TensioBot: a chatbot assistant for self-managed in-house blood pressure checking

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Abstract: Hypertension is a chronic condition that can lead to serious health problems. Patients with High Blood Pressure (HBP) are often asked to have their BP checked at home. The traditional at-home procedure has some drawbacks, such as forgetting to check or write down the values, errors in transcribing the numbers, or the impossibility of immediately notifying medical staff of out-of-range BP values. To facilitate self-measurements by patients at home we devised *TensioBot*, a Telegram based chatbot. The bot sends patients reminders to check their BP, advice on good monitoring practices, measurement tracking, medical alerts and allows healthcare professionals to access up-to-date measurement information. TensioBot has been tested for two years in a randomized controlled trial with 112 patients (55 using the bot and 57 in the control group). We found that, although the bot group showed similar results in terms of adherence to the BP checking schedule, bot users scored better in terms of knowledge and skills on BP checking best practices. Participants rated the bot very positively, perceived it as useful and easy to use, and continued to use it after the intervention. Moreover, all data being equal, we describe some other benefits of using a chatbot for self-managed in-house BP control, both for patients and healthcare professionals and systems.

Keywords: hypertension, blood pressure, chatbots, mHealth

Highlights:

- A chatbot for Telegram was developed to help patients with hypertension to self-monitor their blood pressure,
- The bot improved knowledge on good practices related to blood pressure self-monitoring procedures in intervention patients (p=0.037).
- A majority of the patients, 85%, kept using the bot even after the experiment was over,
- Using a chatbot for self-managed blood pressure checking brings tracking and monitoring advantages for patients and doctors.

Declarations:

- **Funding**: Not applicable.
- **Conflicts of interest**: The authors declare that they have no conflict of interest.
- **Availability of data and material**: xls spreadsheet (raw data) and statistical analysis (R scripts) are available at https://github.com/juananpe/tensiobot-analysis/
- **Code availability**: The source code of TensioBot is published here under a GPLv3 open source license https://github.com/juananpe/TensioBot
- **Authors' contributions**: All authors contributed to the study conception and design. The principal investigator of the project is LE. Project design and data collection were performed by LE and RS. Software design was performed by JR. Data analysis was performed by RS and JP. All authors read and approved the final manuscript.

- **Ethics approval**: The clinical trial "*Utilidad de una aplicación en dispositivo móvil (@TensioBot) para la automedida de la presión arterial*" received authorization from the Clinical Research Ethics Committee of the BioAraba Health Research Institute, with approval number/ID 2017-031 and PI LE.
- **Consent to participate:** Informed consent was obtained from all individual participants included in the study.
- **Consent for publication**: The participants have consented to the submission of this study to the journal.
- **Acknowledgments:** We thank Dr. Ruiz de Alegria and Dr. Yuste, from the School of Nursing of Vitoria-Gasteiz, for their support in the design of the project. We thank Dr. Alcalde head of the Nephrology Department of the Araba University Hospital, for his collaboration. We thank nurses Mrs. Merchan Mendo and Mrs. Gallego Robles for their collaboration in the data collection.

1. Introduction

The importance of hypertension (HTN) as a risk factor for cardiovascular diseases, which cause the highest mortality, is well known. In a meta-analysis with individual data from one million adults (Lewington et al., 2003), they found an association of Blood Pressure (BP) with stroke, ischemic heart disease, and other vascular diseases.-

According to the Global Burden of Disease Study, hypertension is the number one risk factor, responsible for the deaths of 10.8 million people worldwide in 2019, almost 20% of all deaths (Murray et al., 2020). The treatment of HTN has shown a benefit in reducing cardiovascular risk (Staessen et al., 2003). However, it is well known that only half of hypertensive patients have their numbers under control (Fryar et al., 2017). BP measurements taken outside the medical centre, either with automated devices (ambulatory BP monitoring -ABPM-) or home measurements taken by the patient at home (home BP monitoring -HBPM-) show a stronger association with cardiovascular disease risk than measurement by the doctor or nurse in the doctor's office (Muntner et al., 2019). Indeed, it has been shown that the use of telemonitoring of BP through home measurements can improve HTA control and reduce the numbers compared to conventional treatment (Duan et al., 2017). It is therefore of great interest to improve the BP control at home of hypertensive patients.

Patients with high BP are often asked to measure their BP values at home. To carry out this task, patients must fill in a table, manually, to record all data (date, time, systolic BP - top number-, diastolic BP - bottom number) and remember to bring the data record to the next medical appointment. Some problems arise from this procedure. For example, some patients forget to check their BP every day, or do not do so at the stipulated times. Other patients do not write down the correct values or forget to bring the data record to the doctor's appointment. In addition, the doctor and nurses do not know the current BP values until the day of the medical appointment. In addition, when patients bring their notes to their medical appointments, the doctor has to transcribe them all into a digital file. This is a time-consuming and error-prone task.

Here, we propose the development of *TensioBot*, a Telegram chatbot that can alleviate those problems. A chatbot is a computer program that can simulate conversations, acting as a human being. Our work aims at answering the following research questions:

RQ1) *Is it feasible to develop a chatbot that helps patients with high blood pressure to check their BP at home?*
RQ2) *If so, how effective is the TensioBot in terms of BP checking (number of successful measurements, number of missed measurements)?*
RQ3) *Does TensioBot improve knowledge on best practices related to self-managed BP measurement procedures?*
RQ4) *What are the advantages of using TensioBot to record BP measurements compared to the traditional method of writing them down on paper?*

We hypothesise that patients can use TensioBot without problems, because they are familiar with the instant messaging app Telegram (or alternatively, WhatsApp). Chatbots like TensioBot could ease the workload of an already overburdened medical system, while preventing errors and promoting more accurate and complete recording of patients' blood pressure values.

Our hypothesis has been tested and evaluated in a randomized controlled clinical trial with 112 patients (Section 3). We start by framing our work within the area of mHealth interventions.

1.1 Helping patients to control their BP: A review of mobile based solutions

There have been some attempts to use technology to solve the aforementioned problems and improve patient adherence to the BP monitoring procedure. An interesting study is that of Vargas et al., who found that SMS text messaging between physicians and patients was effective in aiding BP control, especially in racial minority populations, as two-way and personalized communication was achieved (Vargas et al., 2017). However, SMS messages are quite limited as they can not deliver multimedia content like videos, graphics or audio messages and, more importantly, can not be used for interacting with the patient. With the aim of overcoming these limitations, efforts have been directed in recent years to develop smartphone apps to support self-management of hypertension. In this line of work, Alessa et al. (2019) reviewed 186 mobile apps for BP self-management, and found that, in general, these apps support BP tracking and self-monitoring of medication-related data. While some of the apps allowed BP readings to be received automatically from the BP measuring device, in general, manual data entry was required.

Providing treatments through mobile apps is an interesting approach but the effort could be hindered by the difficulty to install the app and instruct the user about how to use the interface. These user-experience problems could be aggravated when the target audience of the app happens to be elderly people. That is the case for HTN patients. Our approach taps into using a familiar user-interface, Instant Messaging (IM) apps' interface, where all the user has to do is to chat with a chatbot. Chatbots for mobile health interventions are on the rise. They have been successfully used in different health areas to promote self-management of chronic pain (Chaix et al., 2020; Hauser-Ulrich et al., 2020), neurological disorders and psychiatric conditions (Vaidyam et al., 2019), like dementia (Cruz-Sandoval & Favela, 2017) or Alzheimer (Griol & Molina, 2015), nutritional-metabolic-disorders like obesity (Stephens et al., 2019) or diabetes (Cheng et al., 2018), and addictions like smoking (Calvaresi et al., 2019; Dubosson et al., 2017) or alcoholism (Elmasri & Maeder, 2016). However, as far as we know, mobile chatbots have not been used yet for helping patients with hypertension to track and monitor their BP.

Drawing on the potential and popularity of WeChat, an IM application hugely used in China with more than 1.17 billion users in Q4 2019, Li and colleagues (2019) describe an online intervention where patients with HTN meet in a chat group. Participants were periodically sent articles of health knowledge related to their condition, and offered targeted health advice in a chat. As with TensioBot, the aim is to leverage the popularity of IM systems to improve BP and self-management behavior in patients, early detecting HTN complications. Yet, our strategy differs from Li et al's. Instead of resorting to doctors or researchers to chat with the patients, we target a fully automated intervention using chatbots as a proxy. As far as we know, there is no other study in the realm of self-checked BP that followed this chatbot approach before.

2. Methods

2.1 Overview

A 2-arm, randomized, controlled trial of an intervention based on the TensioBot mobile application was carried out over 2 years (2018-2020). This clinical trial has been approved by the Clinical Research Ethics Committee of the BioAraba Health Research Institute, with approval number/ID 2017-031 and PI LE.

2.2 Subjects and recruitment

We recruited 112 patients that needed to check their BP daily, twice, 7 days before the medical appointment. Half of them were randomly assigned to the bot intervention group and the other to the control group. Near 48% of all the patients had some kind of chronic kidney disease. Table 1 summarizes the characteristics of participants.

Table 1. Description of participants.

	Total	Chatbot	Paper
Group: Participants	112	55	57
Sex: Men	65	32	33
Women	47	23	24
Employment situation: Active	82	44	38
Disabled	4	2	2
Retired	20	6	14
Unemployed	6	3	3
Educational level: Basic studies	28	9	19
Medium studies	25	13	12
Vocational Training	35	17	18
University graduates	14	8	6
Not specified	10	8	2
Diagnosis: Primary HTN	45	23	22
Secondary HTN	54	28	26
HTN suspicion	13	4	9
Diabetes Mellitus: No	94	47	47
Yes	17	8	9
NA	1		1
Cardiovascular disease: No	103	49	54
Yes	9	6	3
Chronic Kidney Disease: No	57 54	30	27
Yes	1	25	29
NA			1
Age: Min.	21.00	21.0	31.0
1st Qu.	42.75	40.0	45.0
Median	52.00	49.0	55.0
Mean	52.08	50.2	53.89
3rd Qu.	61.25	58.0	63.0
Max.	87.00	87.0	80

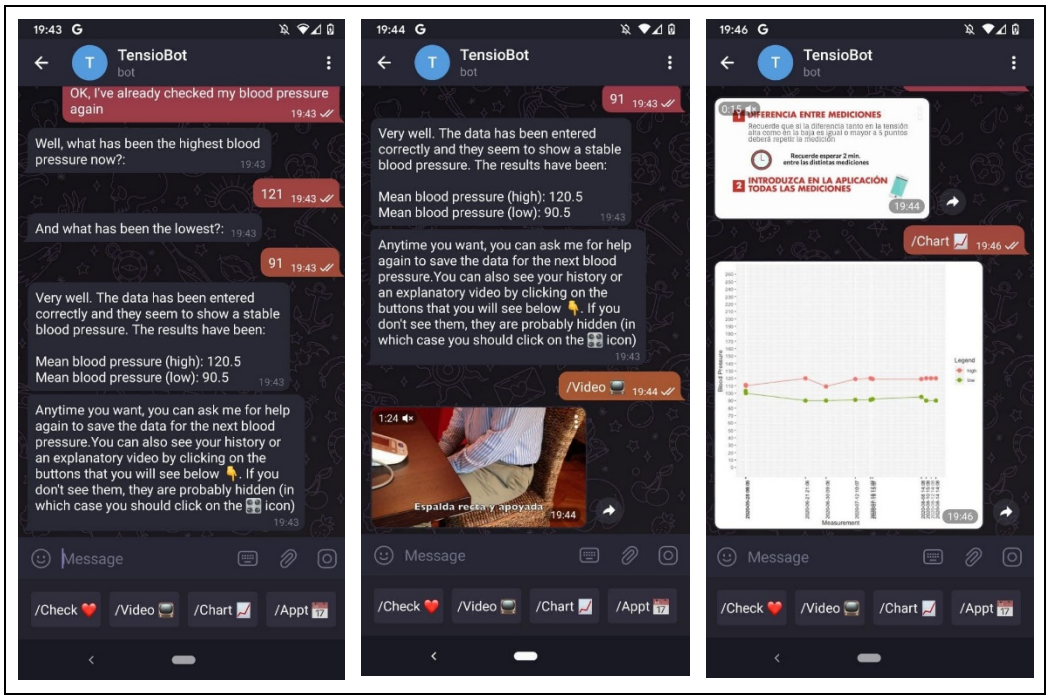

Figure 1: TensioBot is a Telegram based chatbot that can be used from smartphones or desktop computers. The user can type any available command or answer to chatbot's questions. It is also possible to click on any button shown by the bot. From left to right: the user informs the bot about BP numbers, then clicks on /Video command and finally on /Chart button.

2.2.1 Inclusion criteria

- Patients attending the Nephrology outpatient clinic (CCEE) of the Araba University Hospital (HUA), with a diagnosis of hypertension or suspected primary or secondary hypertension. They must be at least 18 years old and have been previously instructed to perform BP checks at home with an information sheet available at the outpatient hospital.
- Patients must have an approved and calibrated a tensiometer and a smartphone with Internet connection at home, and sufficient ability to send messages via WhatsApp or Telegram.
- Patients agreed to participate in the study by signing an informed consent form.

2.2.2 Exclusion criteria

Patients were excluded on the basis of these criteria:

- Previous diagnosis of severe psychiatric disorder.
- Severe illness suggesting a life expectancy of less than 6 months or high probability of needing haemodialysis or transplantation in less than 3 months.
- Severe clotting disorders that can cause bruising if frequent BP measurements are performed.
- Motor or visual disability that makes it difficult to perform self-measurements at home.

2.3 TensioBot intervention description

Patients in the intervention group were asked to contact a chatbot called TensioBot on Telegram. We will start describing Telegram and then define the TensioBot commands. Figure 1 shows some screenshots of a session with TensioBot.

2.3.1 Telegram platform

Telegram is a popular IM application -more than 500 million active users-. In 2014, Telegram was the first IM provider to introduce the ability to develop and interact with chatbots. Chatbots can respond to text or voice commands from the user, display links, images or videos. Users can start a conversation with a bot by searching for its name as if it were a human contact in their contact list. Users can also click on a direct link to automatically open a conversation with a specific bot.

2.3.2 How TensioBot works

One week before the doctor's appointment, TensioBot asks patients to measure their BP twice a day, usually once in the morning and once in the evening (the alert times can be edited at any time). When the user receives the alert, he/she should proceed to use the tensiometer and write down on a paper the BP values (highest, lowest) answering the questions posed by the chatbot. It then informs patients to wait two minutes and proceed again for a second measurement. After the second set of measurements, TensioBot shows a line chart with the entire BP history. If after the two-minute waiting period the patient enters a BP value higher than 5 mmHg compared to the values of the first measurement, the bot prompts the patient to perform a third measurement 2 minutes later.

If a patient enters a BP value that is outside normal levels, the bot asks for confirmation. If it was a typing error by the user, it asks the patient to check the measurement again, and if the number was indeed correctly introduced, the bot notifies the doctor. All the pressure-numbers checked during the last seven days are reflected in a line chart that shows the evolution of the data (third picture in Fig. 1).

TensioBot also offers an option to display a helpful video on good BP measurement practices showing tips on how and when to take it, how to adjust the tensiometer, how to adjust the body position, etc. Once a day the bot also sends a message with other tips related to good BP measurement practices. Finally, the bot offers a command to remind the patient of the scheduled time for the next medical appointment, allowing the patient to change or cancel it directly through a conversation with the chatbot.

2.3.4 Administration commands

All of the above functions are available to any regular user (patients), but TensioBot also aims to help the physician with the management of those patients by offering a couple of administration commands, one for downloading a calc sheet with all the blood pressures for each patient and day and another for showing just the data for a specific patient (passed as argument to the command). Table 2 summarizes all the available commands.

Table 2. List and description of available commands in TensioBot. Some of them are only available for the doctor or nurse.

Command	Description	Role
/check	Main command, used for starting the procedure of blood pressure measuring	Patient
/appt	Allows to change the date and hour of the medical appointment or to cancel it	Patient
/chart	Shows a line chart of historical BP measurements	Patient
/change	Schedule alerts or cancel any of the two daily alerts or both	Patient
/video	Shows a short video about how to	Patient
/cancel	Cancel any ongoing command	Patient
/patients	Shows a list of all the patients (userID, username, date created, appointment date) and downloads an XLS file with all that data	Doctor / Nurse
/query	Takes UserID as argument and shows username, date created and appointment date of an specific UserID, and downloads an XLS file with data: dates, time, systolic and diastolic BP in mmHg.	Doctor / Nurse

2.4 Protocol

Each control patient attending their first medical appointment receives a written procedure on how to self-monitor their BP. The nurse assesses the patients' knowledge and skills on BP self-monitoring using a checklist and ensures that the patient knows when their next medical appointment is and when to perform BP measurements with a Holter device. For patients in the intervention group, the procedure is quite similar, except that they do not receive the the information document on the procedure.In this case, the nurse also helps the user to download and install the Telegram app, if the patient does not already have it installed, and start using TensioBot, registering the user with the bot.

At the second visit, patients in both groups (control and intervention) undergo a knowledge and skills check of the BP self-monitoring procedure. We compare the results between the groups. Besides, we statistically analyze patient adherence with regard to the number of correct BP checks in both groups and the results of a survey administered to the intervention group after the second medical visit.

3. Results

3.1 Knowledge and skills about BP checking

We obtained 88 cases for patients who completed both visits. Of these, we eliminated two cases that had a 100% checklist score during their first visit (and therefore their scores could not improve at the second visit).

We wanted to analyze the results of the checklist in relation to patients' knowledge and skills regarding home BP measurement technique. For each question answered, we gave a score of 1 for those answered correctly and a score of 0 for those answered incorrectly. We summed all the questions and divided by the maximum value, expressing the final value as a percentage

Then we obtained two columns, one representing the knowledge gain for each set of control patients and a similar one for the set of intervention patients. We wanted to know if the differences in knowledge gains between the two groups were significant, so we applied a t-test, obtaining a t= 2.1159, df= 82.34, p-value= 0.03737, 95 percent confidence interval (0.3915, 12.679) and mean in the Bot group= 24.126, mean in the control group=17.591.
The p-value associated with the test is 0.0374, so we can reject the null hypothesis ($H0$) of no difference between the (true) mean, suggesting that the difference in acquired knowledge of both groups is significant (favouring patients from the bot group).

3.2 Effectiveness of TensioBot with regard to the BP checking in-site

In the second visit, a nurse helped each patient to put on a Holter device (ABPM) to check BP during 24 hours, and we discarded measurements during sleep to calculate the daytime means of systolic and diastolic BP (it is well known that BP values are lower during sleep). Considering the Holter values as the gold standard, we contrasted them with the BP checking values of the control and intervention groups (mean difference, for systolic and diastolic values). We applied a two-sample t-test to the difference of the means t =0.956, df= 73, p-value= 0.342 (Holter systolic BP vs. Bot systolic BP vs. control systolic BP). 95 percent confidence interval (-2.343, 6.667) sample estimates, mean in the intervention group -0.338, mean in the control group -2.500. There was a smaller difference for the TensioBot group, but not significant (Fig. 2).

Applying the same procedure for difference in diastolic BP means, two sample t-test t= 0.12959, df= 73, p-value= 0.8972. 95 percent confidence interval (-2.856, 3.253) sample estimates, mean in the intervention group -1.879, mean in the control group -2.078. Again, there was a smaller difference for the TensioBot group, but not significant. The difference and scattering of values can be better seen on Fig. 3 and Fig. 4.

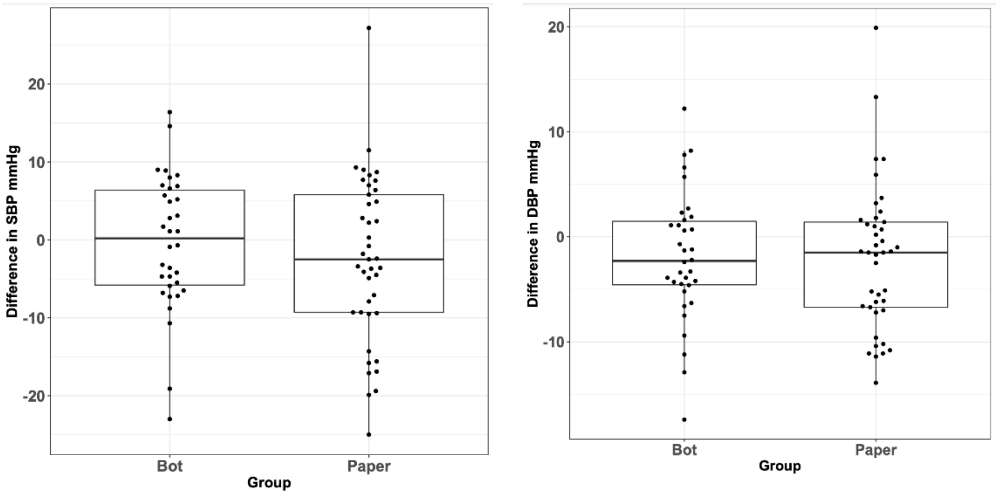

Figure 2 shows a boxplot with the differences (in mmHg) between the mean diurnal systolic (left) and diastolic (right) BP values with a Holter device (ABPM) and the mean self-managed systolic BP values at home (HBPM), for the intervention and control groups. We can see a more scattered boxplot for the control group, and a negative difference (in contrast to a difference close to 0 in the bot group), but again the difference is not significant.

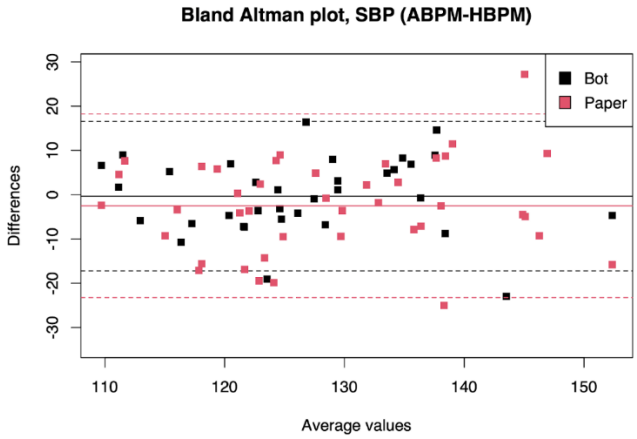

Figure 3, a Bland Altman chart, shows the mean difference between Holter values and self-managed systolic BP checks on the Y axis and the mean of both values on the X axis, colored by control and intervention groups. We can see three outliers, two for the control group and one for the bot group.

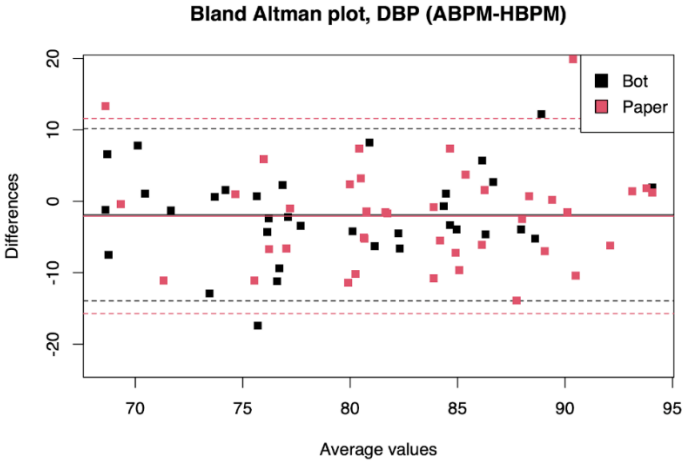

Fig. 4 shows a similar chart, focusing on diastolic BP. The results are quite similar, but with less variation because the diastolic values are lower than the systolic ones.

3.3 Results of the satisfaction survey administered to TensioBot users

There were 4 questions in the survey, answered by n= 40 patients from the intervention group: 1) "*Do you think that TensioBot is easy to use?*"; 2) "*Do you think that TensioBot is useful to help you better record your blood pressure values at home?*"; 3) "*How do you prefer to register your TA?"* and 4) *"Have you stopped using TensioBot?*"

1) *Do you think that TensioBot is easy to use?*
92.5% of those surveyed patients think it is quite easy or very easy to use. Yet, there were 3 patients that thought that it was quite difficult.
Very easy n= 23, Pretty easy n= 14, Quite difficult n= 3.

2) *Do you think that TensioBot is useful to help you better record your BP values at home?*
72.5% of respondents think it is very useful to use / All respondents think it is quite useful or very useful.
Very useful n= 29. Quite useful n= 11

3) *How do you prefer to register your BP?*
92.5% indicate that they prefer to register their BP at home using TensioBot instead of doing the registration on paper.
Prefer to use the bot n= 37
Prefer to write the numbers down on a paper n= 3 (despite the fact that some of these 3 people answered that the bot is very easy to use and very useful in the previous questions).

4) *Have you stopped using TensioBot?*
Only 6 people (15%) stopped using TensioBot. Among the reasons given are difficulties in using a mobile phone.

4. Discussion

With the data at hand, we are now in a good position to answer our original research questions.

RQ1) *Is it feasible to develop a chatbot that helps patients with high BP to check their BP at home?*

More than 55 patients (mean age= 50.2) successfully participated in this experiment and a large majority (92%) stated that the bot was easy to use and useful (72.5%). Among the survey respondents, 85% continued to use the bot even after the experiment was over. Considering that patients with HTN are, in general, not young people (including in our study patients as old as 80 years of age), where this kind of smartphone-based intervention might be less accepted, these results pave the way for using chatbots for assisting in self-managed BP monitoring procedures at home, easing the burden on healthcare system, which are overwhelmed by this and other procedures, specially in our current pandemic context. This finding alignes with the current positive literature on how to leverage chatbots for healthcare interventions (Gabarron et al., 2020). As far as we know this is the first time that a chatbot is used to help in self-managed BP checking procedures.

RQ2) *If so, how effective is the TensioBot in terms of BP checking (number of successful measurements, number of missed measurements)?*

We have found that the differences in both groups (intervention and control) between their BP values at home (HBPM) and those obtained using a Holter device (ABPM) were not significantly different. Thus, this means that chatbot users are just as good at checking their BP as regular users (using paper and pencil). But what about our initial hypothesis that chatbot reminders might improve treatment adherence? The data show that there is no significant difference in the number of BP checkings between the Bot and the Paper group (mean= 12.0 and 13.4, respectively, t-test t= 1.61, df= 80, p-value= 0.109). Therefore, both methods are equivalent in terms of treatment adherence.
This contrasts with previous work in which the application of behaviour change techniques for health improvement using chatbots seemed to obtain better results than ours (Pereira & Díaz, 2019).
However, both methods being equal in terms of treatment adherence, chatbots offer many other advantages over the usual pen-and-pencil way of BP tracking, as we will see in the following RQs.

RQ3) *Does TensioBot improve knowledge on best practices related to self-managed BP measurement procedures?*

Reminders and advice regularly sent to patients by the chatbot, along with the opportunity to review a video about best BP measurement practices, appear to have had a positive impact on the knowledge and skills acquired in the intervention group. Although small, the mean differences in checklist scores (between the first and second visit) appear to favor the bot group (Bot group mean= 24.126, control group mean= 17.591, differences are significant, p= 0.037).

RQ4) *What are the advantages of using TensioBot to record BP measurements compared to the traditional method of writing them down on paper?*

Having the option of using a chatbot to help patients perform a self-managed BP monitoring procedure has many advantages over the usual pen-and-pencil procedure, not only for the patient, but also for doctors and the healthcare system in general.
The main advantages for the patient are that he/she spends less time in the health centre, something that is especially interesting nowadays due to the COVID pandemic situation. On the other hand, it prevents patients from forgetting to bring the record sheet on the day of the medical appointment, as the data is automatically stored in the bot (in fact, the BP data history is kept for two years). In addition, the bot sends you appointment reminders so that you don't forget to go to the health centre on the appointed day.
Moreover, the bot reminds the patients when to take BP measurements, thus preventing them from forgetting to check it or being delayed in the procedure. It also periodically reminds them of the correct way to check their BP. Finally, if they make a mistake in recording the data, these are automatically corrected thanks to the bot. A major advantage of this mobile application is that, due to the integration of the bot with a popular IM application (Telegram), it is usually not necessary to train users in the use of the bot because they are already used to the interface.
Regarding the benefits for the healthcare system, the doctor/nurse does not have to enter the data by hand, saving time and avoiding transcription errors, as well as being informed in real time of possible out-of-range BP values, without waiting for the next appointment. Such alerts can be customized so as not to overwhelm the system (specifying threshold BP values). All these advantages are achieved thanks to an inexpensive and immediately usable solution, as the source code has been provided under a GPLv3 license, so any interested practitioner could use and adapt it to their needs. Moreover, being on Telegram, users of our bot do not need to provide their phone number to start using it, which could be a crucial aspect for privacy in a mHealth intervention.

5. Limitations

The main concern is internal validity. Our setting is that of patients with HTN who were asked if they were willing to participate in the TensioBot experiment. This could lead to a situation where patients invest more effort collecting the data correctly than they would do otherwise. However, as this is a health-related intervention, we could not assign a person to the intervention group directly without confirmation.

As for external validity, our setting is that of a country where IM applications such as WhatsApp or Telegram are quite popular among the population. However, that might not be the case in other countries. Moreover, some patients might not be willing to install Telegram just to use TensioBot because they are currently using another one (most probably, WhatsApp). This could be a problem, as although WhatsApp (the most widely used IM app in Europe) has a user interface almost identical to Telegram´s, it lacks a public bot API.

6. Conclusions and future work

This work addresses the problem of self-management of home BP measurement by hypertensive patients through a specific intervention (a chatbot). Based on previous work within the mHealth field, we have designed a chatbot to help patients to correctly check their BP at home. Strategies include: 1) alerts and notifications; 2) video and text-based advice on good BP measurement practices; 3) reminders and rescheduling of upcoming medical appointments; 4) notifications of data recording errors; 5) graphical tracking of BP values.

For patients, chatbots might help them to keep track of their BP, remind them when to check it, and keep them in contact with the doctor, while improving their knowledge about BP checking best practices. For doctors and nurses, chatbots provide the opportunity to better track patients' BP numbers, freeing them from routine paperwork (translating data from paper to a digital form), and keeping them informed when noticeable BP numbers occur. We could leverage natural language processing techniques for improving on this area.

Although the investigated intervention seems to yield equal results in both groups (intervention and control) regarding adherence to the procedure (BP check at a fixed schedule), TensioBot users scored better on a subsequent test of knowledge and skills related to self-managed BP, meaning that they improve their technical skills to perform a more correct measurement. In addition, the introduction of chatbots to alleviate paperwork for doctors and nurses could be a great advantage in a currently overburdened healthcare system.

As a future line, we plan to study the advantages of integrating our bot with digital devices already in use for BP monitoring, freeing the patient from the need to manually enter numbers into the bot. Finally, we would like to devise ways to adapt our chatbot to help patients with other conditions to better follow their treatments. In fact, we have already adapted our bot to help pregnant women keep track of their BP. This bot, which we have named *GestaBot*, is already being tested in a clinical trial at the Araba University Hospital (HUA), approved by the Clinical Research Ethics Committee of the BioAraba Health Research Institute (with approval number/ID2019-002 and PI LE).

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