International Journal of Human-Computer Studies 140 (2020) 102449

Contents lists available at ScienceDirect

International Journal of Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

Apps That Motivate: a Taxonomy of App Features Based on Self-Determination Theory

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ARTICLE INFO

Keywords:
Behavior Change
Human Motivation
Mobile Apps

ABSTRACT

Nowadays, thousands of popular applications are designed to help users improve their lives through behavioural adjustment (e.g., meditate more, stay hydrated). However, our understanding of how certain design features align with constructs of behavior theories remain limited. We analyze 208 apps from the Apple App Store and identified 12 design features afforded by current tools that we classified according to the Self-Determination Theory. The taxonomy reported in this paper, we argue, provides a simple tool for designers to evaluate how specific features, and combination of features, may work to motivate users towards their desired goals. Additionally, the presented taxonomy is intended to help researchers test new interventions by discussing relevant research gaps.

Outer changes always begin with an inner change of attitude (A. Einstein).

1. Introduction

In the last few years, there has been a dramatic increase of apps that are intended to bring about positive behavioural change (e.g. losing weight, quitting cigarettes, learning a new language or reducing waste). We will refer to this group of applications as *behavior change apps* because these have been explicitly designed two"to foster and assist behaviour change and sustainment" (Hekler et al., 2013, p. 3308).

Recent surveys reveal that over 100K health applications (apps) are available worldwide for smartphones; the most popular apps are for exercise, diet, and weight management, and 500M users use mobile health applications Edwards et al. (2016); Fox and Duggan (2012). The reason for this growth is apparent: smartphones are pervasive and provide a unique opportunity to reach a broad audience of users. Also, behavior change apps have been increasingly used in app-based health promotion programs, which might have contributed to their diffusion Lee et al. (2018).

Behaviour change apps use numerous strategies to modify the behaviour of the user. For instance, some apps pay the user a *reward* for completing the specified activity (e.g., `Clue` app Clue by Biowink GmbH (2019)). Others provide accurate *feedback* about the user's performance and how it evolves over time (e.g., `Goalify` app GmbH (2019)). Recently, the usefulness of some of these apps has come under scrutiny Ferrara (2013); Jebelle and Burrows (2019); Skarecki (2015). Despite the wealth of Internet resources on behavior change, designers often face scarcity of professional guidelines or industry standard Lister et al. (2014). In some cases, apps fall flat in producing changes, specifically when we look at the long-term effects of these interventions Harrison et al. (2015); Jeffery et al. (2000), or even backfire, which is what happens when an intervention triggers audiences to adopt the opposite target behavior Erskine et al. (2010); Stibe and Cugelman (2016).

In this work, we look at how psychological theory can inform design. By taking this approach we do not imply that all design is (or must be) informed by theory. Also, often the mapping between theory and practice is mediated by two"real-world necessities, complexities, budget limits, stakeholder feedback, market testing and politics" (Stibe and Cugelman, 2016, p. 3). However, we argue that psychological theories can suggest new avenues to designers and reveal new areas of inquiry to HCI researchers.

Therefore, it is relevant to ask: *Can psychological theories suggest characteristics that behaviour change apps would need to possess to support behaviour change interventions? Do behaviour change apps on the market possess these?* To this end, several behavioral theories exist, and many have been used extensively in the field of HCI. A non-exhaustive list includes: the Social Cognitive Theory (or SCT)Bandura (1986), Theory of Planned Behavior (or TPB) Ajzen (1985), the Trans-Theoretical Model (or TTM)Prochaska and Di Clemente (1983), the Health Belief Model (or HBM)Rosenstock (1974), and the Goal-Setting Theory Locke

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https://doi.org/10.1016/j.ijhcs.2020.102449
Received 24 December 2019; Received in revised form 9 April 2020; Accepted 10 April 2020
Available online 18 April 2020

and Latham (2002). These theories focus on *observable behaviour*: they predict whether people might enact target actions (e.g., perform physical activity, hydrate regularly) based on various constructs (constructs are the basic determinants or mechanisms that a theory postulates to influence behaviour (Hekler et al., 2013, p. 3309)).

Many constructs of the theories above relate to *motivation*, which concerns what moves people to action. Within these theories, the concept of motivation is a unitary concept: it is typically undifferentiated for types, qualities, or orientations Ryan and Deci (2017). For instance, theories such as the SCT or the HBM predict motivation from the two"strength of one's beliefs about being able to achieve outcomes" (Ryan and Deci, 2017, p. 13). Taking a different stance, Self Determination Theory (or SDT) Ryan and Deci (2000a) is especially different from other approaches to motivation because it emphasizes the different types and sources of motivation that impact the quality and dynamics of behaviour. SDT suggests that some forms of motivation are entirely volitional (i.e., they reflect one's interests and values) whereas others can be wholly external (i.e., when paid, coerced or otherwise pressured into doing something).

Several studies informed by the SDT show the effects of incentives on motivation Deci and Ryan (1985); Deci (1971, 1972); Deci and Ryan (1980). These incentives, can be used to bootstrap the internalization process[1], however these can harm the motivation of people who are already intrinsically motivated.

While the theories above attempt to explain how internal antecedents to action (i.e., knowledge, beliefs, or attitudes) influence behaviour, SDT aims at explaining how external conditions hinder support to the internal processes of change that might lead people to adopt the target behaviour.

SDT has been shown to have applicability across multiple life domains Deci and Ryan (2008), and it has been used to describe the development of causal action and self-determined behaviour Wehmeyer et al. (2017). Furthermore, SDT-based interventions have been shown to have long-term benefits Friederichs et al. (2015).

Scholars began systematically reviewing the design of apps that support behaviour change in order to categorize their features. Few of these efforts have attempted to relate behaviour change theories with the functionalities of these applications. A recent study classified exercise apps according to HBM, TTM, TPB, and SCT Cowan et al. (2012). More recent classifications also covered several behaviour change theories but did not look at SDT (cf. Lister et al. (2014); Michie et al. (2013)).

In this paper, we review 208 behaviour change apps and perform a functional decomposition to identify the basic features of these apps that support behavior change. We will explain in detail the method in Sec. 3. As a theoretical lens to organize and evaluate these tools in their ability to support behaviour-change interventions, we apply the SDT.

From the analysis of the apps, we identified 12 distinctive features that support the constructs of SDT. Only 25.5% of the reviewed apps provide full support for all the constructs required by SDT. We find that certain mechanisms are widely supported in current applications (e.g., Reminders), and that there are design possibilities aligned with the theory which are under-explored (e.g., Intergroup Competition).

In Sec. 5 we demonstrate the value of the findings by discussing how the taxonomy suggests how behavior change apps features should be designed. Furthermore, we discuss relevant research gaps suggested by the taxonomy. Next, we review prior work.

2. Related Work

Human behavior is defined by Davis et al. as two"anything a person does in response to internal or external events" Davis et al. (2015). These responses are often recurring (e.g., I am bored therefore I eat). Modifying the typical responses one gives to a situation (or set of stimuli) might prove hard, as these often provide gratification, safety, comfort and other forms of satisfaction that might not be available otherwise. Behavior theories employ a set of concepts, definitions and propositions that explain or predict responses to events or situations Glanz et al. (2008). Here we highlight a few points of distinction among the theories that brought us to focus on Self-Determination Theory for the study reported in this paper. /

2.1. Behavior Theories and Human Motivation

Behavior theories are models, a simplified representation of reality. Every model has points of strength and weaknesses. Social Cognitive Theory is defined as an *ecological* theory as it focuses on the importance of context (i.e., the social and physical environment) as a determinant of health behavior McLeroy et al. (1988). Social Cognitive Theory offers interventionists clear targets to minimize external barriers to behavior change. However, it falls short when describing internal stages of change and the processes that determine this change Rejeski and Fanning (2019). Similarly, other behavior theories such as the Health Belief Model or the Theory of Planned Behavior have an *extrinsic focus*: they are concerned with how specific belief-based antecedents determine behavior Hagger and Chatzisarantis (2014); Leavell (2017). These models emphasize decisional balance: the relative weight of perceived benefits as compared to perceived barriers to engage in a target behavior. Another theory that focuses on external determinants to action is the Goal-Setting Theory Locke and Latham (2002). The theory involves the development of an *action plan* (an external artifact) designed to motivate and guide a person in attaining behavior change Grant (2012). Although these theories support many behavior-change programs and they have lots of merits, recent research urged the community to complement this view by looking also at *internal* aspects of change (i.e., how individuals live, account for and cope with life changes) (Rapp et al., 2019, p. 2).

Therefore in this work we decided to focus on the level of analysis encompassing inner psychological changes. Here, the qualifier inner or internal has *not* to be mistaken by the term 'unconscious'.[2] twoWhen we use the adjective *inner* or *internal*, we specifically refer to psychological processes that lead individuals to recognize specific behaviors as part of one's world, the fabric of our intentions. Extrinsic incentives, external barriers and facilitators could be very important in a behavior-change intervention. However, in this work we focus on the internal aspects of change because these can produce long-term benefits to the individuals (we will come back this this point in Sec. 2.2 and in Sec. 2.3). Two prominent behavior theories provide constructs that can explain different types of motivation and the internal processes that can lead people to move across them: the Trans-Theoretical Model and SDT. TTM consists of five interrelated stages of change that are delineated with a time frame and tasks associated with movement through that stage Kennedy and Gregoire (2009). twoRecent critics to the theory do not identify the qualitative differences between each stage Davidson (1998). twoOther researchers question whether the stages should be ordered in a specific way – that each stage is linked integrally to instances of those following it DiClemente (2003). More importantly, TTM does not distinguish between internal and external sources of motivation with respect to decisional balance Kennedy and Gregoire (2009). Conversely, SDT makes of the distinctions between exogenous vs. endogenous sources of motivation one of its core constructs. Next, we review SDT in detail.

[1] Namely, making attitudes or behavior part of one's own nature by assimilation.

[2] SDT posits that there are two types of motivated behaviors: those that are consciously chosen in the service of intrinsic or extrinsic needs (i.e., the self-determined behaviors) and the 'mindless' or automated behaviors (i.e., the non consciously chosen). We we will discuss this point more in detail in Sec. 2.3.

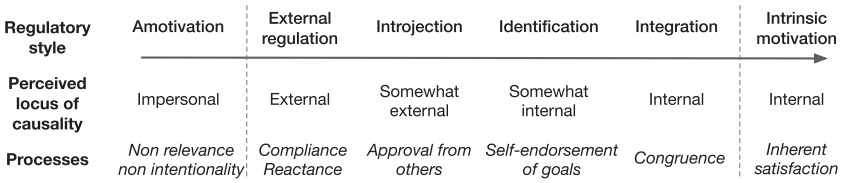

Fig. 1. Various levels of human motivation postulated by SDT (adapted from Ryan and Deci (2000a)).

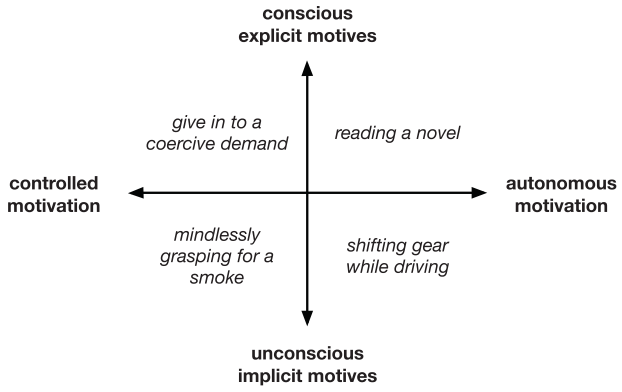

Fig. 2. Contrasting graph of various types of motivational processes.

2.2. Self-Determination Theory

SDT postulates that people have not only different amounts of motivation towards a certain activity but also –and more importantly– different *types* of motivation, specifically different orientations with underlying attitudes and goals that give rise to action Deci and Ryan (1985). The most basic distinction is between *intrinsic* and *extrinsic* motivation. The former refers to doing something because a person finds it inherently interesting or enjoyable (e.g., reading a book), whereas the latter refers to doing something because it leads to a separate outcome (e.g., preparing for an exam). Furthermore, SDT proposes that there are several types of extrinsic motivation that differ in the degree of internalization (i.e., the degree to which the behavioral regulation is autonomous versus controlled). As described by Ryan and Deci two"behaviors can be externally regulated, meaning they are

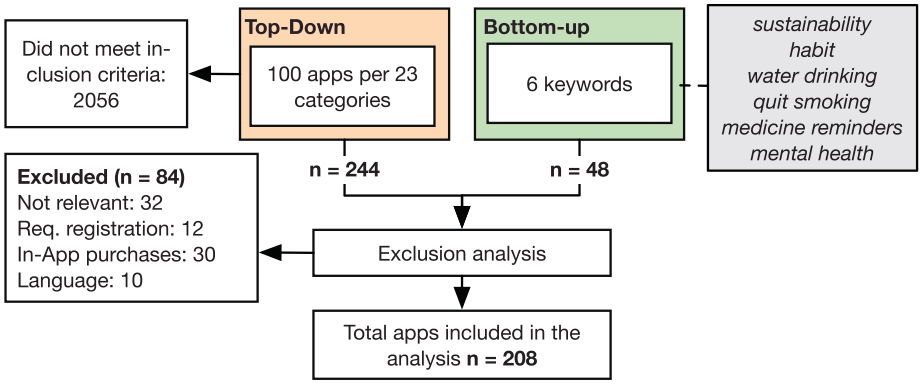

Fig. 3. Selection process of the behavior change apps.

Table 1
Keywords extracted from literature on behavior change applications. These were used in the bottom-up search. The last column indicates the reference to the literature from which the concept was taken.

Keyword	twoSelection Rationale	Ref.
sustainability	Develop environmental-friendly behavior.	Brynjarsdottir et al. (2012); Midden and Ham (2018)
habit	Quit/curb bad habits or start good habits.	Purpura et al. (2011); Renfree et al. (2016)
water drinking	Encourage staying hydrated.	Lally et al. (2010)
quit smoking	Smoking cessation support.	Graham et al. (2006); Khaled et al. (2009)
medicine reminders	Medication compliance and adherence.	de Oliveira et al. (2010); Stawarz et al. (2014)
mental health	Promotes mental well-being.	Grist et al. (2017)

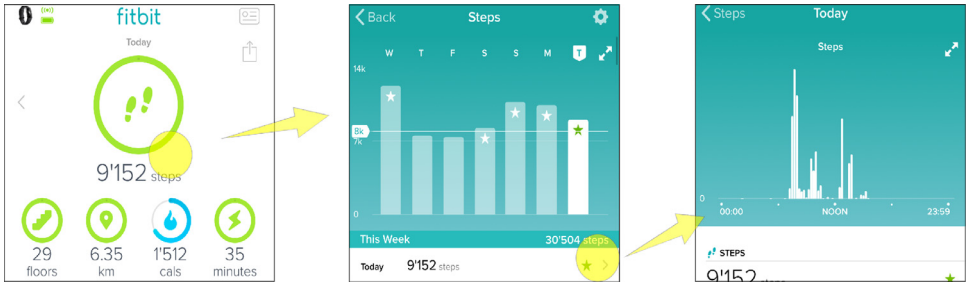

Fig. 4. (left) Dashboard of the Fitbit App (main sub-system, cropped). Tapping the number of steps switches the view to the number of steps sub-system (center). Tapping on a given day brings the user to the daily number of steps functionality (right). At this level, there are no further sub-systems that can be decomposed.

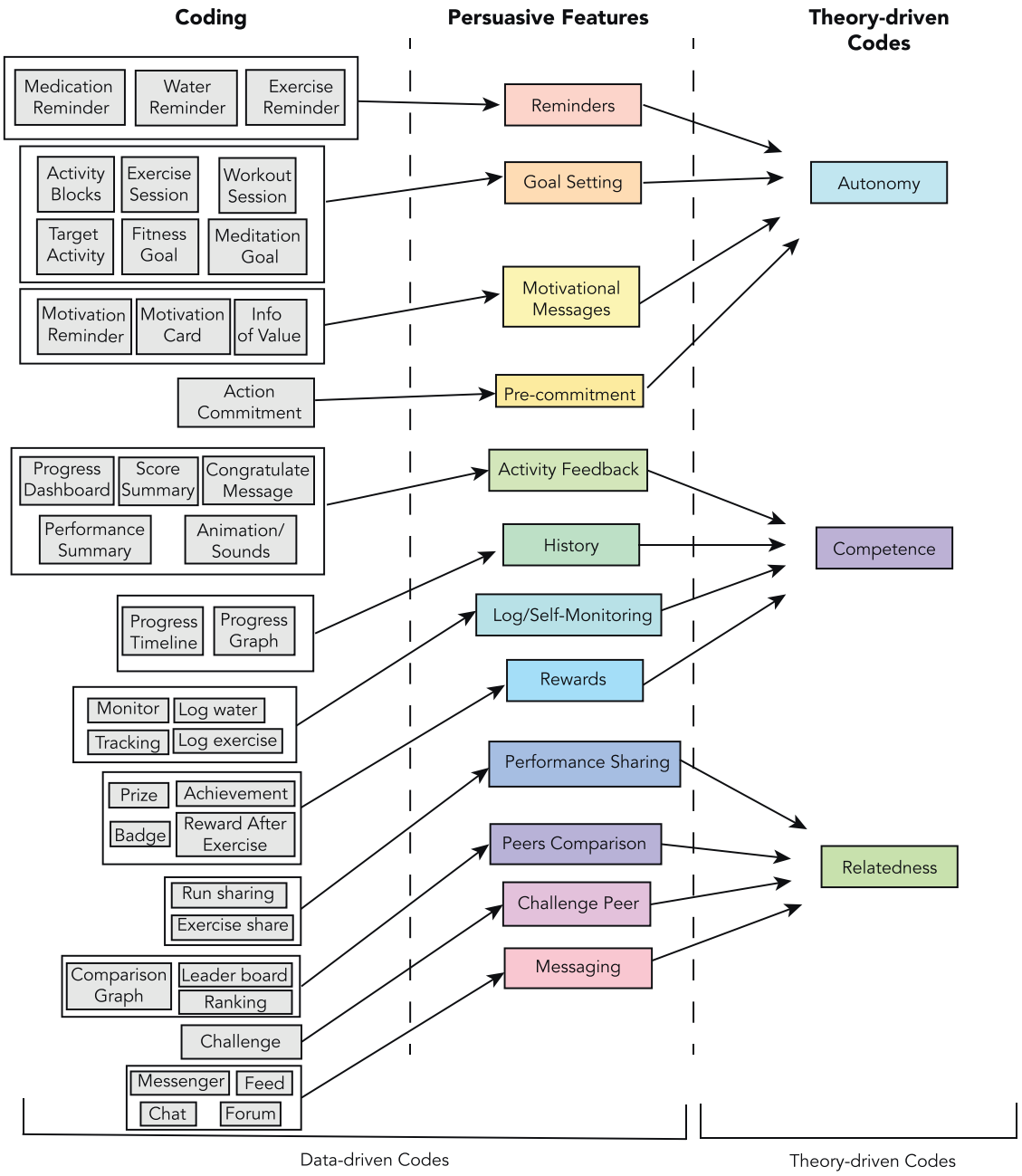

Fig. 5. Diagram showing the taxonomy creation process. From left to right the Data-driven Codes which includes the coding and the clustering of codes to generate the themes/features. Next, the Theory-Driven Codes which include the three SDT Basic Psychological Needs as categories.

directly controlled by external and self-alien forces; or they can be controlled through introjection, in which case the person has taken but not fully accepted external controls" (Ryan and Deci, 2017, p. 14). This source of the regulation of the autonomous behavior plays a very important role in moderating the basic need of autonomy and is often referred to as *perceived locus of causality* DeCharms (1968). Therefore, SDT organizes the different types along this *control–autonomy continuum: amotivation* (or absence of intention to act), *external regulation* (to obtain a reward), *introjected regulation* (to avoid guilt), *identification* (accepted external regulation), *integration* (self-determined action). Figure 1 presents the various levels of human motivation postulated by SDT. On this last stage the individual has acquired autonomous motivation towards the target activity.

According to SDT, extrinsic motivation types can encourage a person to behave a certain way in the short-term, but fail to maintain the behavior over time Deci and Ryan (1985). Behavior-change interventions that are designed around extrinsic motivation types might not produce modifications of behavior that last after the intervention has ended. Conversely, when individuals reach intrinsic levels of motivation, they develop self-determined action towards the target activity. When this state is reached, interventions are no longer needed, and the changes in behavior become consolidated and persistent through time.

The theory posits that people have natural tendencies toward self-determined action. However, in order for this to happen people require contextual conditions to satisfy three basic psychological needs (or BPNs): *autonomy, competence*, and *relatedness* Ryan and Deci (2017): autonomy refers to feeling willingness and volition with respect to one's behavior; competence refers to feeling effective in one-s interaction with the social environment; and relatedness refers to both experiencing others as responsive and sensitive and being able to be responsive and sensitive to them. When their basic needs are satisfied, people

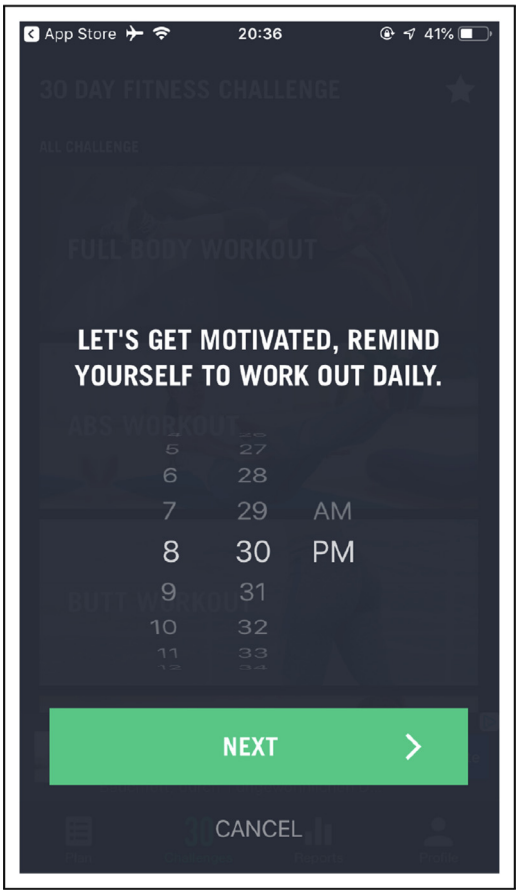

Fig. 6. Reminders: notification set by the user (`30 Day Fitness Challenge` Abishkking Ltd. (2019)).

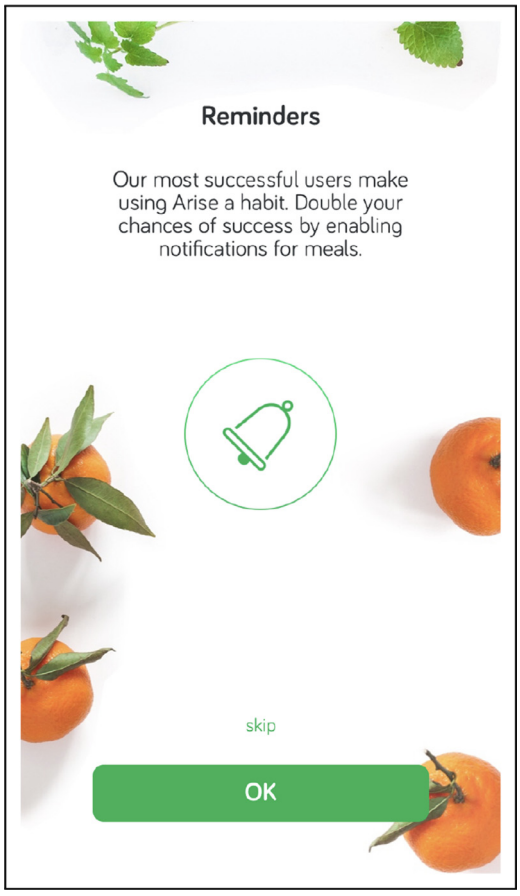

Fig. 7. Reminders: notification set by the app (`Arise`ARISE Ltd. (2019)).

experience growth, integrity, and well-being. Conversely, when their psychological needs are not met, there could be psychological harm Deci and Ryan (2000). Satisfying the BPNs pushes the individuals to move along the control–autonomy continuum to reach autonomous motivation towards the target activity. One point that is often debated in the literature which deserves further discussion is the role of *implicit processes*–processes for which the individual might not be consciously aware.

2.3. Conscious vs. Unconscious Influences to Human Behavior

In the last few years, research on psychology has moved away from models that focus exclusively on deliberative, intentional and explicit influences on behavior and towards theories that also account for the non-conscious, impulsive and implicit influences on behavior Jonathan and Keith (2009); Stanovich (2010); Strack and Deutsch (2004). These approaches are referred to as *dual systems models* of motivation (Hagger and Chatzisarantis, 2015, p.20). These recognize that behavior is a function of deliberative, volitional and planned inferences as well as those that are automatic, non-conscious, and unplanned. Recent research has demonstrated that automatic processes are key to habit formation, which in turn can be used for behavior change interventions Pinder et al. (2018). This line of research also pointed out that many interventions fail to achieve behavior change because they neglect the role of automatic, non-conscious behavior Verplanken and Wood (2006). Within the conceptual framework of SDT, the issue of conscious and unconscious motives needs to be distinguished from the issue of autonomous versus heteronomous motivation. These are orthogonal concepts, and present some interesting interfaces: implicit or unconscious events may prompt either autonomous or controlled behaviors, just as behaviors that are conscious may be regulated by either autonomous or controlled motivations (Ryan and Deci, 2017, adapted from p. 77). Figure 2 presents examples of situations that are driven by different degrees of autonomous motivation and cognitive awareness. SDT also cautions that instigating behaviors *exclusively* through interventions that leverage unconscious mechanisms (for instance, *subliminal priming* Pinder et al. (2017)) are at risk of making the person feel controlled as the locus of control is likely to be perceived external Niemiec et al. (2010a); Schultz and Ryan (2015). While implicit and explicit influences are distinct, a number of experiments have revealed that when people are self-determined in their values and commitments, they also show congruence between their implicit and explicit motives and attitudes Legault et al. (2007); Radel et al. (2017). In other words, when target activities are intrinsically motivating, self-regulation is not needed to perform such tasks as those are inherently pleasurable: the reflective and impulsive systems of the mind are aligned van Hooft (2018). Next, we looked for studies that classified the behavior change apps according to the support these provided to the BPNs.

2.4. Classifications of Behavior Change Apps

A large body of HCI research exists on the effectiveness of behavior change apps (see for instance Consolvo et al. (2008); Fritz et al. (2014); Hsu et al. (2014); Purpura et al. (2011)). Most of this research focuses on the study of app design, as a whole, and on the effects that the resulting designs yield on behavior change. For example in relation to how behavior change apps can help users eat more healthily Coughlin et al. (2015); Okumus et al. (2016), quit smoking Abroms et al. (2011), exercise more Consolvo et al. (2008), or cope with stress Gimpel et al. (2015); Konrad et al. (2015), to list a few. twoMore recently researchers

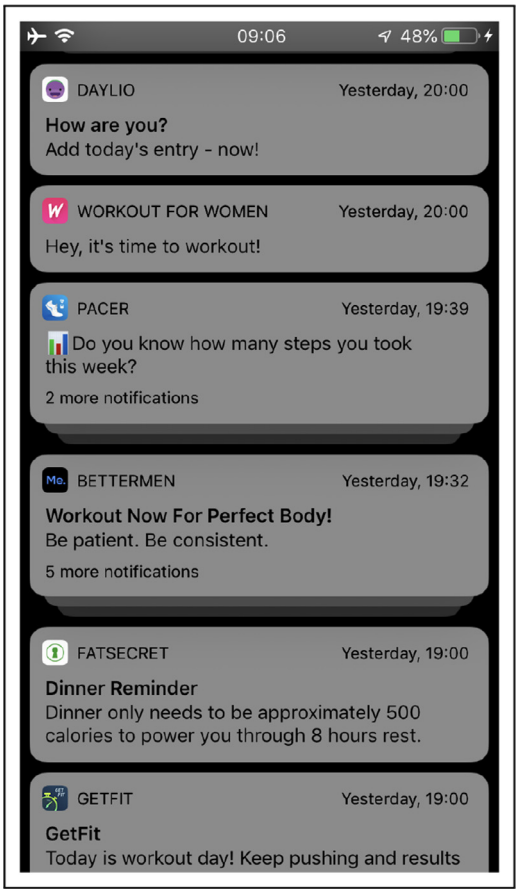

Fig. 8. Reminders: examples of notifications

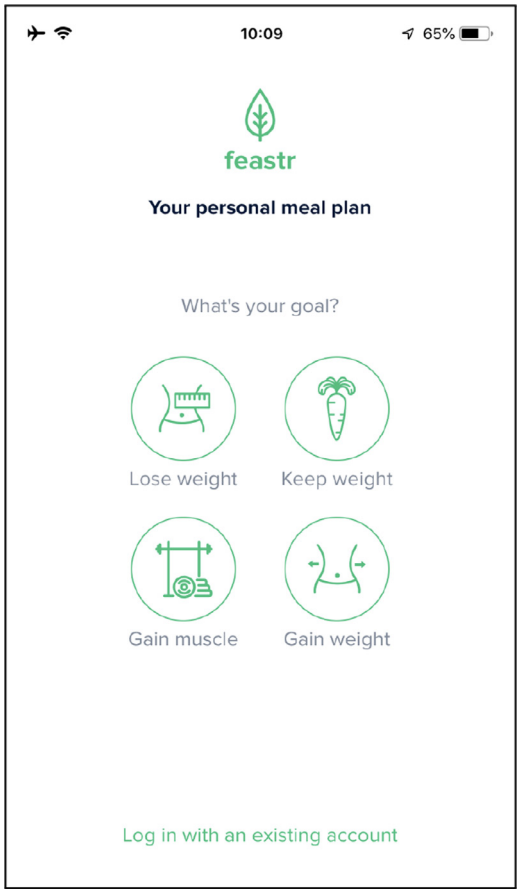

Fig. 9. Goal Setting: activities suggested by the app (FeastrFeastr GmbH (2019)).

started focusing on the distinct *features* of apps, because each feature could provide support to distinct cognitive processes Heffner et al. (2015); Stawarz et al. (2014). Therefore, to understand which specific aspect of app design relates to a particular change in behavior, it is necessary to decompose the app into its constituting functionalities.

In the last few years, two taxonomies were proposed to classify behavior change strategies and techniques. Oinas-Kukkonen et al. Oinas-Kukkonen and Harjumaa (2009) developed the Persuasive Systems Design framework that proposes 28 behavior change design principles. More recently, Michie et al. Michie et al. (2013) presented a comprehensive 93-item taxonomy of theory-supported behavior-change techniques. More recently Caraban et al. Caraban et al. (2019) conducted a systematic review of papers published in the last years in the domain of HCI and identified 23 strategies of behavior change. Unfortunately, for our purpose these classifications are of little use since they presented categories that are not specific to software features, and more importantly, they were not derived around the internal processes of change we discussed before. More recently scholars classified behavior change applications using a variety of strategies. Edwards et al. Edwards et al. (2016) reviewed 64 apps from the health domain and classified their behavior change principles around 16 categories. They found no correlation between user rating (a possible proxy for health benefits) and game content or price. Similarly, Geuens et al. Geuens et al. (2016) reviewed mobile apps designed for chronic-arthritis patients and derived 37 behavior change principles.

Unfortunately, these classifications were not based on theories of human motivation. More relevant for this research is the work of Lister et al. Lister et al. (2014), who conducted an analysis of of *gamification* constructs in 132 apps that support individuals in their of physical activity and healthy dieting. They identified 13 behavior-change constructs. Similarly, Stawarz et al. Stawarz et al. (2015) conducted a review of 115 habit-formation apps and found 10 behavior-change technique. Cowan et al. Cowan et al. (2012) performed content analysis on 127 apps from the 'Health & Fitness' category. Apps were generally observed to be lacking in theoretical content. Although these studies looked at the constructs from the angle of several psychological theories, they missed coverage of SDT. Some researchers in the digital-games domain have mapped game characteristics to SDT Birk et al. (2016); Deterding (2016); Kappen and Nacke (2013); Ryan et al. (2006). However, their work focuses on games exclusively and does not include a systematic evaluation of design features in relation to the basic psychological needs. Our specific interest is to categorize design features according to the BPNs specified by SDT. By using the three BPNs as drivers orienting our review we are implicitly focusing on those features that support individuals towards the autonomy end of the motivation continuum. We do this because we are interested in interventions that can produce *long-term benefits* to the user. Persistent changes are in fact required for many behaviors, such as diet and exercise, to reduce long-term risks (e.g., hearth disease, cancer) Haskell et al. (2007). We therefore pose our research question as follows:

RQ: *What features of behavior change apps support the BPNs for human motivation?*

Next, we describe our research methodology.

3. Methodology

We conducted a systematic review and analysis of apps on the Apple App Store. We chose to focus on the Apple App Store exclusively because, as we will detail next, the review process required several weeks to complete the analysis of each app. As we lacked resources, we could not extend the review to other stores. Additionally,

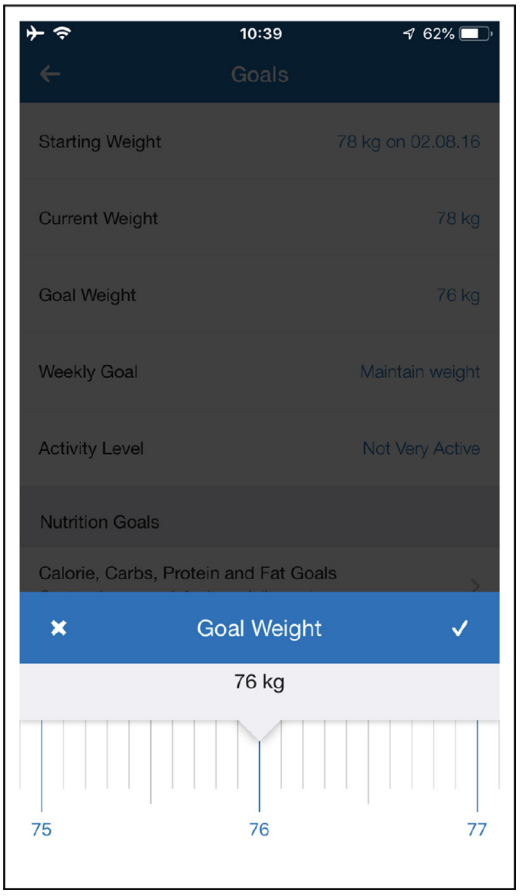

Fig. 10. Goal Setting: goal defined by user (`MyFitnessPal`Under Armour Inc. (2019)

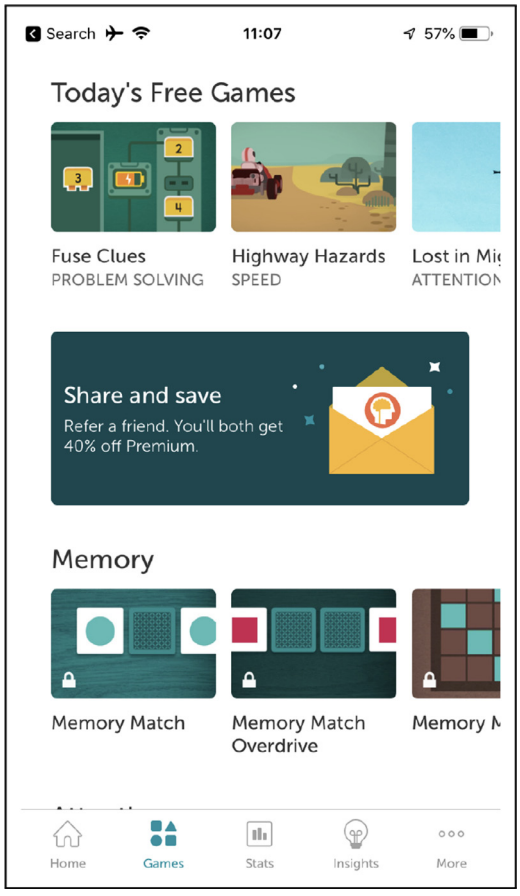

Fig. 11. Goal Setting: activities suggested by the app (`Lumosity`Lumos Labs Inc. (2019)).

we selected the Apple store because, at the time of the study, this had the largest market share in Switzerland Minutes (2020); Statcounter (2020). We identified apps aiming at supporting users who were willing to change their behavior. We then performed a functional decomposition to extract the main features of the apps that were relevant for behavior change, and coded the app features. Finally, we mapped them to the SDT BPNs. A flowchart detailing the features analysis is available online.[3]

This method was derived from previous studies (cf. Alharthi et al. (2018); Edwards et al. (2016); Stawarz et al. (2015, 2018)) and adapted to our specific research goals. Following the approach used in previous work, we decided to not use sampling as a mechanism of app selection. Instead, we collected the "top-rated" apps, guaranteeing a cross-section of popular apps. However, using this approach alone might miss out interesting examples of behavior change apps that were not in the top 100 charts at the time of the review. For this reason, we complemented it with a keyword-based search following also similar studies (cf. Lister et al. (2014); Lyngs et al. (2019); Stawarz et al. (2014)). We note, that any keyword selection is arbitrary to a lesser or larger extent. However, if the same set of keywords is used twoat a given time point and from the same place, the selection process is perfectly reproducible[4].

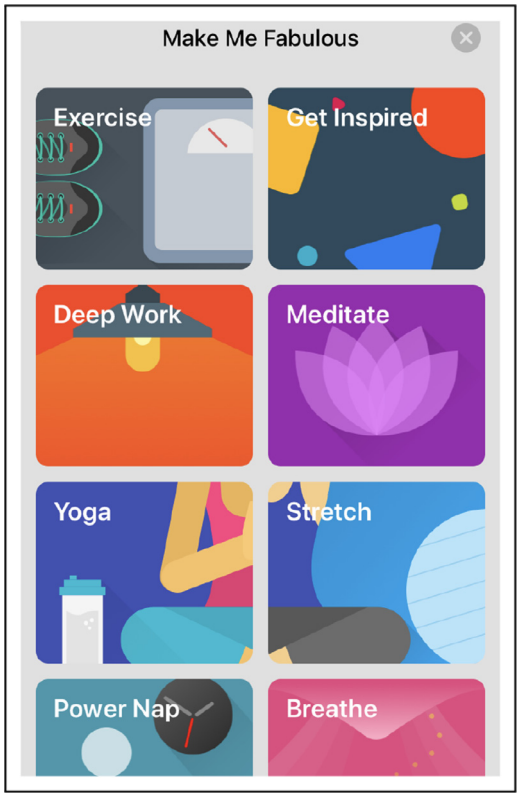

Fig. 12. Goal Setting: choice of activity (`The Fabulous`Fabulous Ltd. (2019)).

[3] See https://osf.io/zy78r/, last visited March 2020.

[4] twoAvailable apps often change in the online stores. If the selection is repeated months apart the results might differ. Similarly, querying the app stores from different places in the world might yield different results because these are customized based on the place from where the query is issued.

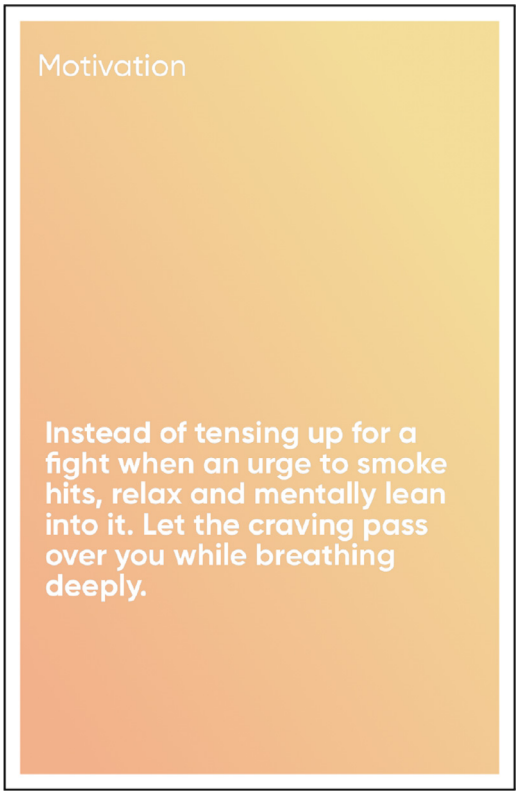

Fig. 13. Motivational Messages: generic feedback not related to the user activity (KwitKwit Ltd. (2019))

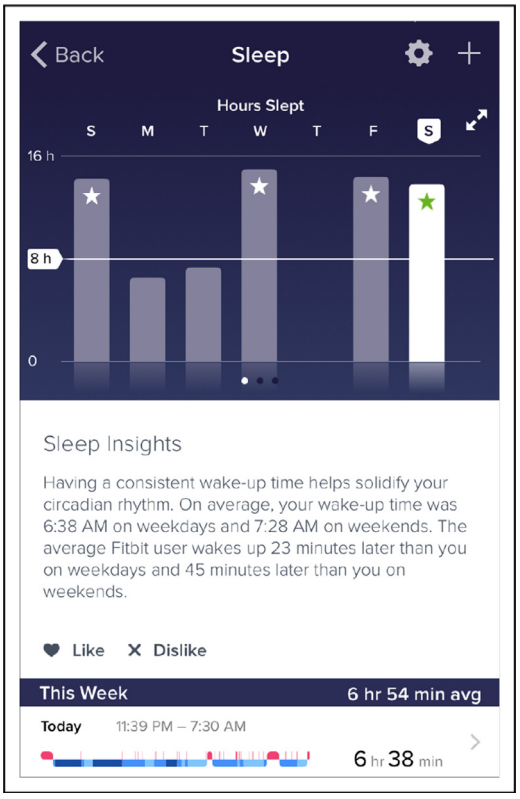

Fig. 14. Motivational Message: task-specific feedback (FitbitFitbit Inc. (2019)). The view displays also Feedback (top and bottom).

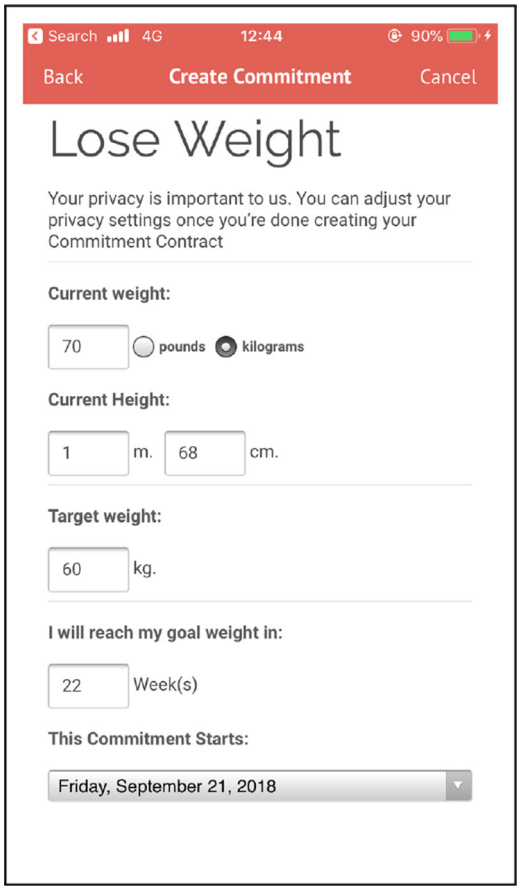

Fig. 15. Pre-commitment: self-challenge setup page (StickkStickK Ltd. (2019)).

3.1. Data Collection Procedure

Top-Down Search. We began our data collection process by looking at the Apple App Store top 100 charts[5] in all 23 categories[6] as reported by AppAnnie App Annie Inc. (2019), a business intelligence provider, on April 5th 2019. Taking our definition from Hekler et al. Hekler et al. (2013), we established that the app description in the App Store should report that the app was designed *purposely* to foster and assist behavior change and sustainment (e.g., stop smoking, sustain an active lifestyle), to form good habits (e.g., meditate everyday, drink 2 liters of water per day), or to improve skills (e.g., learn to cook vegan, learn a new language). For example, in Asana Rebel Asana Rebel GmbH (2019), the App Store description includes the following text: two"Get motivated and build lifelong habits with proven, unique, modern methods". The previous text matched our inclusion criteria as it contained the keywords *motivation* and *habit*. Whereas, the following example did *not* match our inclusion criteria as it describes an app that only provides cooking recipes: two"Get 40+ free healthy recipes and kitchen hacks! Your complete healthy recipe book..." Runtasty Runtastic Inc. (2019). Using this criteria, we reviewed 2300 apps, and we selected and downloaded 244 apps for the next step. See Figure 3 for a diagram of the data collection process.

Bottom-Up Search. To increase the diversity of our sample, we decided to employ also a *bottom-up* approach searching for behavior

[5] The Top Charts represent the rankings on the official App Store.

[6] i.e., Books, Business, Education, Entertainment, Finance, Food & Drink, Health & Fitness, Kids, Lifestyle, Magazines & Newspapers, Medical, Music, Navigation, News, Photo & Video, Prod., Ref., Shopping, Soc. Network., Sports, Travel, Utilities and Weather.

Fig. 16. Pre-commitment: self-challenge setup page (Tiny HabitsB.J. Fogg (2019)).

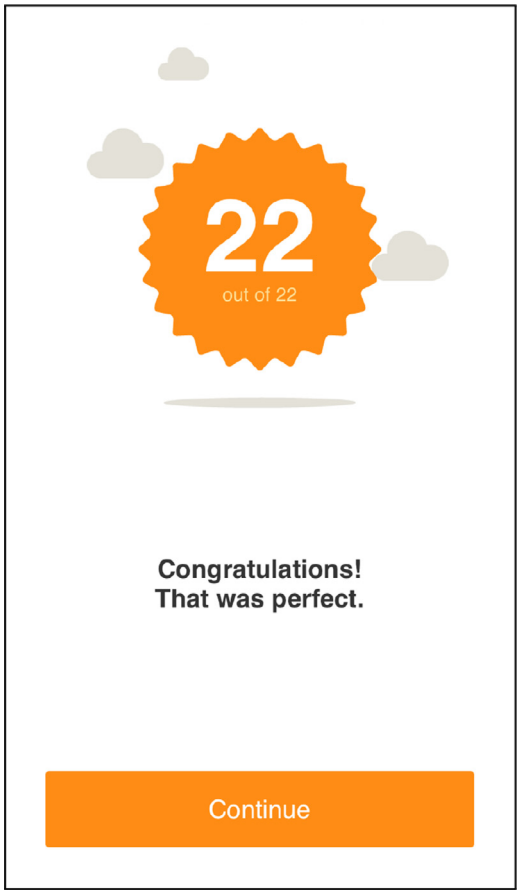

Fig. 17. Activity Feedback: numerical score after training session (BabbelLesson Nine GmbH (2019)).

change apps by keywords. We did this because the top 100 charts we used for app selection included exclusively the top user-rated apps, hence increasing the chances that less popular behavior change apps (i.e., the long tail) could be excluded from our classification. For instance, this was the case of *Simple Habit* Simple Habits Inc. (2019) that includes several behavior change features but is ranked 158 in category Health & Fitness, as of May 2019. As a first step, we compiled a list of *excluded keywords* (e.g., *health, fitness, education*) from the apps we had already selected through the top-down approach. We then extracted search keywords from recent research on behavior change applications. The keywords used were: *sustainability* Brynjarsdottir et al. (2012); Midden and Ham (2018), *habit* Purpura et al. (2011); Renfree et al. (2016), *water drinking* Lally et al. (2010), *quit smoking* Graham et al. (2006); Khaled et al. (2009), *medicine reminders* de Oliveira et al. (2010); Stawarz et al. (2014), and *mental health* Grist et al. (2017) (see Table 1 for the specific references). The choice of this particular set of papers was based on the related work review, references on social media, and the authors' experience. We then extracted the list of keywords from each of the papers and we matched those against the excluded keywords. The keywords that were uncommon between the two sets were used as *search keywords* for the bottom-up approach. In short, we specifically avoided selecting keywords that were already covered extensively by the top-down search. The final list of selected keywords (and their link to related literature) is reported on Table 1. We input each keyword in the search bar of the iPhone App Store app. Then, following the top-down approach described above, we reviewed the description of each app that appeared on the search results. The apps that matched the selection criteria were selected for the next step. As the App Store continued to load search results as we scrolled, we establish the saturation point when the last 10 apps do not meet our inclusion criteria. Finally, we included a total of 48 apps in the sample after performing the 6 keyword-based searches.

Exclusion Criteria. Before moving to the next phase, we had to exclude a 84 apps for one or several of the following reasons: i. Tools intended for general productivity that were selected because of misleading descriptions (e.g., Snap Calc IAC Search & Media Technologies Limited (2019)); ii. Tools that required corporate subscriptions or other types of registration (e.g., Success Factors inc. (2019b)); iii. Apps that hid features behind in-app purchases (e.g., Sworkit Fitness Nexercise Inc. (2019)); iv. Apps whose locale was not English, French, or Spanish as these are the languages authors are familiar with (e.g., Chefkoch SmartList Chefkoch GmbH (2019)). This resulted in 208 relevant apps. Figure 3 shows the process with which apps were selected and excluded from the sample.

3.2. Apps testing

The test of the apps was completed during the eight months that followed the apps selection. Each app was installed on a device and tested for several hours across multiple weeks by the first author of this paper. Multiple apps were tested in parallel. Approximately 36 apps per month were installed during the course of 8 months. More in details, we followed these steps: i. completed the warm welcome in each app (if available); ii. created accounts whenever this was required or suggested by the app; iii. performed the actions suggested by the apps whenever possible (see details below); iv. reacted to app notifications. Target actions were performed when suggestions of the apps fit the personal schedule of the researcher and when she felt motivated to perform them (e.g., reading a book, drinking a glass of water, taking a language module, going for a run). In some cases, target actions had to be

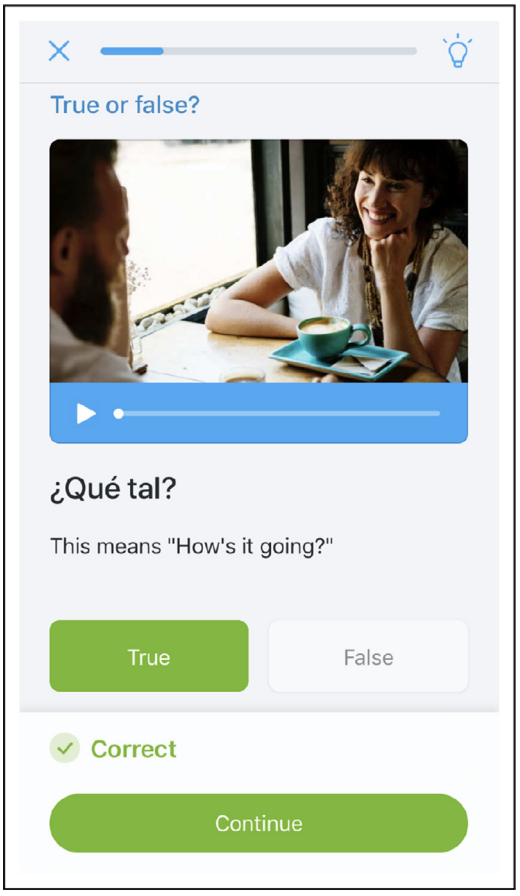

Fig. 18. Activity Feedback: correct response is visualized after True/False question (BusuuBusuu Ltd (2019)).

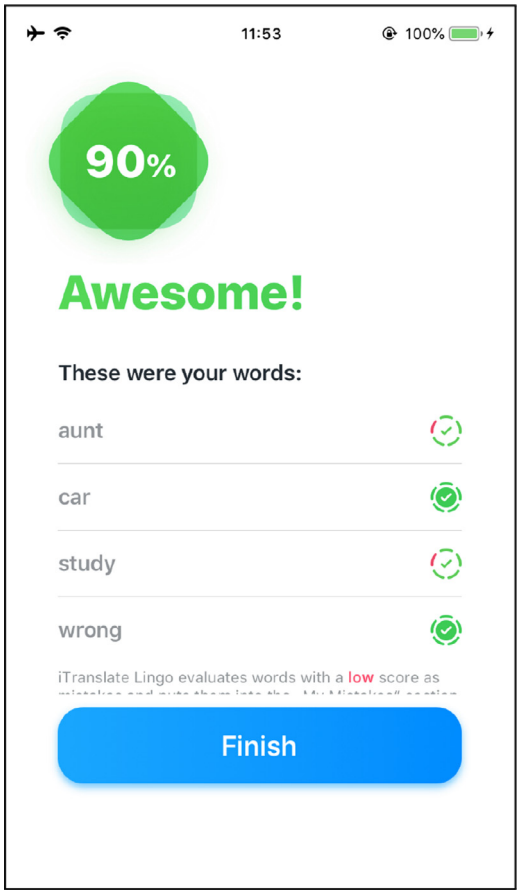

Fig. 19. Activity Feedback: correct/incorrect answers to quiz (iLingo) iTranslate GmbH (2019)

simulated as not applicable in the life of the researcher (e.g., tracking intake of birth control pills). Performing the target actions ensured familiarization with the data that had to be coded two Braun and Clarke (2006) (i.e., the features of the app). This step is required by the methodology we used to code the features (see Sec. 3.4). During this time, unstructured notes and thoughts were captured in the researchers' diary. Particularly, the researcher documented whether she felt pressured by the app to perform the target activity, whether she felt competent to perform the target activity, and whether she felt supported by others. These three elements corresponded to the BPNs of the SDT and informed the subsequent coding process. Furthermore, testing the features across several weeks provided us with a longitudinal exposure to the app features that could reveal adaptability of functionalities over time (e.g., delivery of reminders at particular times of the week based on the user's activity). The features that tailored interventions during this time frame were analyzed. Next we describe the functional decomposition process.

3.3. Functional Decomposition

To extract the main functionalities of each app, we followed the guidelines of *functional decomposition* proposed by Chiriac et al. Chiriac et al. (2011). The first step of functional decomposition, involves dividing the system (or app) into *self-controlled* sub-systems (or functions). The second step requires identifying how these sub-systems interact with each other. These two steps define the first level of decomposition. On the second level of decomposition, each of the sub-systems are decomposed into other subsystems. We stop the process when the next decomposition level reaches the level of basic UI components (e.g., buttons, labels, icons, sliders). As an example, while performing the decomposition process for the Fitbit app Fitbit Inc. (2019), we first identified the *dashboard, challenges, community*, and *notifications* as self-controlled sub-systems (see Figure 4). By tapping on the steps indicator (top of the screen), the system presents the *list of steps* sub-system (see Figure 4, center). Then, when tapping on "Today", the system showed the *steps number* sub-system that can not be further decomposed (see Figure 4, right). Next, we classified the sub-systems.

3.4. Features Coding

We coded the sub-systems identified during the functional decomposition process using a procedure adapted from *thematic analysis* Braun and Clarke (2006). The analysis process involves two stages. The first stage consists in grouping together sub-systems that despite visual design differences provide the same basic functionality. These groups are formed and labeled using an inductive approach that started from the analysis of the sub-system derived from the first 30 apps. These formed the initial codebook. Then, both codes and their definitions are updated as new apps are analyzed. We stopped refining the codebook around the hundredth app, because we kept seeing recurring functionalities and no significant changes occurred. Once the codebook was stable, two coders (the first author and a master's student) coded independently all the identified sub-systems of the apps. In the second stage, overarching themes are evolved from the more granular data. For example, the functions that provide statistics concerning the number of activities performed or the task performance formed the theme: 'Activity Feedback'. We clustered codes where we had evidence from the literature that these were providing the same support to the behavior change process. This phase was done collaboratively by the first and second author of the paper. These themes are the patterns under which we

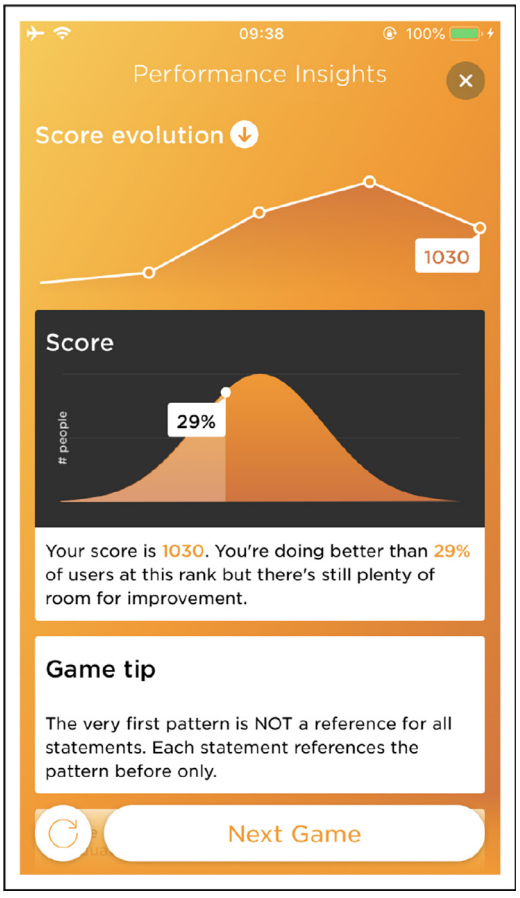

Fig. 20. History: graph visualization of weekly activity (top of the screen) (PeakBrainbow Ltd. (2019)).

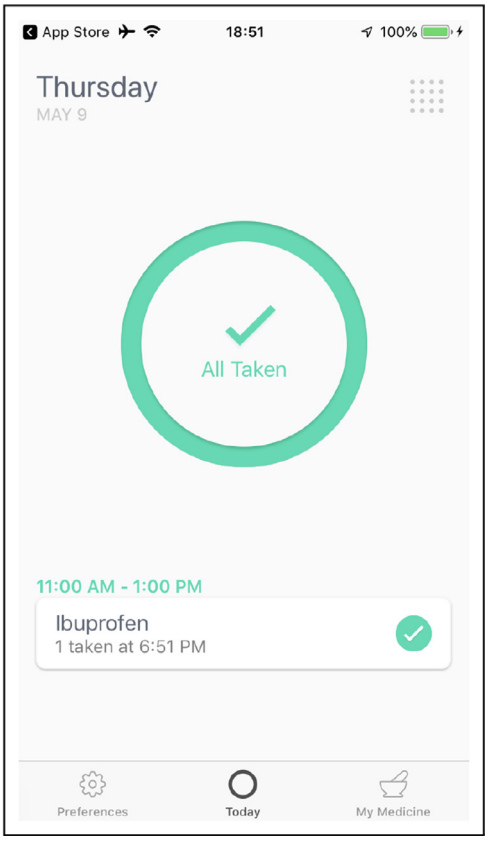

Fig. 21. Log/Self-Monitoring: round button to report medication intake (RoundCircadians Design Inc. (2019)).

organized the results section and we will refer to them as *Behavior Change Features*. Next, we classified the Behavior Change Features according to which Basic Psychological Needs they cater to.

3.5. Theory-driven coding

As discussed, the codebook we applied during this last step was theory-driven and derived from the SDT Ryan and Deci (2017). Basically, we applied one of three labels: Autonomy, Competence, or Relatedness. The link between each behavior change feature and the BPN it caters to was conceptualized applying one or multiple of the following heuristics: i. studies that demonstrated effects of the feature on the BPNs (the reader will find the relevant references in the next section); ii. perception of the effects of the feature on the BPNs, as noted by the first author who tested the feature on herself, and as discussed with the second author during the analysis process; iii. comparative analysis of the variation of designs identified in the sample of behavior change apps. In the majority of cases, applying the three heuristics above led the authors to associate each behavior change feature to only one BPN. This was also facilitated by the fact that BPNs are in their definition orthogonal to one another. However, we found three features which cater to two BPNs (as it emerged from the comparative analysis of apps). In these three cases, we classified the feature according to the BPN with the highest relevance (i.e., primary classification), but also to the additional BPN that could receive support depending on how the feature was implemented (i.e., secondary classification). We will discuss these specific cases in the next section. In addition, one might expect that each feature, depending on its particular implementation, to be influencing a BPN to a lesser or higher degree. This is possibly true, but assessing the exact extent to which a particular implementation influences a BPN goes beyond the scope of the present study, and it likely requires controlled experiments with full factorial designs. Figure 5 presents the coding process. As for the previous coding step, the first two authors of the paper independently assigned the features to the BPNs.

3.6. Inter-rater Reliability

We used Cohen's κ to assess inter-rater reliability for the thematic analysis (data-driven coding) and for the BPNs coding activity (theory-driven). For the data-driven coding, we measured an agreement of $\kappa\omega = 0.85$ (with 95% CI 0.81 to 0.89). For the theory-driven coding, we measured an agreement of $\kappa\omega = 0.91$ (with 95% CI 0.87 to 0.95). The level of agreement was considered sufficient to warrant the subsequent analysis of the data. All discrepancies were then resolved through discussion with a third trained reviewer.

4. Taxonomy

After the functional decomposition and coding of the features of the behavior change apps, we identified 12 features that cater to the BPNs defined by the Self-Determination Theory[7]. In the following paragraphs, we introduce each feature and detail which characteristics was related to the satisfaction of the basic psychological needs. For each feature, we provide examples taken from the functional decomposition. See Table 2 for a summary of the findings.

[7] The complete list of apps coded in this research is available at https://osf.io/zy78r/, last visited December 2019.

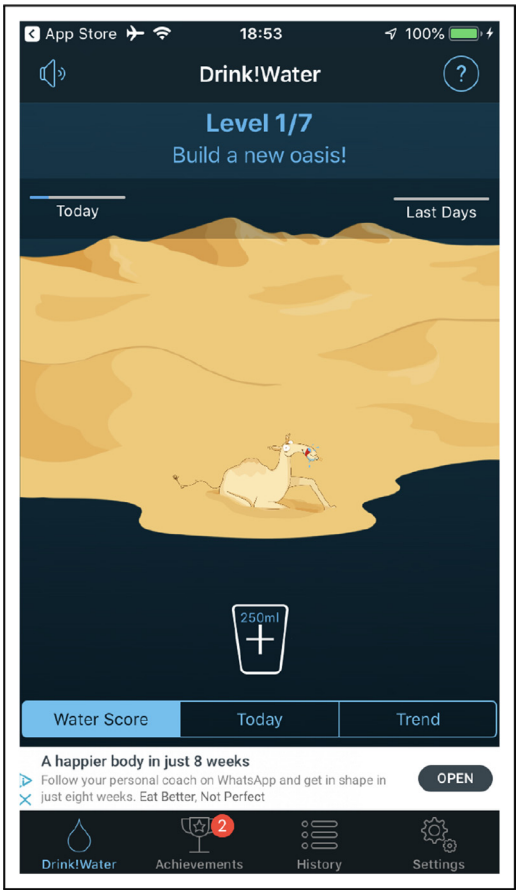

Fig. 22. Log/Self-Monitoring: page to report water intake (`Drink Water-Health Reminder`murbit GmbH (2019)).

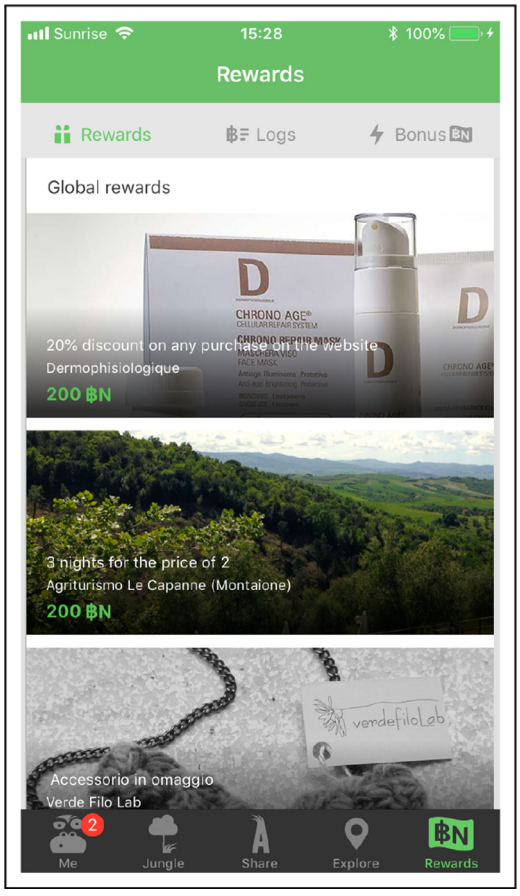

Fig. 23. Rewards: different physical rewards the user can choose from (`GreenApes`srl (2019)).

4.1. Autonomy-Supportive Features

two"Autonomy refers to feeling willingness and volition with respect to one's behavior. The need for autonomy refers to the need of an individual to experience self-endorsement and ownership of their actions" (Ryan and Deci, 2017, p. 86).

Reminders. This feature is often implemented as a message delivered around the time the user should perform a specific activity. The times of delivery of these messages are identified by the app (see Figure 7) or input by the user (see Figure 6). Most often, this feature is implemented as a push notification, and we could observe it in most of the apps we reviewed and in all categories of apps: in educational apps (e.g., `iTranslate Lingo` iTranslate GmbH (2019), `Memrise` Memrise Inc. (2019)), fitness apps (e.g., `30 Day Fitness` Abishkking Ltd. (2019)) and productivity apps (e.g., `Better Habits` Betterment (2019), `Today` The Today App Ltd. (2019)). See Figure 8 for an example.

SDT considers that self-organization is a natural effort, toward which individuals lean, and that it occurs under *autonomy* supportive conditions Niemiec et al. (2010b). In this context, reminders help the individual stay organized and on track with regard to the target behavior. SDT cautions that, depending on how this feature is implemented, the user might experience the opposite of autonomy, namely *heteronomy*, as when a users acts out of pressures that are experienced as controlling (Ryan and Deci, 2017, p. 86). Therefore, it is best for reminders to be set by the user (e.g., as for the app '30 Day Fitness'), rather than set by the designers of the app (e.g., `Arise app` ARISE Ltd. (2019)). When this feature is not perceived as controlling, it can gently move the person to perform the specified activity. For instance, receiving *one* reminder a day to track breakfast for the first three weeks could be considered OK by most users willing to change their eating habits. However, sending multiple reminders every day might have a negative effect on the person, reduce their self-determined interest in using the app, and eventually cause them to stop being interested in the activity Mehrotra et al. (2016). Renfree and colleagues Renfree et al. (2016) also studied the reminders feature on `coach.me` Lift Worldwide (2019), the reminders sometimes caused negative reactions because they were deemed annoying, particularly when participants were going through busy or stressful periods.

Goal Setting. This feature provides the user the possibility to input or define the target for the activity they will perform. We identified three patterns: (1) the user proactively sets goals up (e.g, `MyFitnessPal` Under Armour Inc. (2019)); (2) the app prompts the user directly about what their goals are (e.g., `Feaster` Feastr GmbH (2019)); and (3) self-competition: a bid against oneself or against a previously obtained result. For instance, in `Yazio` Yazio GmbH (2019) users can challenge themselves on the time elapsed since last eating chocolate. The pattern (2) typically occurs during *onboarding*, and it is pivotal to defining the subsequent interaction (e.g., `fatsecret` Fatsecret Ltd. (2019)). See Figures 9 and 10 for examples of this feature. Another way this feature is embedded in behavior change apps is by letting users choose, from a series of predefined activities/exercises, which one they want to perform. These are usually presented as individual blocks labeled with the activity name, or as a list with illustrative icons. Most of the time, these include a description and the requirements to accomplish it successfully (e.g., `Fabulous` Fabulous Ltd. (2019), `Luminosity` Lumos Labs Inc. (2019)). See Figures 12 and 11 for examples.

The goal-setting feature supports the SDT basic psychological need of *autonomy* because it contributes to an *internal perceived locus of causality* DeCharms (1968). Specifically, an intentional behavior can be

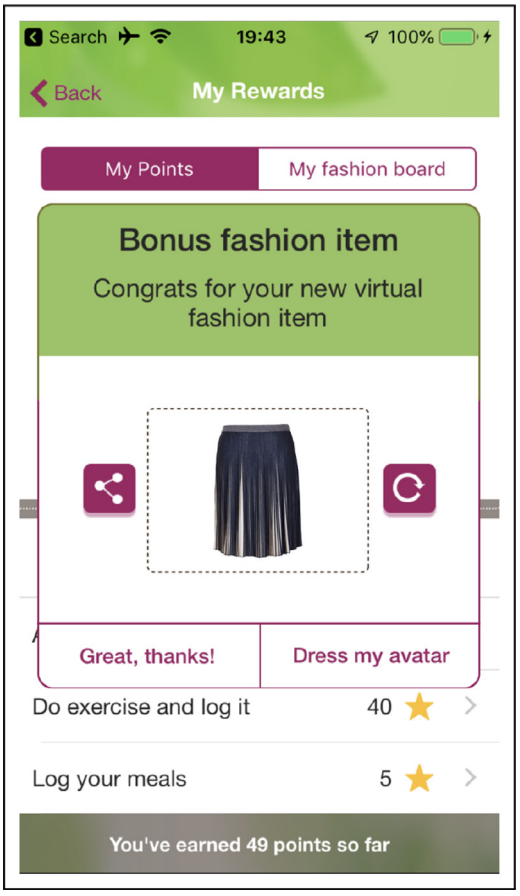

Fig. 24. Rewards: list of virtual rewards the user can choose from (MyDietCoachAnat Levi (2019)).

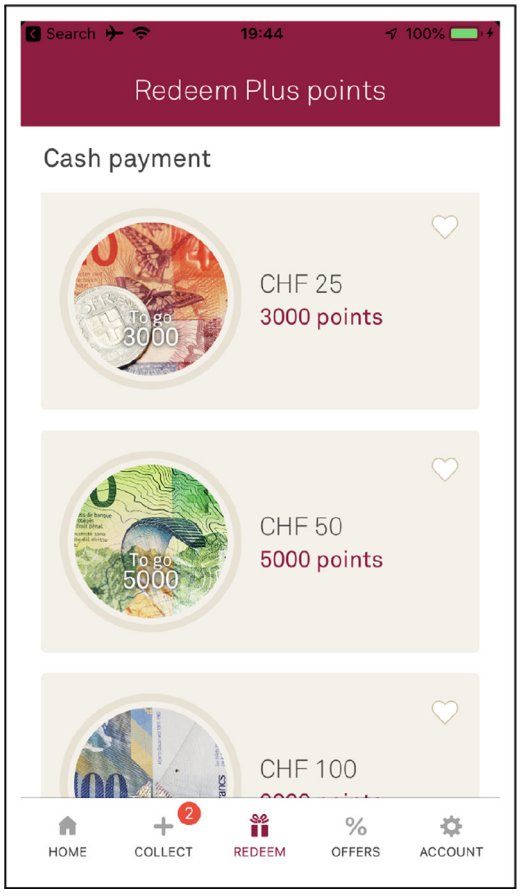

Fig. 25. Rewards: monetary rewards (Helsana+Helsana Insurance Ltd (2019)).

either intrinsically motivated (it has an internal perceived locus of causality) or extrinsically motivated (it has an external perceived locus of causality). For example, researchers found that in a learning environment where teachers gave students choices and options, the learning outcomes of the students increased Deci et al. (1996); Patall et al. (2010). According to the SDT, a goal imposed by someone else (or by an app) would undermine autonomy, which in turn would reduce the motivation of the subject to perform the activity. Whereas, a self-imposed goal would contribute to the basic need of autonomy and support autonomous motivation to perform the specific activity (cf. Deci and Ryan (1980); Ryan et al. (1985, 1996)).

Motivational Messages. Some apps present the user with pre-set messages that explain why performing the specific activity is good for their health or well-being. These messages are often displayed in the shape of cards (e.g., Kwit Kwit Ltd. (2019), Stop Smoking d bel Ltd. (2019)). Other instances for this feature take the form of instructional videos (e.g., Yoga-Go A. L. Amazing Apps Ltd. (2019)). An important quality of these messages, from an SDT standpoint, is that these are not *task inherent*, meaning that they are provided to the users at specified time intervals, regardless of completion of the target behavior or performance. See Figures 13 and 14 for examples of how these are typically implemented in apps design. Another pattern this feature can take is the *letter to self*: a text field in which users can type a short message about why it is important for them to keep engaging with the target activity. This is then saved in the app and made available whenever needed (e.g., MyPlate Leaf Group Ltd. (2019)) or it gets automatically resurfaced at specific time intervals (e.g., Brainbuddy AppStudio Australia Pty Ltd (2019)).

From an SDT perspective, these messages can help the user reflect on the reason they want to engage in the specific activity, hence they have the potential to support the basic need of autonomy. Kinnafick et al. studied the effects of supportive text messages on a person doing physical activity and found that regularly receiving this content increased their levels of intrinsic motivation Kinnafick et al. (2016). Concerning self-directed messages, encouraging the users to write a message to themselves, is a forcing function that lets them write down the specific reasons they wanted to change their behavior. This contributes to changes in the person's regulatory style, toward more internal and integrated forms of motivation that are associated with autonomous control. Bargh shows how actions that are initiated by the individual have outcomes stronger than those that are more implicit or unconscious Bargh (2007).

Pre-commitments. This feature enables users to create *commitment contracts*: a binding agreement the users signs with themselves. Basically, it asks the user to define a goal, a given time frame to accomplish it, and a penalty if the deadline is not met. Typically, the penalty consists in donating a specific amount of money to a charitable organization of choice. Then, to establish whether the challenge was truly accomplished, the challenge is shared with other users (of the same app) who might act as referees. Examples of this feature can be observed on Stickk StickK Ltd. (2019), see Figure 15 and 16 for visual examples. This feature contributes to the satisfaction of the SDT basic psychological need of *autonomy* because users can bind, or pre-commit, their own behavior Wertenbroch (1998). If the implementation requires other users to act as referees, then the feature contributes as well to the satisfaction of *relatedness* as the users will feel connected and involved with others.

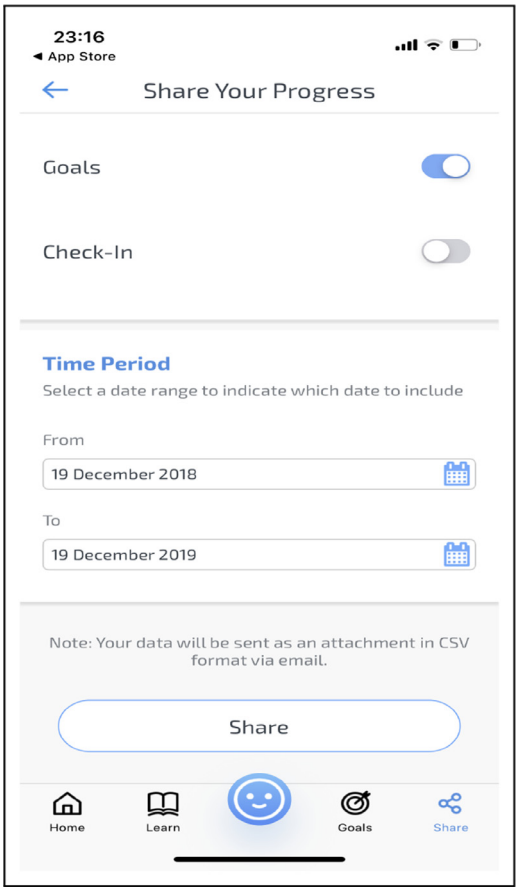

Fig. 26. Performance Sharing (MindShiftAnxiety Canada Association (2019)).

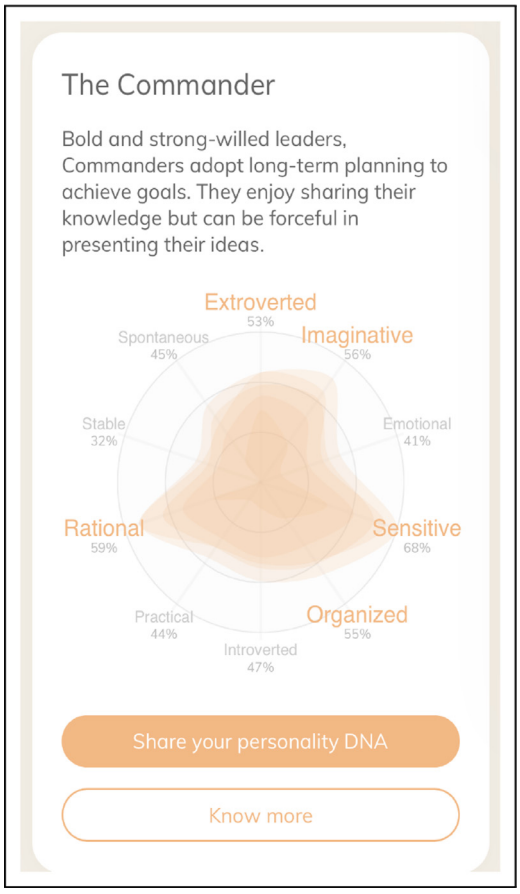

Fig. 27. Performance Sharing (YouperYouper Inc. (2019)).

4.2. Competence-Supportive Features

two"Competence refers to feeling effective in one's interactions with the social environment–that is, experiencing opportunities and support for the exercise, expansion, and expression of an individual's capacities and talents" (Ryan and Deci, 2017, p. 86).

Activity Feedback. This feature provides the user with information about how the task was performed in a given session and it might also present the user with details on the overall progress towards completing a predefined set of activities. This information might also be accompanied by a score that represents the performance (e.g., Babbel Lesson Nine GmbH (2019)), or a small encouragement message (e.g., Duolingo Duolingo Inc. (2019)). Furthermore, a different instance of this functionality might also present cumulative statistics aggregated over a given time period (e.g., a week, a month); this might help the user evaluate temporal trends and compare current with past performances. For instance, these scores might include the consecutive or non-consecutive days in which a given activity was completed (e.g, Calm app inc. (2019a) shows total number of meditation sessions). See Figures 17, 18 and 19 for examples of this feature.

Both session-specific and cumulative statistics provide *feedback* to the users of behavior change apps. When this feedback is positive, showing growth or improvement trends, this can enhance an individual's sense of competence Deci and Ryan (1980). However, when feedback is negative, this can have the opposite effect, particularly when the information does not provide any actionable advice Sjöklint et al. (2015). Unsatisfactory results, such as underachievement, do not lead to behavior change but rather the emergence of coping tactics: e.g., disregard, procrastination, and neglect. Research conducted on feedback also revealed that the *timing* of delivering feedback also plays a role in its overall effect on motivation. When feedback in *unexpected*, receiving this information does not make people feel being controlled. When feedback is experienced as an evaluation, pressure or control, it prompts people to perceive the activity as imposed on them (i.e., external perceived locus of causality), hence it undermines intrinsic motivation Smith and Sarason (1975). SDT states also that feedback alone might not be enough to motivate users. Ryan demonstrates that simply providing positive feedback is not enough to motivate people if they do not also experience autonomy Ryan (1982). Another quality of feedback that was found to be connected with its effectiveness in motivating recipients is that feedback must be specific to the performed task (i.e., *task inherent*) and actionable Hewett and Conway (2016). In summary, feedback enables recipients to gain a sense of their effectiveness, hence to enhance their feeling of competence Suh et al. (2015).

History. This functionality presents the user with a representation of the user activity over a period of time. Whereas Activity Feedback provided statistics, scores, or other information on the person's performance, History is simply a crude chronological representation of what occurred in the various sessions during which the activity was performed (e.g., Peak Brainbow Ltd. (2019) shows a line graph with the score progress for each time an activity was completed). See Figure 20 for an example.

History enables users to reflect on the temporal component of the activity of their behavior-change goal. By looking at what occurred on specific days, users are able to relate success or failures to meet specific goals to contextual factors that might have played a role in influencing their activity (e.g., peaks of stress, work deadlines, menstrual cycles). This information helps the users know themselves and how their personal circumstances might influence the behavior their aim to change, hence it supports the basic need of competence. If the temporal representation of the activity demonstrates progress or continuous

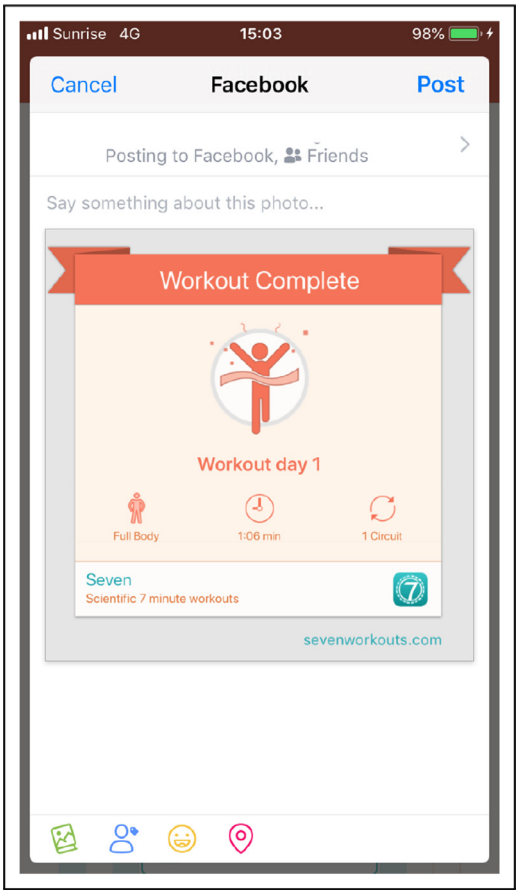

Fig. 28. Performance Sharing: posting progress on Facebook (`7 Minute Workout`Bytesize Systems Pty Ltd (2019)).

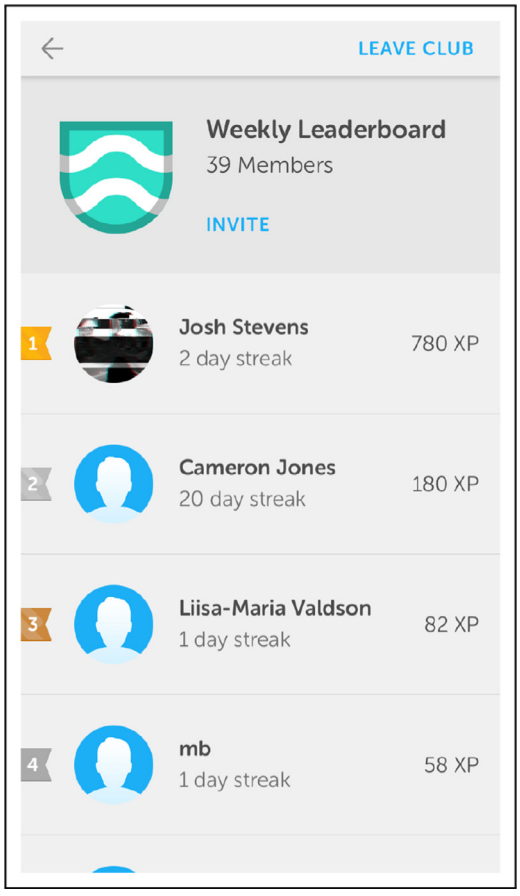

Fig. 29. Peer Comparison: leader board (`Duolingo`Duolingo Inc. (2019)), a weekly basis comparison displaying various information

maintenance of the target activity, this increases the user's sense of effectiveness, thus supporting intrinsic motivation Grouzet et al. (2004). Whereas, if the chronological sequence of activity shows the protracted inability of the user to reach the goal of the target activity, this might decrease the user's intrinsic motivation Carpentier and Mageau (2013).

Log/Self-Monitoring. This functionality provides the user with the possibility of recording the accomplishment of a goal or the completion of a task related to the specific activity (e.g., drinking a glass of water, taking a medicine, beating the performance of a previous run). Examples of this functionality can be seen in `Drink Water` murbit GmbH (2019) and `Round Health` Circadians Design Inc. (2019). See Figures 21 and 22 for examples.

Whenever the users log an activity, this represents a confirmation that they maintained the activity, consequently it enhances their feeling of *competence*. Ryan et al. found self-reporting the achievement of tasks positively associated with an increased intrinsic motivation towards the target activity Ryan and Deci (2000a). At the same time, the simple act of opening the app to input data about a completed session represents an expression of volition that supports the BPN of *autonomy*. By feeding data to the app, users also express their interest in keeping up with the activity and reinforce their willingness to modify their behavior.

Rewards. We identified two forms of rewards: *tangible* and *non-tangible*. Concerning the former, some of the surveyed apps provide points to the users that can be exchanged for vouchers, products, or cash payments. In `GreenApes` srl (2019) the user receives "BankoNuts" that are transformed into coupons for obtaining discounts on products. Similarly, `Changers` Blacksquared GmbH (2019) assigns "ReCoins" to obtain vouchers for acquiring various goods. See Figures 23 and 25 for visual examples of this feature. Concerning non-tangible rewards, these might take the form of virtual points that can be exchanged for digital goods, experience points, or badges. In `My Diet Coach` Levi (2019), the user gets reward points to dress their avatar. See Figure 24 for an example of non-tangible rewards.

According to SDT, rewards can have a detrimental effect on intrinsic motivation, particularly when these are seen as the only reason to engage with the target activity (Ryan and Deci, 2017, p. 128). Externally administered rewards can be perceived coercive and controlling, hence hinder the basic need of autonomy. Researchers demonstrate that participants who received money for solving puzzles (i.e., task-contingent reward) showed a decrease in their subsequent intrinsic motivation (measured as a free-choice persistence of the target behavior) Deci (1971). In a later study, Deci and Ryan argue that offering an extrinsic reward (e.g., money) for an activity individuals were already interested in performing can prompt them to experience an *external perceived locus of causality* in their behaviour, hence producing the feeling of being controlled Deci and Ryan (1985, 1980). Non-tangible rewards, however, when connected to experience gained while performing the target activity can support the BPN of competence hence yield positive benefits for the intrinsic motivation of the participants Ryan and Deci (2000c). Rewards such as badges, or unlocked achievements, fosters positive emotions towards the target activity Deterding (2012).

4.3. Relatedness-Supportive Features

two"Relatedness refers to both experiencing others as responsive and sensitive and being able to be responsive and sensitive to them–that is, feeling connected and involved with others and having a sense of belonging" (Ryan and Deci, 2017, p. 86).

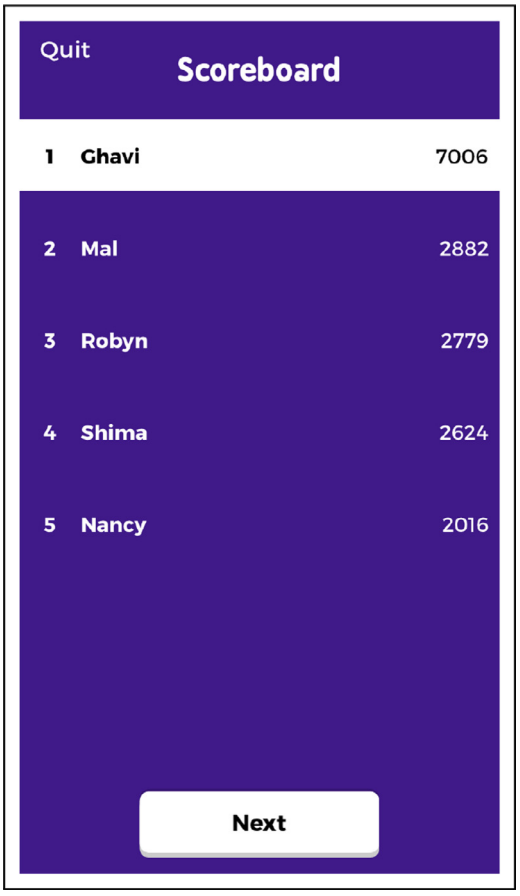

Fig. 30. Peer Comparison: leader board (Kahoot! Kahoot AS (2019)). Shows a comparison after completing an activity.

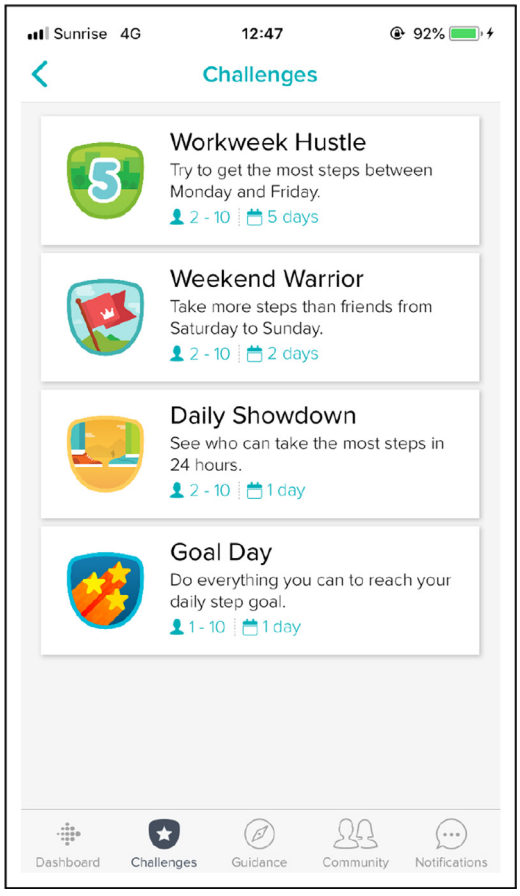

Fig. 31. Challenge Peer: different types of challenges against other peers (fitbit Fitbit Inc. (2019)).

Performance Sharing. This feature enables the user to share their achievements with their peers (e.g., through social networks, e-mail, instant messaging or text messages). Typically, the user shares the score of the recently completed task or challenge. When sharing happens on social networks, then a scorecard is published on the news feed of the social network. Other instances of this feature might include the maps of the trajectory the users followed during their activity, the distance walked/ran, or the type of exercise performed (e.g., Runtastic, Strava Strava Inc. (2019), Youper Youper Inc. (2019)). See Figures 26,27, and 28 for visual examples of this feature.

By showing their progress to their close contacts, people can receive *acknowledgment* and *support*. Also, through this mechanism people can appreciate whether they matter to others and see the *impact* they have on them Baumeister and Leary (1995). SDT states that by adopting attitudes and acting in manners that are endorsed by peers or significant others, individuals can feel a greater relatedness and sense of belonging that drives self-determined motivation (Ryan and Deci, 2017, p.202). One of the aspects designers should consider when providing this feature is that although it enables users to receive supportive messages, it also opens the door to possible critics. Receiving negative responses –or even a lack of responses– from peers might lead users to experience opposite effects, specifically feeling that they might not be appreciated and cared for. In turn, this might lead to a detrimental effect on their motivation to perform the activity.

Peer Comparison. This functionality is typically implemented with a list of people who are performing the same activity. The list is ordered using quantitative scores and might include user names, actual user pictures, or avatars (e.g., Freeletics Freeletics GmbH (2019)). In game-related studies this feature is often referred to as *leader board*. In other instances of this functionality, the comparison might be enabled by other visualizations (e.g., a Gaussian curve, like for Peak app). See Figure 29, 30 and 20 for an example of this feature.

Through a comparison with their peer, users can assess the impact of their actions on others and feel more effective Ferguson and Olson (2014). Therefore, this feature supports the BPN of *relatedness*. Additionally, 'Peer Comparison' contributes to the SDT basic need of *competence* because, through this feature, individuals can assess their level of efficacy and mastery toward the specific activity (Ryan and Deci, 2017, p.97). It is important to notice that this feature might also have negative effects on the motivation of the users: losing a direct competition might lead the 'loser' to experience a decrease of intrinsic motivation (i.e., turn towards amotivation) McAuley et al. (1989). This is particularly true when the only goal of the competition is seen as winning against the opponent Vansteenkiste et al. (2004). The negative effect of losing can be moderated by setting optimal challenges Deci (1975), and by providing positive competence feedback Vansteenkiste et al. (2004).

Challenge Peer. Several behavior change apps we reviewed enabled users to directly challenge other users towards a given goal. These competitions could be limited to one peer or towards a group of people; they can be private (with friends and relatives) or public (with other random users) (e.g., JouleBug Joulebug Inc. (2019)). See Figure 31 for a visual example of this feature.

Competitions against other players provide users the ability not only to compare the final outcome of the performance (i.e., the score) with other players, as per the previous category, but also to relate, test strategies, and match executions with those of the opponents. Through the interplay of seeing and being seen, this feature supports the BPN of relatedness by supporting interpersonal connection, recognition, and trust between the players (Ryan and Deci, 2017, p. 87). Challenging

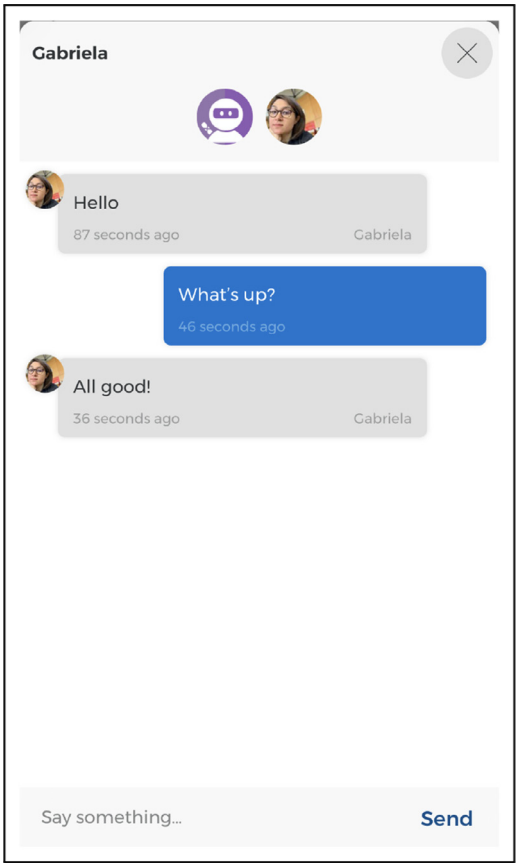

Fig. 32. Messaging (Goalify! GmbH (2019)).

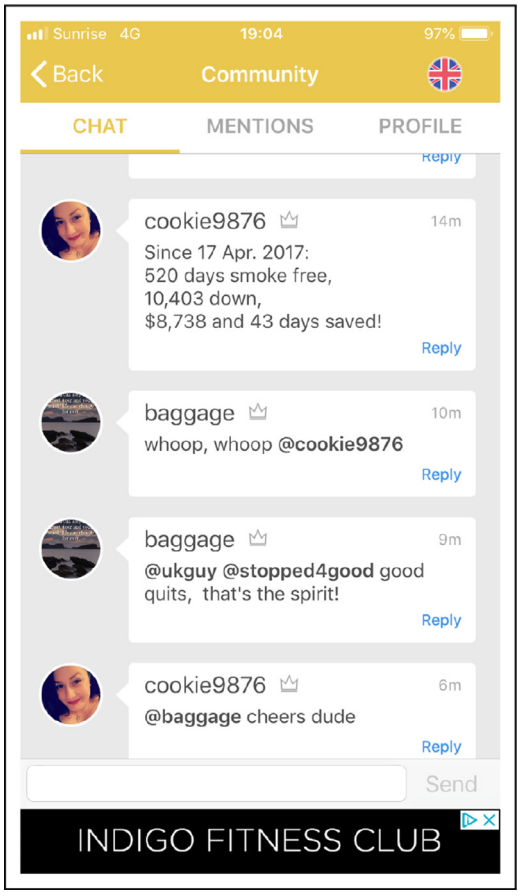

Fig. 33. Messaging (QuitNow! Fewlaps S.L. (2019)).

peers might have detrimental effects on intrinsic motivation, especially if the challenge is imposed on the users without letting them choose when and with whom to compete Standage and Ryan (2012). Also, users might feel controlled if they perceive winning as the only objective of performing the target activity.

Messaging. This feature enables the user to exchange text messages with other users who are using the same app. Some apps enable one-to-one communications (e.g., Goalify GmbH (2019)), whereas others support a group chat (e.g., QuitNow! Fewlaps S.L. (2019)). In other instances of this feature, the communication functionality is afforded through a feed interface where messages are represented as cards that can be scrolled, and to which other users can reply and provide responses. These cards are used to share ideas to help other members of the community improve their skills (e.g., GreenApessrl (2019)). Typically feeds enable one-click responses (i.e., 'thumbs-up' or down). See Figure 33 and 34 for a visual example.

Messaging enable users to connect with other users who live similar experiences and face the same challenges. Through this feature, they can exchange experiences, provide and receive support to others, and experience a sense of belonging Baumeister and Leary (1995); Deci and Ryan (2000); Ryan (1993). With respect to motivation, prior research finds that when people feel that their relatedness need is satisfied, they tend to be autonomously motivated and they can maintain the specific activity over time Edmunds et al. (2006). Researchers also found that the opportunity to interact with others is one of the main driver people have when playing causal games Ferguson and Olson (2014).

4.4. Coverage of the BPNs in the Sample

The two most popular behavior change features that caters to the BPN of Autonomy are Reminders (71.8% or 149 apps) and Goal Setting (55.9% or 116 apps). If we consider the BPN of Competence, the most popular feature is Activity Feedback (40.9% or 85 apps). Finally, for Relatedness, the most popular feature is Performance Sharing (18.2% or 37 apps). These results are reported in detail in Table 2, see also Figure 35 for a visual representation of the behavior change features coverage in the Sample. From the total of 208 apps included in the analysis, only 25.5% (or 53) implemented at least one feature that supports all three BPNs. About 44% (or 91) of the reviewed apps provided support for only two of the basic needs. It is interesting to notice that the most popular combination we observed was 'AC' covering 35.6% (or 74) of reviewed apps, while the least popular combination was 'CR' with only 1% (or 2) of the reviewed apps. Finally, about 31% (or 64) of the reviewed apps provided support for only one of the basic needs with autonomy being the most popular basic need for which features were afforded in behavior change apps (i.e., 26%, or 54, of the sample). Table 3 presents a summary of the frequencies of apps implementing the behavior change features described in this section.

5. Discussion

In this study, we map the different techniques adopted by current behavior change apps and relate them to the Self-Determination Theory of human motivation. We reviewed 208 apps designed purposely to support behavior change and found that the most popular feature is Reminders. This resonates with previous reviews of habit formation apps Stawarz et al. (2015). This is likely due to the fact that designers overuse this feature to try to compel individuals to use their app. When mapping design features to SDT, we found that only one fourth of the sample provided users support for the three basic needs. For the apps that do cover all the BPNs, a common design pattern consists of letting users select the target activity (i.e., Goal Setting), then providing statistics after the activity is performed (i.e., Activity Feedback) and

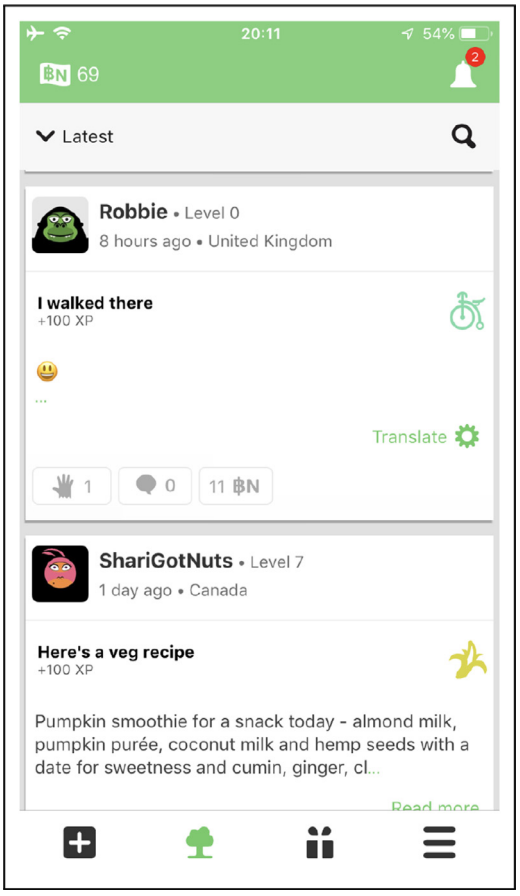

Fig. 34. Messaging: feed (Green Apessrl (2019))

Table 2
Behavior change features and % of coverage in the sample, including examples of apps containing the given feature. A: autonomy, C: competence, R: relatedness, •: primary classification, ◦: secondary.

Feature	A	C	R	Coverage %	Example of App	Figure no.
Reminders	•			71.8	30 Day Fitness Challenge	6
Goal Setting	•			55.9	Feastr	9
Motivational Messages	•			9.1	Kwit	13
Pre-commitments	•		◦	0.9	Stick	15
Activity Feedback		•		40.9	Babbel	17
History		•		30.9	Peak	20
Log/Self-Monitoring	◦	•		29.6	Round	21
Rewards		•		19.1	GreenApes	23
Performance Sharing			•	18.2	MindShift	26
Peer Comparison		◦	•	11.8	Duolingo	29
Challenge Peer			•	11.4	Fitbit	31
Messaging			•	6.4	Goalify	32

Table 3
Frequency of apps implementing behavior change features per BPN identified in the reviewed sample.

BPN	no. apps	% coverage	% aggregated
A	54	26	
C	8	3.8	30.8
R	2	1	
AC	74	35.6	
AR	15	7.1	43.7
CR	2	1	
ACR	53	25.5	25.5
Total	**208**	**100**	**100**

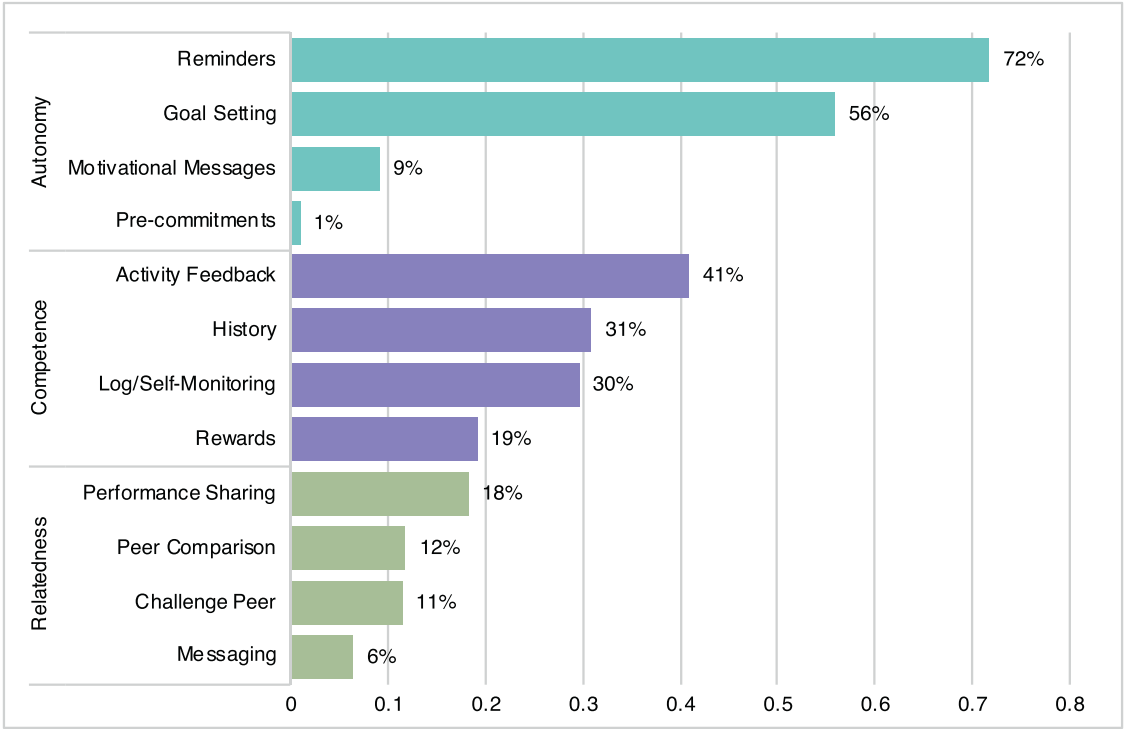

Fig. 35. Percentage of apps in the sample that afforded a given behavior change feature. The features are listed by decreasing frequency in each BPN (they follow the same order reported in Table 2.

enabling users to share their performance through social media (i.e., Performance Sharing). Conversely, we found that 74.5% of behavior change apps do not support all the basic psychological needs: According to the SDT, supporting the three BPNs enables the person to move towards self-determined action for the target activity.

Here, we discuss how the analysis reported in this paper can inform future design and research by pointing to: (i) rarely used design features in current behavior change apps that are underexplored in HCI research; and (ii) feature gaps identified by looking at the app design through the lens of Self-Determination Theory. Finally, we outline limitations and future work.

5.1. Research Opportunities Suggested by Rarely Used Design Features

The analysis of the behavior change apps reported in this experiment highlighted design features that are seldom used: pre-commitment and intergroup competition. These might appear less frequently for multiple reasons: because they have been tested and discarded in prior iterations of the design of popular apps, or because they represent unexplored design space yet to be exploited. Both possibilities would warrant HCI experiments that might reveal properties and applicability of these features.

Pre-commitments: This feature was implemented only in ∼ 1% of behavior change apps. Pre-commitment could be a powerful mechanism to counter procrastination that can arise when preferences are inconsistent over time and across contexts. One of the causes for the apparent changes in preferences over time is a change in the saliency of the costs and benefits of the activity in question Akerlof (1991). Although such time-inconsistent preferences can form serious obstacles to following a planned course of action, they can be overcome. In addition to exercising willpower to resist temptation, people can constrain or pre-commit their behavior Schelling (1992); Thaler and Shefrin (1981); Wertenbroch (1998). Binding behavior is characterized by the voluntary imposition of constraints (that are costly to overcome) on one's future choices in a strategic attempt to resist future temptations. Ariely et al. experimentally studied pre-commitment Ariely and Wertenbroch (2002). The results of their study show that people are willing to self-impose meaningful (i.e., costly) deadlines to overcome procrastination and that these self-imposed deadlines are effective in improving task performance. This technique was studied in behavior change apps for regulating the use to digital devices. Kim et al. reviewed several behavior change apps to regulate use of mobile devices Kim et al. (2019). Similarly, the aforementioned work of Lyngs et al. reviewed apps and browser extensions of which many implement varying levels of friction if users wish to override their own past preferences Lyngs et al. (2019). To the best of our knowledge, pre-commitment has not been covered in other domains of behavior change from HCI research. From an SDT perspective, the feature in its most common implementation supports the BPN of autonomy. However, alternative design might involve peers (or family members) as referees on the bids, thus enabling also support to the BPN of relatedness. Social support was studied in the domain of self-regulation (cf. Hiniker et al. (2016); Ko et al. (2016)). These studies revealed that social support helped users mitigate smartphone distractions. However, we are not aware of studies that focused on pre-commitment *and* social support. A user betting on the achievement of a given task, might feel more compelled to bring it to completion if a friend or another user of the same system will be checking on her/him (as opposed to an algorithm).

Intergroup Competition. Many of the behavior change applications that we reviewed give users the ability to compete against other users. However, we could not identify apps that enable users to cooperate towards a given goal. Furthermore, we could not identify apps that enable users to compete in groups (i.e., inter-group competition). Both competition and cooperation can affect intrinsic motivation in a number of ways. Research has demonstrated a positive effect of competition on intrinsic motivation Epstein and Harackiewicz (1992); Reeve and Deci (1996); Tauer and Harackiewicz (1999). There are two main mechanisms in which competition affects intrinsic motivation: (1) through the competitive context established at the outset of an activity, which can affect how individuals approach a task, and (2) through performance feedback Sansone and Harackiewicz (1996). Other research has revealed that if individuals focus on winning rather than the activity itself, their intrinsic motivation can decrease Deci and Ryan (1985); Harackiewicz et al. (1998). Cooperation also has the potential to affect intrinsic motivation in a number of ways, because individuals can experience the benefits of being part of a team that works toward a common goal; this engenders a sense of relatedness among their teammates. Cooperation also has the potential to provide positive feedback if a team completes the goal. This can promote perceived competence and, in turn, intrinsic motivation Deci and Ryan (1991); Ryan and Deci (2000a,b); Vallerand and Losier (1999). However, cooperation can have negative effects on motivation if they perceive the group goal as externally controlling (loss of autonomy), or if they fail to meet their goal. A safer approach –with regard to affecting intrinsic motivation– could be letting the users compete in groups (i.e., inter-group competition). Tauer et al. found that inter-group competition leads individuals to experience levels of intrinsic motivation higher than pure cooperation and pure competition Tauer and Harackiewicz (2004). Therefore, it would be relevant to empirically compare cooperation and inter-group competition with individual competition in their ability to support behavior-change interventions.

5.2. Feature Design and Research Gaps Suggested by the SDT

By classifying and looking at the behavior change features from the SDT perspective, we also identify three areas that are currently underexplored in research focusing on these apps: (a) Design that support the individual in reaching higher level of intrinsic motivation; (b) Design that provide support for all the three basic needs as identified by the SDT; and (c) Tailoring of the interventions that resonate with the constructs of SDT. We argue that conducting more research in these areas can lead to new powerful designs for behaviour change apps.

(a) Nurturing or Thwarting Intrinsic Motivation. Through this analysis, we observed *Reminders* and *Activity Feedback* features in almost every app we analyzed. We have also observed examples of *Motivational Messages* whose content was disconnected from the performance of the recipient of the messages. The connection provided by the taxonomy between design and theory, allows us to derive implications for the *content* and for the *deployment* of these messages. SDT research has demonstrated that providing feedback that shows progress increases intrinsic motivation Vallerand and Reid (1984). However, if the feedback does not show consistent improvements on the target activity, it might discourage the user Burgers et al. (2015). An SDT-informed design for activity feedback would require information provided to the user to be: i. *personal* (i.e., specific to the participant); ii. *contextual* (i.e., providing task-inherent information that can help the user connect their performance of the activity with its outcomes); and iii. *goal-oriented* (i.e., providing the next challenge to push their work further by being phrased in a way that is specific to the level of the user) Cherubini et al. (2020). Concerning the deployment of these messages, we note that these are often sent through a channel that is already overloaded by other communications and might lead the user to experience *notification fatigue* Pielot and Rello (2017). Also, if the delivery of these messages becomes repetitive and predictable, the user might experience them as *controlling* and this might be detrimental to intrinsic motivation Kast and Connor (1988); Ryan (1982). Instead, it would be more beneficial to deliver these messages opportunistically when the user performs a spontaneous activity, perhaps at a time or place where this did not occur in the past Cherubini et al. (2020).

Another point of discussion concerns the use of *rewards*. SDT researchers conducted many experimental studies on rewards, punishments, and other extrinsic events Deci and Ryan (1985); Deci (1971,

1972); Deci and Ryan (1980). SDT specifies that these external events might support or thwart a person's feeling of *autonomy* and *competence* and this, in turn, influences intrinsic motivation. SDT research showed that if rewards are seen as the only goal of performing the activity, these can yield detrimental effects on intrinsic motivation Deci and Ryan (1985); Deci (1971); Deci and Ryan (1980). External rewards can be perceived as controlling or coercive, consequently harming the basic need of *autonomy*. An SDT-informed design for rewards should provide tokens that celebrate the users' renewed competences, rather than anchoring users on the extrinsic value of the prize. In this context, we can think about non-monetary rewards (e.g., badges, experience points) that can be given to the user when specific goals or sustained performance are achieved. These incentives might be perceived by the recipients as recognizing their knowledge, rather than placing a value on their behavior.

In summary, to ensure that users will have self-determined motivation for the specific activity, it is not sufficient to implement any of the behavior change features described in the taxonomy. Erroneous designs of these features might lead users to feel controlled, inapt, or not at the level of their peers, thus hurting the users' intrinsic motivation.

(b) Providing Support to the Three Basic Needs. SDT posits that it is fundamental to a person's growth, well-being, and integrity to fulfill the three basic needs (Ryan and Deci, 2017, p.98). In the analysis of the pool of apps selected for this work, we found that only one fourth of the apps (i.e., 25.5%) include features that trigger all three of these psychological sensibilities in some form. However, we lack controlled experiments that could shed light on the effect of implementing multiple features that cater to the BPNs on the motivation of users for the specified activity. We suggest three open questions: (i) It is still unclear whether providing support for only one, or two of the basic needs can yield positive effects on a user's motivation. (ii) The majority of behavior change apps implement multiple behavior change features that provide support to the same basic need (i.e., 74.5%). However, we do not know whether implementing multiple features that support the same BPN would actually increase the overall positive effect, or be detrimental towards supporting self-determined action towards the target activity. (iii) In the analysis, we found that 43.8% of the apps provide support to two BPNs. It is not clear whether a particular combination of supports for the three basic needs would be better suited to help users with varying levels of intrinsic motivation (measured at the onset of the intervention). Longitudinal and large-scale studies that include a post-experiment observation are necessary to understand the long-term effects of the interventions (cf. Cherubini et al. (2020); Patel et al. (2016)). These experimental designs might also account for individual differences, and record effects on ceiling performance and lapsed use.

(c) Optimal Challenge. When surveying the behavior change apps, we realized that there are very few applications that tailor the intervention to the specific characteristics of the user. Recent research focusing on serious games revealed that users respond differently to behavior change strategies Orji et al. (2017, 2014); Sundar and Marathe (2010). For instance, for a given user who walks an average of 8K steps a day, walking or running 10K steps a day is a challenging but realistic goal. However, the same goal, for a person that walks or runs 4.5K steps a day, might be completely unrealistic (we referred to this concept as *optimal challenge* Deci (1975)). The analysis reported in this paper reveals that app designers often opt for a one-solution-fits-all approach; during the few weeks of testing, we could not identify any tailoring or personalization mechanisms. However, SDT cautions that although some users might be motivated for a specific activity by challenges they consider interesting, others might simply react the opposite way if they perceive the challenge as too difficult. More research in this area could demonstrate the effect of providing personalized challenges to users of behavior change apps.

5.3. Limitations and Future Work

Our work has some limitations. As the Apple App Store and App Annie do not provide information about the number of users, we focused on functionality, leaving considerations on the number of installs or the content of user reviews to future work. This is similar to the approach taken by Lyngs et al. (2019); Stawarz et al. (2015, 2014). The study of behavior change apps reported in this paper was limited to the iOS App Store and to free apps. Behavior change features that could have been provided after in-app purchases might have not been analyzed. In our sample this might have been the case for 30 apps that we excluded from the initial sample. Future work should extend the analysis also to these paid features. The analysis of the feature was also limited in time. The apps were tested for several hours across multiple weeks, which provided us with a longitudinal exposure to the features. We created accounts and tested it with real interactions (e.g., drinking water when the app told us so). The features that tailored interventions during this time frame were analyzed. Our analysis does not take into account tailoring strategies on long term interventions. Additionally, in this study we did not look at hardware counterparts for behavior change apps (i.e., wearables). Looking at our sample, only two apps in our sample have a hardware counterpart but they can be used without it and recent research shows that wearable trackers have high attrition rate Lazar et al. (2015). Future work should also look at other app stores. As highlighted by Lyngs et al. Lyngs et al. (2019), iOS apps tend to have fewer features than their Android counterparts (especially for pre-commitment and tracking), because iOS provides fewer permissions to developers. Therefore, reviewing only apps for iOS might give a limited picture of what features have been explored in behaviour change apps. Furthermore, future work should cover user reviews (cf. Cowan et al. (2012)).

Finally, SDT as a theoretical framework is not exempt from criticisms. As we have reviewed in Sec. 2.3, SDT focuses on self-determined behaviors, which are chosen consciously. However, recent research also highlighted the importance of non-conscious mechanisms to form habits and modify behaviors Pinder et al. (2018); Verplanken and Wood (2006) but also theories that focus on rational deliberative processes, as SDT, are typically insufficient to explain the intention-behavior gap in the presence of strong habits Sheeran et al. (2017). Other streams of research focused on the BPNs and suggested that other basic needs also play an important role on human behavior Martela and Ryan (2016); Sheldon et al. (2001). Finally, other scholars looked at rewards and reached different conclusions from those suggested by SDT, however the topic is still debated Cherubini et al. (2020); Deci et al. (1999).

6. Conclusion

The challenge of designing effective behaviour-change interventions is important to address. In this paper, we contribute to this effort by providing a functionality analysis, according to the Self-Determination Theory, of current apps for behaviour change. This survey reveals gaps for future studies that can further develop our understanding of the domain and intervention design. We hope that this research informs a future where technology will be used to reinforce and enable the autonomy of individuals, rather than necessitating dependencies.

Acknowledgements

We would like to thank Amon Rapp and Florian Brhlmann for their valuable comments that contributed to the development of this work. We also thank Tolulope Omuku and Khaled Lala (master students at UNIL) for their help analysing the data. Finally, we would like to thank Holly Cogliati-Bauereis, James Tyler and Mercedes Alpzar for their precious comments. twoFinally, we would like to thank the anonymous reviewers for their precious comments.

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