MoviPill: Improving Medication Compliance for Elders Using a Mobile Persuasive Social Game

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ABSTRACT
Medication compliance is a critical component in the success of any medical treatment. However, only 50% of patients correctly adhere to their prescription regimens. Mobile and ubiquitous technologies have been proposed to tackle this challenge, mainly in the form of memory aid solutions that remind patients to take their pills. However, most of these methods do not *engage* patients in shifting their behavior towards better compliance. In this paper, we propose and evaluate a mobile phone-based game called *MoviPill* that persuades patients to be more adherent to their medication prescription by means of social competition. In a 6-week user study conducted with 18 elders, the use of *MoviPill* improved both their compliance to take the daily medication and also the accuracy of the drug intake time according to the prescribed time. Moreover, the improvement in the latter increased from 43% to 56% when we considered only participants that had any interest in games, which reveals the importance of applying persuasive techniques in a personalized manner. We conclude with a set of implications for the design of persuasive mobile solutions in this domain.

Author Keywords
persuasive mobile interfaces, elderly, medication compliance, user study.

ACM Classification Keywords
J.3 Life and Medical Sciences: [Medical information systems]; H5.2 Information interfaces and presentation: User interfaces—*Evaluation/methodology*

General Terms
design, experimentation, human factors, verification.

INTRODUCTION
Human memory is one of the most intriguing cognitive processes. It dynamically retains the most relevant elements of our life. At the same time, it is prone to failures. Hence, it is no surprise that the automated capture and access to live experiences is considered among the top three main research themes in Ubiquitous Computing [4]. Relying on our memory may be a dangerous practice when our health depends on it, as it is the case in medication compliance. A recent review of 139 studies reporting compliance data showed that only 63% of patients keep complying with their medication after a year and patients take their medication only 72% of the time [13]. Adherence rates are typically higher among patients with acute conditions, as compared with those with chronic conditions. Clinical trials report average adherence rates of only 43 to 78 percent among patients receiving treatment for chronic conditions [17]. Similar results were obtained in a study involving 325 elderly (average age of 78 years) [31], whom are frequently taking medication for chronic illnesses.

In order to tackle this challenge, medical experts have tried a variety of approaches that remind patients to take their medication. Simple intervention methods such as telephonic follow-ups by the pharmacist were shown to be effective in enhancing medication compliance [24, 27] and reducing the overall costs to the health provider [18]. However, this type of approaches are difficult to sustain in the long-term and at a large scale [32]. With the pervasiveness of mobile phones and the advent of "smart packages" (*e.g.,* GlowCaps [3]), automated reminding could be addressed to solve the problem of scalability. Still, previous work reports cases in which no improvement in medication compliance was observed by using reminders *alone* [23, 25, 38], or even where automated reminders were perceived negatively by the users [39].

Persuasive techniques could address this problem by shifting the focus from a human activity that we are not typically good at (*i.e.,* remembering) to an activity that we tend to be good at and enjoy (*i.e.,* socializing). Previous work in this area has already shown promising results to obtain positive changes in people's behavior in a variety of domains (*e.g.,* motivate physical activity using personal awareness [22] and social competition [11, 16]). However, most of the strategies that address medication compliance involve reminding patients to take their pills and educating them on the effects of non-compliance, which do not seem to be enough to *motivate* people to comply with their medication regimens [36]. Alerting patients to do the same thing everyday does not *engage* them in actually doing it by themselves.

Our approach towards increasing levels of compliance (remembering to take a dose) and adherence to medication regimens (taking doses at the prescribed time) focuses on changing the way people perceive the drug intake task. Particularly, our main hypothesis is that *patients become more compliant in taking their medications when the task is not seen as an obligation, but rather as an entertaining and engaging experience.* In this paper, we address engagement by means of a game. We have implemented a mobile phone application called MoviPill to encourage compliant behavior by giving more points to players that take their medica-

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tion very close to or at the prescribed time, and less or no points otherwise. The game includes a social competition component by connecting all players through a social network and allowing them to check how disciplined they are in regard to the other competitors. To validate our approach, we have conducted a 6-week user study using a crossover design with 18 elders that considered themselves compliant, did *not* know each other, and did *not* receive any monetary incentive for winning the game. Results confirm our hypothesis: both prescription adherence (remembering to take daily doses) and regimen adherence (taking doses at the prescribed time) were improved when participants played the game. To the best of our knowledge, the work presented in this paper is the first approach to look at the challenge of medication compliance from an *entertainment* and *user engagement* perspective in the form of an mobile social persuasive application. Also, the presented system is one of the first that aims at encouraging compliance to recurrent activities that happen at specific times.

RELATED WORK

Medical Literature

Medication compliance/adherence is typically defined as *"the extent to which a patient acts in accordance with the prescribed dosing regimen"* [13]. Research on this matter has suggested different strategies to increase the patients' levels of medication compliance, including: (1) counseling, (2) simplified regimen plans, and (3) compliance aids [9].

The *counseling* strategy focuses on patient education, including risk factors of non-compliance, information about their illness, instructions on how to take the prescribed medication correctly, and explanations of the benefits and possible adverse effects of the therapy. This method has been extensively applied yielding mixed results in different studies. For instance, Russel *et al.* identified that 21 out of 42 studies on counseling interventions did not reveal any difference between treatment and control groups, while the remaining 21 studies did [36].

Simplified regimen plans include drug reminder charts [23], calendar packaging [15], and dosage boxes [14]. These studies reveal that this strategy *alone* is unlikely to improve drug compliance.

Finally, *compliance aid* has proven to be one of the most effective strategies to date. For instance, telephone follow-ups by the pharmacist were extensively tested and proven to be effective in enhancing medication compliance [24, 27] while also reducing the overall cost to the health provider [18]. However, this intervention method does not scale well for a large population on a long-term basis [32]. Other successful methods include "smart packages", such as the MEMS [2] and GlowCaps pillboxes [3], which record date and time every time they are opened. The GlowCaps pillbox also addresses automated reminding. The main assumption behind this approach is that when patients are alerted about their non compliant behavior throughout the day, they will take the appropriate actions to change that behavior. However, these methods focus on reminding patients of something they already know they have to do, without *engaging* them in doing it by themselves.

Combinations of these strategies have been frequently proposed in the literature with the assumption that a single approach cannot be effective for all patients. An example is the use of both counseling strategies and compliance aids to trigger the patients' motivation towards adherence to medication. Unfortunately, even this combined solution has been shown to be ineffective in a few cases according to both objective [23, 38] and subjective [25] measures. Another approach – motivated by a recent study reporting that 40% of adults delayed care or failed to follow prescriptions to save money [19] – consists of providing patients with monetary incentives, which reveals how inefficient reminders can be when people are more interested in immediate rewards.

Computer Science Literature

According to Mynatt *et al.* (2004), *"the next revolution of technology in the home will arise from technologies aimed at helping older adults maintain their independence and quality of life while helping avoid a transition to a more expensive, institutional setting"* [33]. Indeed, the Ubiquitous Computing community has been addressing this challenge in recent years [26] by proposing that technologies for elders should be designed with a systemic approach: keeping in mind the networks of caregivers usually involved with the care of old people [12], and their social interdependence [8].

Research on persuasive technology draws from psychological theories such as the *goal-setting theory* [28] and the *trans-theoretical model* [35]. The former describes how individuals respond to different types of goals, while the latter identifies the stages through which an individual progresses to intentionally modifying his/her behavior. Following these theories, different persuasive health-related applications have been proposed in the literature and have shown promising results in positively changing people's behavior. For instance, Franklin *et al.* [21] demonstrated that by providing text-messaging *reminders* to diabetes patients they could improve self-efficacy and adherence to glycemic control. As another example, Mamykina *et al.* [30] investigated the deployment of a prototype of a health-monitoring application that was designed to offer *feedback* to individuals with diabetes concerning their blood sugar levels throughout the day. Their study demonstrated positive outcomes of participants interacting with their system, thus revealing that individuals need to proactively engage in the investigation of their disease rather than relying only on guidelines. Similarly, Sashima and Kurumatani [37] proposed a *monitoring* infrastructure through which caregivers can keep track of the health status of a patient wearing physiological sensors using mobile phones.

Recently however, the transtheoretical model was criticized because of its over-reliance on intrinsic factors to explain motivation. The critics argued that extrinsic factors, such as community influence, might just be as important as self-motivation [5]. Therefore, other researchers focused on designing applications for compliance aid that could leverage group interactions. Consolvo *et al.* [11] designed a prototype mobile application for encouraging physical activity by *sharing* step counts with friends. They found that participants who shared their step counts were significantly more likely to meet their goal than participants that did not share this information. Similar results were obtained by Fujiki *et al.* [22], who designed a *ubiquitous game* application to encourage physical activity. Data from a wearable accelerometer was logged to a cell phone and used to control the animation of an avatar that represented the player in a virtual race game with other players. More related to medication compliance is the study of Mamykina and Mynatt [29], who designed a ubiquitous health monitoring application to *facilitate the discovery and learning from past experiences* within a community of patients with diabetes. Finally, Chiu *et al.* [10] designed a mobile social persuasion system to motivate users to drink the right quantities of water during the day. Results suggested that the two hydration games implemented by the authors (single/multiple players) were effective for encouraging regular water intake by users. While this work is promising and relevant, it cannot be generalized to the domain of medication adherence for different reasons, including the fact that while drinking is a biological primary need for the human body –regulated by various physiological reminders, the need to take a medication is in many cases not signaled by our bodies until it is too late. Moreover, the drug intake task is a recurrent activity that should happen at specific times in order to provide the body with the appropriate quantities of the medication throughout the day, as opposed to the task of drinking water.

RESEARCH QUESTIONS

The primary goal of our proposal is to change the patient's non-compliant behavior by engaging him/her in the drug intake task. Taking medication is not typically considered a fun activity and we do not claim that our proposal changes this fact. However, by creating a social game around this activity, we expect users to: (1) approach it with additional curiosity; (2) find support – and a certain level of entertainment – by connecting their medication routines with those of other people; (3) increase their interest in the task; and in consequence (4) improve their medication compliance. Even though the prototype presented in this paper could be used by any demographic group, we have focused our effort on elders: adults of 60 years or older, for whom medication compliance is most likely to be a contributing factor to their quality of life. In particular, the two research questions addressed in this paper are:

RQ1: *Can a mobile social persuasive game help elders adhere to their medication prescription (i.e., take all daily doses)?*

RQ2: *Can a mobile social persuasive game help elders adhere to their medication regimen (i.e., take the daily doses at the prescribed time)?*

MOVIPILL PROTOTYPE

Architecture

MoviPill's architecture can be explained by the following scenario, sketched in Figure 1. For illustration purposes, let us consider a user that takes two doses per day of a certain medication. For the first dose of the day, the user opens the pillbox containing the medication and takes a dose of it (step 1 in the figure). On the inner part of the pillbox lid, there is a sensor that registers date and time the pillbox was opened (similar to current technology [2]). When the user opens the pillbox, the data is sent wirelessly to a nearby computing device that runs the MoviPill application –*e.g.,* mobile phone, PC, *etc.* (step 2). Whenever the device is connected to the Internet, it sends to the MoviPill server the identifiers of both the user and the medication, and the date and time that the pillbox was opened (medicine supposedly taken; steps 3 and 4). On the server side, the user's information is validated and his/her drug intake profile is updated in the database (step 5). Finally, the server sends a confirmation back to the computing device (via the Internet), which updates the status of the MoviPill game (steps 6 and 7).

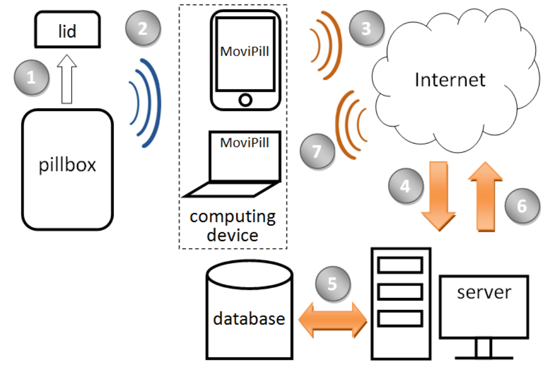

Figure 1. MoviPill's architecture. Step (2) was not implemented to help us answer the research questions.

An alternative implementation to the previous scenario would enable the pillbox to send the information directly to the server without the need for the pillbox to be closer to a device running MoviPill at the moment of the drug intake (*i.e.,* step 2 in Figure 1). This approach would entail extra complexity to the pillbox manufacturing and the user would still need the internet-enabled device for the game. Hence, we opted for the first alternative in our implementation. In addition and for the purpose of the experiment (see Section "**Procedure**" for more detail), step 2 was not included in order to investigate whether participants would try to cheat in the game (*e.g.,* confirming the drug intake closer to the prescribed time – using the smartphone interface – but actually opening the pillbox way later or not opening it at all).

Game Dynamics

MoviPill players have a well defined, single goal: *to take their medication the right number of times per day (prescription adherence) and as close as possible to the time prescribed by their doctor (regimen adherence).* The closer to the prescription time, the more points they obtain: (a) two points if the intake occurs within $\pm$15min of the prescribed time; (b) one point if they take their medication within $\pm$15 to $\pm$30min of the prescribed time; (c) zero points if within $\pm$30min to $\pm\frac{12}{dose\ regimen}$ hours; and (d) -1 point if they forget to take their medication. By the end of each week, MoviPill highlights that week's game winner to all players and restarts the game for the following week. Figure 2 exemplifies the game's dynamics.

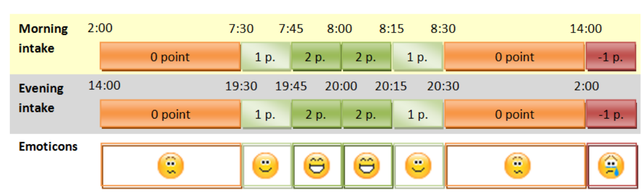

Figure 2. Example of points and emoticon assignments for a patient that takes two doses per day of a certain medication (8am/pm).

MoviPill aims to achieve positive changes in people's behavior towards medication compliance without depending on reminders. Therefore, the application fires a soft alarm 15 minutes *after* the drug's prescribed intake time in the case the user did not take it. Hence, the game players should try to remember to take their doses by themselves if they really want to win the competition. Otherwise, chances are that other competitors will remember to take their medication at the right time and thus win more points.

User Interface

The MoviPill smartphone interface has been originally designed for elders. Therefore special care has been devoted to its layout and interaction design. Buttons and dialogs are personalized with bigger fonts and higher color contrast, while touchscreen interaction is enabled without the need of using a pen stylus. The application primes simplicity by offering only two different screens: *Dose* and *Game*.

The *Dose* screen displays the date and time the medication was taken together with the time of the next intake and a progress bar informing how much time is left to the next dose (see Figure 3 left). The interface was designed to monitor intakes of a single medication to avoid collateral effects in our experimental validation. We plan on expanding the interface to handle multiple medications in the future.

The *Game* screen displays the status of the game. Special attention was dedicated to including *social competition* without violating the players' privacy. Hence, the data on this screen, which was shared with the other players, did not provide any information on the medication that each player was taking. Moreover, we used emoticons (see the bottom of Figure 2 and Figure 3, right) to represent how compliant participants were on each dose, without revealing the exact time of taking their medication. A social network was created with all the participants and social competition was implemented by ranking all players according to their score in the compliance game (see Figure 3 right).

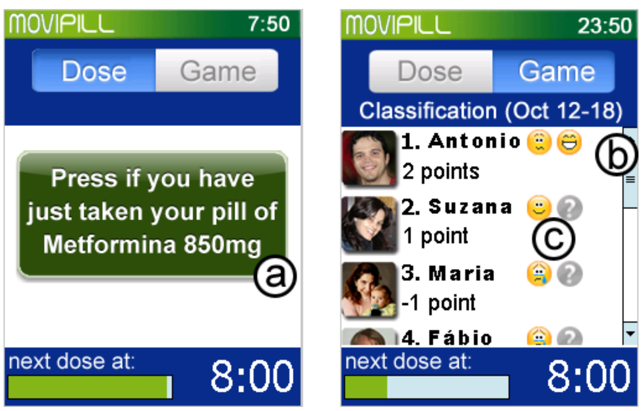

Figure 3. MoviPill's user interface: Dose screen on the left, showing the dose intake button that users shall press when they take their medication (a); Game screen on the right, presenting the ranking of players (b). The number of emoticons next to each participant's score corresponds to the number of doses prescribed per day (c). Emoticons represent how compliant players were with that dose (see Figure 2).

Two clinicians were contacted during the design phase. After trying the system, both of them presented positive feedback regarding the game dynamics and its persuasiveness towards increasing levels of medication compliance. Conversely, they were also concerned that some medications are prescribed to be taken after a meal and therefore the intake time cannot be fixed. In the initial evaluation of MoviPill, we did not take these cases into consideration.

EXPERIMENT DESIGN

Given that the technology proposed in this study was tested in domestic environments, we opted for a combination of research methods: interviews and a field study. In the 6-week field study, participants interacted with the *Dose* and *Game* versions of the MoviPill application for three weeks each –similar to the experimental design of Chiu et al. [10]. The interviews were intertwined with the deployment and helped to assess the drug compliance habits and the reaction to the introduction of the new technology.

Participants

From an initial pool of 20 participants, 18 (m: 9, f: 9) completed all steps required during the 6-week user study (two dropped out in the first week due to personal reasons). The median and mean age of the recruited participants was 67.5 years ($s = 4.19$, min: 59, max: 75).

Sampling. A randomized sampling methodology was used and participants were assessed by a Spanish social foundation service (FASS) [1]. Participants were interviewed over the phone to assess their willingness to participate in the trial. Requirements for being recruited included: (1) being a mobile phone user, (2) taking at least one medication twice per day that (3) does not require to be taken after a meal. Cognitive decline was not measured and therefore the randomized sampling shall have selected subjects with different levels of age-related diseases (in order to prevent a confounding effect from this decision, we opted for a *crossover* design, as described in Section "**Procedure**"). Participants received 40 Euro (about 59 USD) for their participation in the experiment and they *did not* receive any monetary incentive for winning the weekly competitions of the MoviPill game.

Social life. All the participants were retired. Thirty-nine percent lived with a husband or spouse, while the rest lived alone. The participants had a median of 3 siblings. Ten participants (55%) did not have any experience with computers, while 4 (22%) had an intermediary knowledge, and the remaining 4 (22%) were advanced users. The majority of the subjects used to go out for shopping and entertainment a few times per week. The subjects did not know each other.

Medication compliance. The majority of the participants (12 or 67%) reported that they did not typically forget to take their medications; four participants (22%) forgot rarely, and 2 participants (11%) forgot sometimes. Only 2 participants (11%) reported being frequently unsure of whether they had already taken their medication or not, 7 participants (39%) reported forgetting sometimes and the remaining 9 participants (50%) reported never forgetting. Concerning the strategy that participants used to remember to take their medications, 3 participants (17%) reported using some form of spatial arrangements of the pillboxes, while the majority (14 or 78%) remembered because of their daily routines. Only one participant (5%) declared taking advantage of family members to remember to take her medications.

Technology in the household. All participants had a landline in their home and owned a mobile phone. Their use of the mobile was basic: they use it to be in contact with family members when running errands and for emergency situations. Ten participants (or 55%) did not have a computer in their house, and therefore defined themselves as being inexperienced with computers. The remaining 8 participants had a PC or laptop in their premises: 4 (or 22%) defined themselves as "beginners", while the remaining 4 defined themselves as "intermediate" users.

Apparatus

Each participant was assigned a HTC smartphone (model P3300, with its charger) with the MoviPill application and a pillbox equipped with a sensor (maker AARDEX model MEMS 6 [2]). The smartphone was able to transmit data over the GSM cellular network. Medication intake information was entered by participants via the *Dose* interface (previously explained) in the MoviPill application –running on the mobile device– and transmitted in real time to the remote server. Whenever the Internet connection was lost, MoviPill kept a local log of the drug intake and attempted to re-establish the connection every 10 seconds. When one of these attempts succeeded, MoviPill would send the previously saved drug intake data to the server. In addition, MoviPill refreshed the game status every 5 minutes in order to ensure that the data presented was up-to-date. The battery life allowed the user to keep his/her phone unplugged for several hours. The pillbox recorded the intake information independently from the phone and these logs were used as an independent measure of medication compliance as explained in the next section. Figure 4 presents a typical setup of the apparatus.

Figure 4. A typical setup of the apparatus (subject 15): (a) HTC P3300 smartphone running MoviPill; (b) MEMS pillbox containing the medication of the participant, the label on the box reported the regimen information; (c) other medications that were not part of the study; (d) instructions guide of MoviPill; (e) charger of the participant's main phone; (f) charger of the smartphone.

Procedure

We met participants at the beginning of August 2009 for the deployment. We scheduled a face to face meeting in each of the subject's home to conduct the initial interview, deliver the apparatus and train the subjects on using MoviPill. During the initial meeting, we explained the mechanics of the game, supervised each participant during the initial interactions with the application, and helped participants transfer their medication into the MEMS pillbox. For this study, we asked them to choose one – not life threatening, *e.g.,* prescribed for pain, attention, *etc.* – medication that they had to take twice per day so that each participant had the same chances of winning points. We explained to the participants that they had to continue taking their other medications using their usual routines. Furthermore, we personalized MoviPill with a digital portrait of each user and entered the name of the medication that they were taking (see Figure 3) and the correct regimen information. We left their home once we felt that each subject was confident enough to operate the application alone and understood all the aspects of the experiment. MoviPill was disabled in all the phones and was only automatically initialized at midnight of the first week of the user study.

Two intervention methods were evaluated in the 6-week user study: Button and Game. On the Button treatment, subjects used the smartphone to register each drug intake by pressing a single button on the screen (equivalent to the button shown in Figure 3 left, but on a blank screen). In this treatment, participants had to trust their own methods to remember when to take their medication. In the Game treatment, subjects also used the smartphone to register each drug intake (see Figure 3 left), but they also had a "Game" button on the screen that allowed them to view the weekly ranking – by compliance – of all the participants in the game and their daily drug intake status. In this treatment, the application also played a reminder alarm 15 minutes *after* the set intake time for each dose and only in the case that the participant did not take that dose, *i.e.,* didn't press the drug intake button (see Section "**Game Dynamics**" for the reasons why we opted for the delayed alarm in MoviPill). In case the participant did not touch the device, the alarm stopped automatically 30 minutes *after* the set intake time (*i.e.,* the alarm would only play continuously for 15 minutes if no action was taken). The effects of this alarm in the Game treatment are presented in the "Results and Discussion" section.

The Button treatment was used instead of a control group (*e.g.,* electronic pillbox without the phone) because we wanted to guarantee that any experimental difference in compliance was due to the presence of the game, and not simply because of introducing new technology to the participants' day-to-day life. Similarly, we disabled the wireless connection between the electronic pillbox and the smartphone and we requested participants to press the drug intake button on the smartphone screen every time they took a dose because we wanted to allow *game cheating*. Furthermore, this cheating capability was not "advertised" to the participants to guarantee that if they would cheat, it was because they figured it out how to do so and decided to do it.

Given the size and nature of our sample, we decided to conduct a *crossover* experimental design to eliminate individual differences from the overall treatment effect, thus enhancing the statistical power of the results. Therefore, our sample was randomly divided in two groups of nine subjects, and each group was submitted to one of the treatments in the first three weeks (*i.e.,* users 1-9: Game; users 10-18: Button) and to the other treatment in the remaining three weeks (*i.e.,* users 1-9: Button; users 10-18: Game). We balanced the number of female participants in each experimental group.

At the end of the third week, *i.e.* during the crossing of the experimental modality of the two groups, a telephonic questionnaire was deployed to the participants in order to collect their self-reported impressions of how the application helped them remember to take their medications. A similar set of questions was asked at the end of the experiment.

In order to ease comparison with previous work in the literature [36], we opted for measuring medication compliance using the data collected by the electronic pillboxes instead of the data collected by the MoviPill application. Actually, this is a standard non-invasive compliance measurement widely accepted in the literature [17]. However, four participants (users 1, 13, 15, and 17) opened the pillbox only once per day to extract the exact number of pills for the day and organize them with their additional medication. Furthermore, during the individual interviews conducted after the experiment, we noticed that users 11 and 14 did not use the pillbox when they had to go out, but only the smartphone: *"The pillbox is too big. Sometimes, I wanted to go out for a couple of hours and bring the system with me, but the pillbox was* *somewhat obtrusive.*" (participant 14). Hence, we used the data collected by MoviPill instead of the pillboxes only for these six users. We believe that this was an appropriate decision in order to comply with prior standards while also considering the subjects' most accurate drug intake time data.

Observed Variables

One independent variable –*Intervention Method*– was used to investigate the effects of the proposed social persuasive game to medication compliance, named treatments Button and Game. The most important dependent variables are described in Table 1.

Table 1. Main dependent variables logged by the MoviPill application

Variable	[Type*] Description
Drug intake delay	[I] How early/late –in seconds– each subject opened the electronic pillbox to take his/her medication every day according to the prescribed time.
Game access rate	[I] Number of times each subject pressed the game button when submitted to the Game treatment divided by the number of days.
Entertainment level	[O] How entertaining subjects thought it was to use the phone in treatments Button and Game (1: very boring; 5: very entertaining).
Ease of use	[O] Subjective measure of how easy subjects thought it was to use the phone in treatments Button and Game (1: very difficult; 5: very easy).
Win effort	[D] Subjects' attempt to win the game (Yes/No).
Social curiosity	[D] Subjects' interest in getting to know more about the competitors in the game (Yes/No).
Game interest	[D] Subjects' interest in playing the game *after* the end of the experiment (Yes/No).
Subjective prescription adherence improvement	[D] Subjects' perception of the treatments' influence (Button *vs.* Game) to help them remember to take their medication (Yes/No).
Subjective regimen adherence improvement	[D] Subjects' perception of the treatments' influence (Button *vs.* Game) to help them remember to take their medication at the prescribed time (Yes/No).

* I: interval; O: ordinal; D: dichotomous.

Statistical Analysis

A nonparametric analysis was conducted because most continuous variables did not follow the normal distribution and, when they did, their variances were not homogenous. Associations between dichotomous variables were assessed using the Chi-square test and correlations between ordinal/interval variables were assessed using the Spearman's Rho test. Given that a crossover design was conducted, drug intake delays and prescription adherence could be paired by treatment and a Wilcoxon signed rank sum test was used to check differences between treatments' distributions. Similarly, subjective drug intake delay improvement and subjective prescription adherence improvement could be paired by treatment and a McNemar test was performed. The McNemar test was also used to verify differences between number of doses taken within the alarm zone (15 to 30 minutes after the prescribed time) paired by treatment. The level of significance was taken as $p < .05$. These decisions follow standardization methods proposed in the literature [34].

RESULTS AND DISCUSSION

This section discuss the main results obtained with the experiment that address the research questions previously stated. First, we present a few interesting findings that are relevant to interpret the main results, followed by those that contribute to the evaluation of our hypothesis.

The older the participants were, the more non-compliant they were; but not when using the game. Although the standard deviation of age was rather small ($s = 4.19$), we looked for a correlation between the *age* and *median drug intake delay* variables. However, such a correlation could not be verified in neither the Game ($N = 18, \rho = .039, p = .879$) nor the Button ($\rho = .05, p = .844$) treatments. On the other hand, a strong negative correlation was identified between the *age* and *prescription adherence* variables when submitted to the Button treatment ($\rho = -.552, p = .018$). This could be an evidence that the older the subject was, the harder it was for him/her to remember to take the medication. Conversely, when participants were playing the game this correlation was not significant ($\rho = -.077, p = .761$), which could indicate that MoviPill alleviated age-related memory issues.

Prescribed drug intake time did not directly influence medication compliance. One could argue that doses that took place very early or very late in the day may have lead to different levels of compliance. However, no correlation between the *prescribed drug intake time* and the *median drug intake delay* variables could be identified ($N = 18, \rho = -.160, p = .525$ in Game; $\rho = .154, p = .541$ in Button). Similarly, the prescribed drug intake time was not correlated with the participants' prescription adherence in either treatment ($\rho = -.128, p = .612$ in Button; $\rho = -.365, p = .137$ in Game). These results could reflect that shifts in the prescribed time of drug intake are caused by the patient's lifestyle and do not contribute to different levels of medication adherence.

Playing the game was as easy as pressing the button. No significant difference was found between *ease of use* in the Button and Game treatments (Button: $\tilde{x} = 5, iqr = 1$, Game: $\tilde{x} = 4.5, iqr = 1$; $N = 18, Z = -1.823, p = .068$). Additionally, ease of use seemed to be closely related to the perceived level of entertainment (Button: $\tilde{x} = 4, iqr = 0$, Game: $\tilde{x} = 4, iqr = 1.75$), given that these variables revealed a strong positive correlation ($\rho = .554, p = .017$). This observation is consistent with the main principles of usability, as users tend to lose interest in applications they do not understand how to use. Moreover, the application's ease of use and access increased MoviPill's persuasive potential according to Fogg's principles of convenience and mobile simplicity [20]. Note that our sample includes only subjects that had a personal mobile phone and therefore the perceived ease of use could have been lower if we had considered elders with no experience with mobile phones.

The participants' intention to win the game and the number of times they pressed the Game button were two good indicators of whether they enjoyed playing it. A strong correlation was found between the *win effort* and *entertainment level* variables ($N = 18, \rho = .808, p < .001$), and between *game access rate* and *entertainment level* ($\rho = .658, p = .003$). Furthermore, *game access rate* and *self reported intention to win the competition* revealed a strong positive correlation ($\rho = .561, p = .015$), which is indicative of a good connection between the participants' opinions and their actual behavior during the experiment. These results point to an expected user behavior: the more one likes a game, the more attention (s)he devotes to it.

Social competition was present, but not peer competition. Only two participants (11%) thought they might know some-one in the competition while the remaining 16 participants were certain that they did not know any of the competitors. Nonetheless, 10 participants (56%) reported trying to win the game, which shows that despite not knowing the competitors, they were still engaged in being the best player.

Validation of RQ1

Can a mobile social persuasive game help elders adhere to their medication prescription?

Before the experiment, participants considered themselves compliant with their medication prescription. Results confirm they were. From a total of 1512 doses over the 6 week period, only 15 doses were not taken in the Button treatment (1%). However, when participants were playing the game, this small level of non-compliance was reduced by 60% (six missing doses). Moreover, only one out of 18 subjects was more compliant when submitted to the Button treatment than to the Game treatment, which is a good indicator of why a significant difference could be found between the medians of prescription adherence in both treatments ($N = 18, Z = -2.263, p = .024$). As expected, participants could not clearly perceive this subtle difference in their compliance behavior, and therefore no difference could be found on subjective prescription adherence improvement in the Game and Button treatments ($N = 18, p = .219$). Still, the number of subjects that noticed an improvement in their compliance behavior was much stronger in the Game than in the Button treatment (seven *vs.* three). It is reasonable to assume that samples with non-compliant patients might highlight this difference even more. From these results, we corroborate RQ1.

Validation of RQ2

Can a mobile social persuasive game help elders adhere to their medication regimen?

Participants were highly adherent to regimen as well, taking their medication with a shift of ± 25 minutes on average of the prescribed drug intake time ($\bar{x} = 1471$s in Button; $\bar{x} = 731$s in Game). Due to the presence of outliers, the median drug intake delay better characterizes the data, revealing a 43% improvement when participants played the game ($\tilde{x} = 240$s *vs.* $\tilde{x} = 420$s; $N = 720, Z = -8.944, p < .001$). Figure 5 compares median and average drug intake delays over time for each treatment.

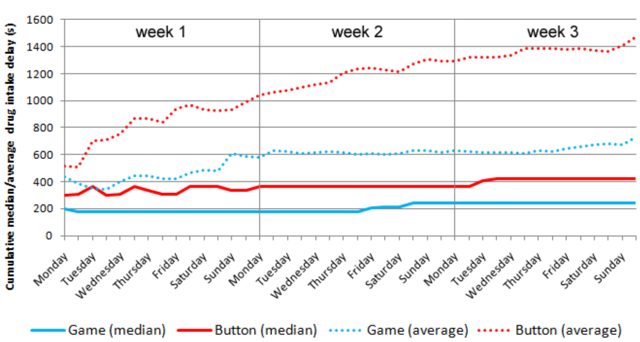

Figure 5. Comparison of median and average drug intake delays over time in the Game and Button treatments.

Although a 43% improvement in regimen adherence is a significant result, we were interested in understanding the role of personal preferences on the results. In the last questionnaire, participants were given a list of possible rewards for medication compliance (*i.e.,* monetary incentives/discounts, family photo, favorite song, or playing a game). Seven participants considered games to be the least interesting reward (users 4, 7, 8, 9, 12, 15 and 17). The improvement in regimen adherence in the Game treatment for the *rest* of participants – excluding the seven that were not interested in games – was of 56% ($\tilde{x} = 180$s *vs.* $\tilde{x} = 405$s; $N = 437, Z = -10.068, p < .001$). This finding reveals the importance of applying persuasive technologies according to the user's profile and context.

Another way to analyze this data is to consider each participant's median drug intake time as a single output and compare the median of the medians between treatments. Again, a significant difference could be found between regimen adherence in the Game and Button treatments ($N = 18, Z = -2.250, p = .024$). This last analysis proves that improvement in regimen adherence could be observed for *most* of the users. Therefore, we corroborate RQ2.

Reminders vs. Social Competition

Previous work has already reported the effects of using reminders (*e.g.*, an acoustic alarm played after a time interval) to improve medication compliance [23, 25, 38, 39]. Particularly, Chiu *et al.* investigated the effects of reminders as part of a game experience [10], although not in the medication adherence domain. Next, we discuss the effects of introducing the 15-minute delayed alarm in the Game treatment but not in the Button treatment, and the consequences to the RQ1 and RQ2 validations presented before.

Impact on regimen adherence (remembering to take doses at the prescribed time). From the 750 doses taken by the 18 subjects when submitted to the Game treatment, 73 (10%) doses were taken during the time that the alarm was playing (alarm zone) while the remaining 677 (90%) doses were taken without any alarm being played. Interestingly, in the same alarm zone but in the Button treatment (when actually no alarm was played), *more* doses were taken: 91 out of 741 doses (12%). Anyway, this apparent difference was not significant ($N = 634, \chi = .764, p = .382$), which confirms that *the reminder had no effect on the subjects regimen adherence*, and hence, supports the validation of RQ2.

Impact on prescription adherence (remembering to take all doses). We acknowledge that no strong conclusions can be drawn here by just looking at the quantitative results that we have. However, six subjects (33%) reported in the questionnaire that the alarm reminded them only once or twice to take the medication and the remaining 12 subjects (66%) answered that the alarm never helped them. These findings point to the conclusion that RQ1 is also valid, but we plan to investigate the potential impact of the reminder on adherence in future work.

Shortcomings of the study

Our experiment lacks a third treatment in which only system reminders would be present, thus allowing the comparison between game and reminders alone. We did not focus on this comparison as previous work has already concluded that users can perceive system reminders negatively [39].

Also, the participants recruited for the study happened to be extremely disciplined in taking their medications. Yet, we could measure an improvement in their regimen adherence. Previous work confirms that elders tend to consider themselves compliant when first asked, but after the study they realize that they are not [25]. Therefore, it is yet unknown how to recruit non-compliant elders if not by selecting them at random and expecting a certain average of non-compliant elders in the sample. We recruited our participants following this standard procedure through a social service foundation (FASS) that had more than 100,000 elders subscribed in the state of Andalucia - Spain. Indeed, it was only after the study that we realized that the elders were very compliant. Nonetheless, we would like to emphasize that the purpose of the study was to investigate whether social competition can improve medication compliance when compared to usual care, which was actually the case. We expect longitudinal studies conducted with samples from different regions/cultures to better exemplify such an improvement.

Summary

The validation of both research questions RQ1 and RQ2 confirms that social competition is an effective tool to improve both prescription and regimen adherence of independent elders living in a non-shared environment. Although we cannot directly extrapolate these results to peer competition applied in shared housing – another usual living setting for elders, we expect the observed positive effects of competition between strangers to be extended to friends, as long as the users involved have an interest to play with people they are familiar with. Furthermore, the results presented in this paper add to prior work, *e.g.,* the study on daily water intake conducted by Chiu *et al.* [10]. Our findings reveal that the users' intake behavior can be improved by means of a social game, even for an activity that is not biologically regulated by the human body (*i.e.,* taking medicines). This strategy also proved to be useful for regimen adherence (*i.e.*, a routine activity that happens at specific times), a dimension not evaluated in previous work on persuasive technologies.

IMPLICATIONS FOR DESIGN

The findings presented in this paper combined with qualitative research conducted *in situ* support a number of guidelines that might serve designers in better addressing computing challenges for elders. Next, we highlight the most relevant ones:

Different elders, different disabilities: The power of multimodal interaction. Even after our first pilot meeting with elders from an independent living community, we could not have predicted the range of motor and cognitive disabilities that we would face in the user study. For instance, two participants had strong vision impairments – one used a magnifying glass to read, but they were very precise when pressing the phone's buttons. Conversely, other participants had good vision, but their hands trembled when touching the phone's screen, thus leading to poor precision. In some cases, elders slid their finger outside the button area while pressing a button, thus involuntarily preventing the system to catch this event. Hence, we recommend using multimodal interaction (both input and output) when designing applications for the elderly, *e.g.,* combining two different sounds (event executed *vs.* not executed) with high visual contrast between button's states (up and down).

Use Walk-through and Think Aloud to catch low visibility of alternative task flows. It is well known that HCI researchers should never assume that users have the basic knowledge to interact with any given interface, as it is illustrated by an interesting phenomenon that we encountered in our study. During the deployment of the study, when we asked participants how they knew there were more than four competitors in the game by just looking at the players list, some never mentioned the scrollbar. For them, the visual clue was that the fourth player was partially revealed, thus indicating more content (see Figure 3). This simple fact led us to realize that the common method of teaching first and asking later prevents the detection of misconceptions between the application's conceptual model and the user's mental model. Actually, the inverse of the method seems quite more interesting, specially in the early stages of prototyping. Indeed, the use of Walk-through and Think Aloud techniques proved to be efficient in our study. These methods revealed what the elders understood about the interface objects and how they used them to accomplish the tasks. After presenting the elders some alternative paths to solve the same task and observing them later on (*e.g.,* checking logs, questions in interviews/questionnaires), it was easier to identify what was their preference between different task flows.

Bigger fonts and more explanatory texts are not necessarily better: Consistency plays an important role. Generally, the size of texts, buttons and other interface elements should be increased when designing applications for older users. Also, tasks are usually described in a more verbose way to ease their comprehension. However, we noticed a case where external consistency was more important. During our first visit to the elders, some of them could not perceive the drug intake button on the center of the phone screen (see left screen in Figure 3). After they were told the big green button on the center of the screen with an explanatory sentence on it was the button we were referring to, the typical answer was: *"Oh! So this is a button?"* Conversely, this reaction never occurred when we asked participants to press the game and the dose buttons on the top of the screen, which are about one fourth of the size and with a single descriptive keyword on it. This experience reinforced our conviction regarding the importance of *matching external consistency with the elders' expectations.*

Elders do engage in competitions: Prevent game cheating. In the first visit to participants, two of them mentioned the possibility of pressing the drug intake button on the phone at the appropriate time while taking the pill later on just to get more points. Indeed, this pattern could be observed in the experiment: seven subjects had at least once opened the pillbox more than one hour *after* they had actually pressed the button on the phone. This reveals how engaged elders were to win the game. Furthermore, from the responses obtained with the final questionnaire, we noticed that caregivers had also an impact on competition engagement: *"I was trying to win the game to look good to my grand-daughter. Actually, there was one night when she reminded me to take my medication because I was playing the game."* (participant 17). Therefore, cheating prevention is of major importance in the success of game-based applications, even when they have been designed specifically for the elderly.

Know your audience: Choosing the "right" competitors motivates the elders. After analyzing the answers of the final questionnaire, we observed that the participants' interest to win the game was associated to the players they were competing against. We interpret the strong association identified between these variables ($N = 17, \phi = .528, p = .03$) as follows: subjects were engaged to win the competition when they had a preference to play against unknown people, as it was the case in the study.

Different rewards for different users. Personalization is key not just to address different age-related problems, but also to understand distinct profiles and choose the most adequate persuasive technique accordingly. In the last questionnaire, participants ranked a list of four symbolic rewards for good medication compliance behavior: earning points to win a game, accumulating points to get discounts in stores or their phone bill, being surprised with a photo from a family member (*e.g.,* grandson), or hearing one of their favorite songs. Surprisingly, the game related reward was listed last by 7 out of 17 participants that ranked the list of rewards (41%). As shown before, when these participants were removed from the data analysis, the improvement in regimen adherence increased from 43% to 56%, thus highlighting the importance of creating persuasive applications with multiple persuasive techniques to better address individual preferences. After analyzing the rankings provided by the participants, there was no significant difference between the game-photo, game-song and photo-song pairs. Interestingly, monetary incentives were the preferred reward when compared to all the others, being the first choice of 13 subjects out of 18 (72%). This is in accordance with a recent report about the main reason for non-compliance [19] and in discordance with latest findings in behavioral economy where monetary incentives have been shown to impair performance [6]. We plan to investigate the *actual* impact of different persuasive techniques, and their related incentive schemes, when compared to their *expected* impact as reported by participants.

Involve caregivers and family members in the study as extra supportive observers. HCI experts should approach elders and caregivers at the same time during field studies for at least two important reasons. Firstly, if the elder doesn't live alone, (s)he is not the only user of the healthcare system. Others might eventually have to interact with it, even if indirectly. Secondly, an extra observer *in situ* can provide invaluable qualitative feedback during and after the study, such as in the following example: *"He was already used to taking his medication regularly, but the game got him excited. Besides, he was the winner in the first week!"* (a female caregiver talking about her husband: participant 2). Furthermore, some caregivers called us when the elder was unsure about something related to the application. It is very important though to make sure caregivers understand that their role in the study is to only observe and never interfere on the elder's interaction with the system.

Privacy is key, but elders seem open to share personal information when it's reciprocal. Indeed, one of the principles of ethics in persuasive computing is that persuasive technologies revealing personal information about a user to a third party should be closely scrutinized for privacy concerns [7]. In our experiment, subjects rated in a 5-point Likert scale how comfortable they were with other participants knowing if they were adherent to their medication. Results revealed that they felt comfortable with that ($\tilde{x} = 4, iqr = 1$). Particularly, one participant mentioned that she saw no problem with this because the information sharing was reciprocal: *"I am comfortable with that. Everybody is sharing the same information as well."* (user 13). Nonetheless and for ethical reasons, we also made sure that everyone in the elders' household knew about the project and that the elders could leave the experiment anytime they wished to do so.

Consider the ecology in which technology will be deployed. During the field trial of MoviPill, we realized how the technology we introduced in the elderly's places was disrupting the practices they were used to. In one case, one of the subjects was sporadically using a clock before the deployment to remind himself to take a certain pill. During the deployment, he used the clock systematically to remember when to press the competition button (so to maximize the number of points). As another example, one of the elders was moving from right to left the boxes containing the different drugs that were inside a cabinet to remember whether she took them or not. As one of the drugs was used for the experiment, she moved it outside the cabinet and used MoviPill to check whether she had already taken that particular medication, thus mixing strategies. In short, each new technology is going to compete with other existing technologies already in use in a certain environment. Users might adapt, replace, and create practices around the new technology, but always in relation to pre-existing routines.

CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed and implemented a mobile phone-based social game called MoviPill that engages users to be more compliant in taking their daily medication. Results from a 6-week user study with 18 elders reveal that playing the game improved both compliance in remembering to take daily doses and accuracy in the drug intake time according to the prescribed time. With respect to the latter, the improvement was even higher when considering data from only those participants that had any interest in games, which reveals the importance of applying personalized persuasive technologies according to the user's profile and context. Another interesting finding was that a strong negative correlation between age and regimen adherence was not significant anymore when elders played the game, which could be an evidence that MoviPill helped alleviate age-related memory issues. The qualitative research conducted *in situ* also revealed a number of findings that are relevant in the design of mobile healthcare applications for the elderly, such as the importance of: providing multimodal interaction, matching external consistency with the elders' expectations, applying Walk-through and Think Aloud techniques to catch alternative task flows, involving caregivers in the user studies as extra observers, and identifying/controlling the key aspects that would make a game more persuasive. Future work will explore other types of persuasive techniques for elders in a mobile computing environment.

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