous survey, only 2 other systems, u4fit and AAFS, considered the users' PA data for personalization. Also, few systems considered the user's preferences to provide personalized suggestions or recommendations.

IHI appeared in the form of social comparison, teamwork, network support and support from a real coach. The most common form was social comparison through individual or group-based competition, followed by network support, which was included in some systems through sharing of results or support from other users. Only 2 systems used IHI by including teamwork features (e.g.,: goal sharing) and only 1 new system, u4fit, included support from a real personal trainer.

Regarding Adaptation (Ad), there is still room for research exploring communication matched to the users' psychological traits (e.g.,: personality, stage of change, self-efficacy, player type). In our review, only the AAFS and INTELiRun covered the concept of Ad. The AAFS system provided FB adapted to user's scores in questionnaires on stage of change and self-efficacy, and INTELiRun adapted FB to the users' personality traits, which were also inferred from questionnaires.

The more sophisticated approaches, Context Awareness (CA) and Self Learning (SL), are still far from taking the most of existing technologies and reaching its full potential in PA coaching systems. Only 3 out of 17 included systems covered CA (Move2Play, Sweetch and On11). However, only the paper describing the On11 provides examples and implementation details on the use of such strategy. Based on frequently visited destinations (e.g.,: home-workplace), On11 proposes different travel routes and suggests mini-walks around the workplace.

Similarly, there was a lack of systems exploring SL (4/17), with only 2 new systems (AAFS and Sweetch) covering the concept compared to the previous survey. SL was used in combination with GS to incrementally set more challenging goals in BeWell+ and Move2Play. The latter included a user model that was continuously updated. The AAFS updated its mechanisms for GS and Ad by learning the user's routine of activity and psychological changes, respectively. The Sweetch app, seemed to take the most advantage of SL, by learning the user's life habits and compliance with certain types of messages, and combining it with FB, CA and GS. Overall, SL is a strategy that can be used as improvement to any system, as it involves learning with the users' interactions with the app. Also, it is closely related to UT as it relies on the creation of user models that adapt through time. Therefore, there is still space for more work using intelligent SL algorithms to dynamically optimize other personalization strategies.

Besides addressing the existing gaps, new contributions should provide a more technical description of the systems. Some of the included applications lacked in details on the systems' architecture, on how the personalization strategies were implemented, and what algorithms were used, which would be relevant for facilitating future research.

B. Behavior Change Theories and Gamification

Although there is a strong body of literature on BCTs, only 6 of the 17 included systems were based on these, and the papers failed to clearly present design decisions taken from such theories. These findings are aligned with the discussed in [5]. However, some of the systems followed a design based on motivation theory. For example, MPTrain/TripleBeat refers to the Persuasive Technology theory from Fogg *et al.*, 2003. Also, Move2Play has been designed considering motivation as the core system part, to tackle user abandonment, and is built upon informative, social and gamification strategies.

Also, despite the recent hype in gamified fitness apps [25], there was a lack of systems considering the existing game or gamification theories, with only 6 out of the 17 included applications explicitly reporting its use. However, a total of 42 instances of elements that could be related to gamification were found in 15 systems, mostly related to progress and rewards.

Gamification and BCTs share similar constructs [80], [81], but they also relate and can be mapped to personalization strategies. For example, BCTs can be directly associated with Ad (e.g.,: adapting to the stage of change) or IHI (e.g.,: considering the Social Influence Theory). On the other hand, gamification elements can be considered in the representation of FB (e.g.,: progress bars, avatars) or in combination with UT (e.g.,: avatars), with GS (e.g.,: levels and rewards), or with IHI (e.g.,: social interaction). Therefore, we believe both BCTs and gamification should be considered in the design of personalized PA coaching applications, to help creating highly individualized, engaging and effective experiences both in the short and long-term. Also, it is important to consider the theory behind gamification to understand how to best leverage it for motivation and to avoid any potential detrimental effects of misuse. For example, the simple integration of external rewards (e.g.,: points or badges) without considering a design driven towards increasing intrinsic motivations (e.g.,: sense of progress), might engage users in the short-term but fail to do so in the long-term.

A related conceptual question that remains to be explored regards the understanding of whether the creation of an app should be driven by gamification and other persuasive strategies, or by BCTs.

C. Evaluation

Near half of the evaluation studies assessed the effectiveness of the proposed system (10/22), but, half of them did not include a control group and near half (6/10) had sample sizes of less or equal than 30. Also, the same proportion of studies (6/10) evaluated the outcomes in the short-term, with intervention duration of less or equal than 1 month, remaining unclear the long-term effects these systems have on users. An exception is u4Fit whose effectiveness was analyzed using a retrospective observational study using data collected in more than one year. Therefore, there is still a need to assess in a structured and controlled manner the long-term effects of using these real-time personalized systems, with an analysis on user adherence and attrition rates.

Besides, there is still lacking evidence on the individual effects of particular personalization strategies, as normally these systems are tested as a whole. Some studies make use of different versions of the same system, that are compared in small scale studies. However, adopting the optimal methodological approaches is time and resource consuming and therefore challenging to put into practice. Furthermore, as commented in [5], whether or not personalization in real-time PA coaching applications increases engagement and motivates behavior change has yet to be rigorously examined.

D. Other

The majority of the systems were targeted at coaching over daily activities (10/17), with fewer targeting exercise-based (3/17) or sedentary-based coaching (2/17). However, 2 of the systems that provided coaching on daily activities also promoted sedentary breaks or provided simple feedback on sedentary behavior. These results are in accordance with the highlighted in [82], that an emerging area of PA intervention research is focused not only on increasing PA, but also on decreasing sedentary behavior.

Few of the included systems were targeted at particular populations, such as the elders or chronic patients. These individuals have specific needs, which can inform design decisions on personalization mechanisms, motivation elements and behavior change constructs. Such can be facilitated through user-centered design approaches, as done for the It's Life app [50]. We believe that system personalization can be particularly relevant in the context of disease prevention and management, having the potential to increase the acceptability of these applications by creating relevant and targeted user experiences. This has also been highlighted in literature, for example, in a study on the opinions of cancer survivors for mobile PA applications [83].

A particular factor that raised concern was that only 3 of the included systems were available in the app stores, which reveals the existing barrier in knowledge transfer and implementation of research work to society. This could be related to a discontinuation of the development of such systems, which in some papers were only presented in the form of early concepts or prototypes.

This work is extending the knowledge on this topic primarily through inclusion of new research that has been published in the 5 years that have passed since the last substantive review in the field. In these 5 years we have witnessed a significant number of new systems and associated research studies based on personalized coaching apps. Informed by the previous work, we have explored if previously reported gaps were addressed in the new contributions, we identified new gaps and we provide suggestions for future work. We took a more systematic approach to this scoping review, which allowed us to perform a detailed analysis on each particular aspect reported by op den Akker *et al.*, but also to explore the topic of gamification and to identify the type of interventions being used to test these solutions. We present a comprehensive analysis of 17 PA coaching systems, which maps the general characteristics, personalization strategies, the theoretical foundations, and the evaluation methods used by these technologies. Also, the information is presented in a streamlined layout, using tabular format, which makes understanding and comparison easy to the reader. Hence, this work can help inform future work related to the development and evaluation of technology-based health promoting and coaching systems, and also the research focused on exploring ways to overcome the underlying challenges of user abandonment and lack of engagement with these systems.

V. Limitations

The process of analyzing the applications regarding the real-time criteria was challenging, as some papers did not fully or explicitly detail the architecture of the systems. Such doubts were solved by consensus between the researchers. More advanced and elaborated types of personalization might have been used in systems not considered in this review, such as those with feedback delays due to more complex processing on the cloud. However, this was not the purpose of this review, which focused on analyzing the personalization mechanisms used specifically in real-time systems. We did not take a comprehensive review of BCTs, as none of the authors was experienced on such procedure. Instead, we extracted the theories reported in the systems' description. The authors consider taking a more extensive analysis on this matter in a future publication, by considering the Behavior Change Taxonomy [84] or the CALO-RE Taxonomy [85] to classify these apps. Statistically significant conclusions were not drawn, given that in the majority of cases evaluation was conducted through pilots and/or small scale trials, and only one study assessed long term effects. Additional results could have been obtained by taking into consideration specific journals, specific conference proceedings, grey literature, other databases, paid publications or even unpublished work. To reduce the chances of missing relevant papers we have searched both journals and conference proceedings from 7 different databases across multiple fields. Given the particular focus of this literature review, and our adoption of the same inclusion criteria as op den Akker *et al.*, it might have led to the exclusion of some studies using well known commercially available fitness trackers. Chiefly this is due to the strict inclusion criteria in this review regarding real-time coaching that relies on direct communication between sensor and the coaching app/interface (without online synchronization), which is not easily achieved when integrating with commercial activity trackers. Studies that focused on coaching apps that involved delayed access to sensor data via a web API were excluded due to the lack of real-time feedback. Furthermore, there might have been other apps relevant to this review, not available in the literature, that could be found in the app stores. For example, apps such as Google Fit have recently introduced real-time feedback and coaching features. However, these have not yet been reported/evaluated in the scientific literature and so are not included in this review.

VI. Conclusion

In this work, we reviewed the most recent contributions on real-time physical activity coaching applications that used personalization strategies. From our findings, it is clear that these systems are not referring to the theory and practice in the field and, in most cases, are using the more simple forms of personalization. There is still limited evidence addressing the gaps highlighted in prior research, which include the lack in exploration of Adaptation and the more advanced forms of personalization, Self Learning and Context Awareness; the lack in proper evaluation of the effects of particular personalization strategies and overall system effectiveness; and the lack of design foundations on behavior change theories. Besides, we believe that future work should consider the model and suggestions proposed by op den Akker *et al.* in 2014; explore the use of gamification to increase engagement; and leverage the end-user insights for system design and personalization.

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