Digital Health Twin in the Prevention Era for Personal and Corporate Wellbeing

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Abstract. The availability of new miniaturized technologies for measuring the health status in self and remote conditions is rapidly pushing the development of new digital health solutions. The new AI and Metaverse era is also targeting the health field. This requires the evolution of new integrated models for health data fusion and representation. This paper presents development of a novel Digital Health Twin dedicated to prevention and implementing a cardiovascular risk index. Cardiovascular pathologies are the most diffused and relevant in the society. The model is combined with a Heath Pod solution for a territorial medicine approach even through corporate welfare solutions. This setting was adopted for the validation of the Digital Health Twin model and its User eXperience. A panel of 1314 subjects participated to the pilot test: they carried out a total number of 3755 test, that meant and average of 2,72 test per subject. Very good and promising results were obtained. The DHT model was well appreciated by 90% of subjects with excellent (about 70%) or good (about 20%) positive answers. Also the collective dashboard demonstrated to be a useful representation and tools to identify a status of health of a population, capable to highlight both individual issues and problems in specific category of people (by age, by gender, by occupation or section in the company).

Keywords: Health Twin · Digital Health · Prevention · Muti-domain representation · Health Pod

1 Introduction

Digital health is emerging as a priority for many public and private healthcare systems as a way forward to drive value for every global citizen, to ensure healthcare is accessible and equitable, and high performing [1]. In addition, recent scientific literature findings describe how 84% of pathologies are in direct correlation with lifestyle so that a new clinical branch is the so-called 'Lifestyle Medicine' where definition, promotion and personalization of coaching interventions are the most promising strategies. To achieve this proactive healthcare promotion goal, the most important action is said to be the patient empowerment that is defined as the process which people can gain a better control

A. Marcus et al. (Eds.): HCII 2023, LNCS 14034, pp. 269–278, 2023.
https://doi.org/10.1007/978-3-031-35705-3_20

about decisions and actions related to his/her own Health through digital biomedical technologies [3]. This is also the 5-P Medicine vision adopted by the European Union recommending to push on Digital Transformation and towards Predictive, Preventive, Personalized, Participatory, and Psycho-cognitive Healthcare that is the target for 2030 [3–6].

Lifestyle diseases share risk factors like prolonged exposure to four modifiable lifestyle behaviors, that are responsible for about 60–65% in their development in comparison with the genetics that impacts only for about 30–35% [6–9]. Fortunately, most of the risk factors mentioned above are reversible and, if corrected in time, so are the diseases they trigger. The measurement of signals related to these factors allows for identifying and quantifying the risk so to produce the necessary awareness to promote a behavior change able to correct the situation. In this perspective an active role of the subject is needed before he/she becomes a patient. This action for the proactive healthcare promotion, is also called patient empowerment, in a multidimensional approach needed for a successful outcome [9]. New systems like Health Pods [10] offer a new typology of innovative check-up points to provide self-measurements of the main bio-signals related to lifestyle and health status, but a new digital twin model is needed.

2 Materials and Methods

The basic human domains [11] were selected and described in term of main features, parameters, and correlations among them: cardiovascular, metabolic and nutritional systems, physical state and psychological status have been identified as key bricks of human health, and the main non-invasive parameters for their measurement have been identified to build the corresponding health pod for their self-measurement (Fig. 1).

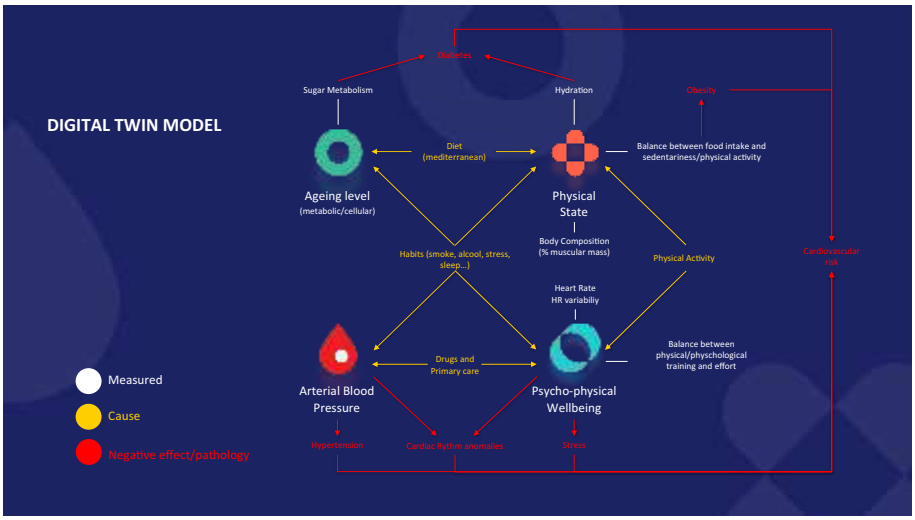

Fig. 1. The Physical-Physiological model underneath the Digital Health Twin general health and cardiovascular risk computation.

The domains are described by one of the most representative parameter, a physiological bio-signal that could be measured non invasively and through a device supporting a self-procedure i.e. without the presence or assistance of a clinical operator:

– Arterial blood pressure for the cardiovascular system;
– Advanced glycation endproducts (AGEs) for nutrition and metabolic functions describing the ageing level;
– Heart rate variability (HRV) for the psychological wellbeing;
– Body weight and body composition for the physical status.

The human model underneath the Digital Health Twin describes the complexity of human health through a set of correlations between the different domains. In Fig. 1 these links are represented by lines and arrows and the model is also able to identify the relationships with the most relevant and diffused pathologies, whose measured parameters are indicator of.

At the same time, these domains have been identified to provide information on lifestyles in a simple and intuitive way: data about nutrition, sleep and stress, exercise and blood pressure are combined with information on users' habits, such as alcohol consumption, smoking, diet, allow different data to be collected and express the psycho-cognitive and physical well-being of the individual in a holistic way. The basic set of measurements available to the user entering Capsula health Pod, provide her/him a quantitative assessment of the general health status. At the end of it, by means of a QR code, the individual has access to the Capsula web app which assimilates further information in order to build the user's Digital Me. This information is acquired in three ways:

- by means of binary or numerical input questions;
- by means of validated questionnaires (in particular, questionnaires were identified to detect physical activity, perceived stress and sleep quality of the individual);
- by means of questionnaires formulated by Capsula's partners, i.e. offering a service within the web platform (such as a questionnaire formulated by nutritionists to assess the individual's diet).

These data integrate the measurement and provide a more complete view of the health status. The Digital Health model or Digital me, is the digital integrated representation of this individually tailored and "smart" electronic health record. It is smart because it is not a simple database but the linking functions can be used for the computation of a global health index or of a risk index.

There are many ways to represent the heterogeneous set of these data, ranging from the more classical tabular to the more structured like radar charts or block sections as in the iOS health app. The choice that has been made is to develop a more intuitive representation, i.e. one that is capable of identifying human complexity in a simple way, but without framing it in a tabular format. For this purpose, the 'Digital Me' representation was chosen, i.e. a Health Digital Twin (HDT) prototype, implemented within a web app. The Digital Me (Fig. 2) can express the multifactorial organization of the human body in a clear, intuitive and authoritative manner, representing it as a kind of digital avatar.

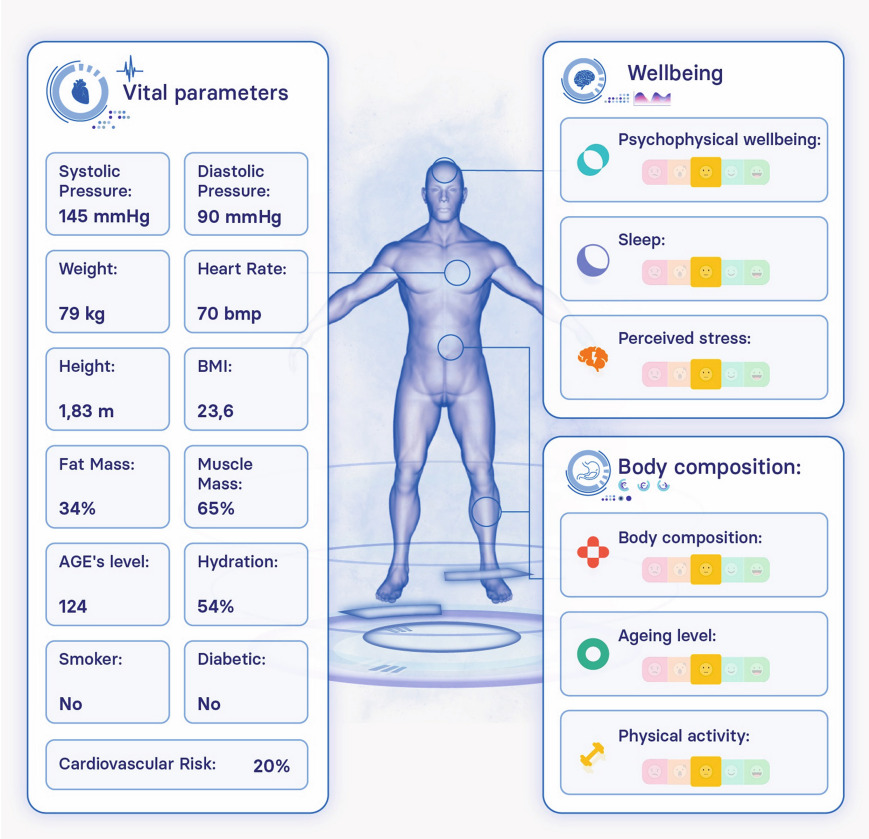

Fig. 2. The DHT or Digital-me representation in the mobile App, providing all the quantitative information measured or input by the user. An intuitive representation of the assessment of the global health in each domain is provided by means of an emoticon.

The Digital Me is an example of "data fusion", which is the integration of heterogeneous data from sources that were not designed to be brought together. This virtual representation of the user remaps his features on three levels:

- a vital parameters tab that identifies and blatantly expresses the individual's measured characteristics, assigning the most up-to-date numerical value (each box then encloses the measurement history). This card is intended to briefly represent some specifications that characterize the person, also assigning a cardiovascular risk by means of computational models;
- a "physical twin" that represents with semaphore scales the user's level of physical well-being due to his/her physical activity, fitness and nutrition;
- a "psycho-cognitive twin," which represents with semaphore scales the user's level of psychological well-being due to his or her mindfulness activity, sleep quality, and stress.

A preview of the mobile visualization of the "Digital Me" is shown below (Fig. 3).

Fig. 3. The DHT or Digital-me representation in the Web-App.

A pilot tests on a large sample of healthy volunteers was conducted. The first goal of the test was dedicated to the verification of the acceptance and usability of the individual "digital health me model". The second objective was dedicated to the validation of the implementation of a digital health collective model for a small homogeneous community. To this goal a corporate welfare application was implemented for its well-fitting characteristics: adult healthy volunteers in a common workplace and conditions, and digital skills to have a community of people. An individual and collective representation was then studied, designed, and implemented to match this application field and case study. This collective analysis was synthetized into a global score to evaluate the overall wellbeing status in the company: this index has been computed considering the average scores in the four tests (corresponding to the human domains), weighted by the number of trials for each test and the percentage of subjects with low values in the CAPSULA assessment. This CAPSULA index aimed at evaluating the community wellbeing level.

3 Results

The pilot study involved a court of healthy adult volunteers working in a multinational company in the period running from June 2022 to 14 February 2023; the CASPULA system was installed in the entrance of the office building and employees were noticed by email of this opportunity; the participation was free and when a subject entered into CAPSULA she/he was asked to carry out at least one test and evaluate the user experience (Fig. 4).

General data about the test are reported in Fig. 4. In the testing period, 1314 subjects participated to the survey: they carried out a total number of 3755 test, that meant and average of 2,72 test per subject. The sample population was composed by women for 35,2% and 64,8% by men with a similar mean age of 50 years.

All the tests were successfully executed to evidencing the technical reliability of the Health Pod solution with very good intuitiveness of the commands (Fig. 5).

Fig. 4. A test subject executing the health assessment in the CAPSULA Health Pod in the company selected for the pilot experimentation.

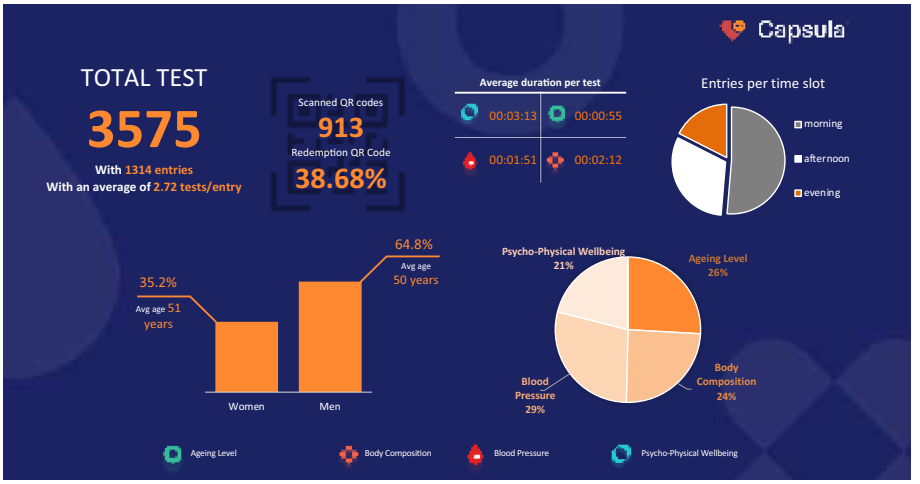

Fig. 5. The general results of the CAPSULA test.

The choice of the test is well balanced among all domains, with just a small preference for blood pressure, probably due to its well know significance and maybe for the mean age of the participants.

From the performance point of view the average time for the total subject experience is about 5 min; for the single test, the quickest one was the ageing level assessed by AGEs (mean duration: 55 s), followed by blood pressure (mean duration: 1 min and 51 s), Body weight and composition (mean duration: 2 min and 12 s), and finally psycho-physical wellbeing measured by HRV (mean duration: 3 min and 13 s).

At the end of the experience the users received a QRcode where they could find a detailed report and explanation of the meaning of the measures; a indirect assessment of patient empowerment and user engagement was given by the number of scanned QR codes (N = 913) corresponding to a QR Code Redemption rate of 38.68%.

The Individual Model well fitted to the general health conditions and the biomedical devices used for the measurements have provided the necessary reliability.

3.1 Acceptance and Usability

The evaluation of acceptance and usability was carried out through an automatically administered questionnaire composed by 4 items/questions investigating easy of use, satisfaction, and the willingness to repeat the experience as measure of the acceptance:

- Q1: I found use and understanding CAPSULA functioning EASY
- Q2: I found useful for my health and wellbeing this CAPSULA experience
- Q3: I would participate again in this experience
- Q4: I'm satisfied with this experience.

This short usability questionnaire was displayed on the screen of CAPSULA Health Pod at the end of the set of measurements, and the subject is asked to to select her/his answer evaluating the level of agreement according to the following scale: level of agreement score: 1 = no, 2 = poor, 3 = neutral, 4 = good, 5 = excellent.

The results were very satisfying with an average excellence level scored by 70% of participant for all questions and a positive assessment in 90% of subject for all factors (Fig. 6).

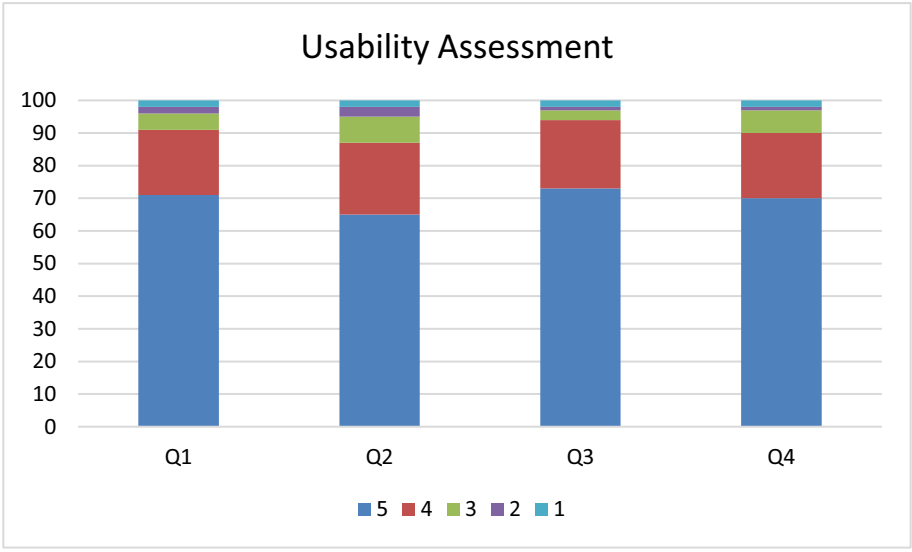

Fig. 6. The results of the usability and acceptance test on DHT.

From the answer to Q2, it could be also argued that for 88% of users, the individual model well fitted to the general health conditions and the biomedical devices used for the measurements have provided the necessary reliability.

3.2 Community Health and Wellbeing Test

In the same company the CAPSULA experience was proposed for the screening of the general health status as a corporate welfare intervention in the same period. The general outcomes (in Fig. 7) were proposing a division of the population by gender and by age. The threshold was set (also in accordance with the company management and in relation to the employees age range) at 45 years. For highlighting situation worth of consideration, a health threshold of 10% of respondent was identified: this meant that an attention level to poor health condition is obtained when more than 10% of the population has a value below the normal reference provided by the scientific literature findings. This situation is shown in the community dashboard through a red color for the corresponding datum.

Fig. 7. The results of the analysis of the general status of the population in a corporate welfare setting using the DHT and its computational model for cardiovascular risk.

The Collective Dashboard was appreciated by the management and its outcomes were qualitatively coherent with the general perceived health conditions.

It was interesting to consider that 3 out 4 domains showed low healthy values in an appreciable amount of population. In particular, 41% of male over-45 subjects had blood pressure values (systolic and diastolic) higher than the recommended ones. This datum is also coherent with a not appropriate body weight and body composition for 37% of the tests.

In general, the best conditions are recorded for female subjects under 45 years.

The best domain is the ageing level measured by AGEs.

All these data led to a general index of community health and wellbeing of 57 on 100, meaning that the overall company health level is slightly below the normality value (60 points).

4 Discussion and Conclusions

This study aims at highlighting Digital Twin development for future personalized preventive healthcare matching individual needs in terms of ubiquitous health and better, high quality, care services and improved quality of life. For our society resources optimization and cost reduction of the healthcare expenditure are the expected outcomes.

The DHT model was well appreciated by 90% of subjects with excellent (about 70%) or good (about 20%) positive answers.

Also the collective dashboard demonstrated to be a useful representation and tools to identify a status of health of a population, capable to highlight both individual issues and problems in specific category of people (by age, by gender, by occupation or section in a company).

The proposed solution has many advantages: it has a good integration capability allowing for the aggregation of fluid and heterogeneous data such as those from the patient's electronic record, data measured in real time with wearable devices, and those from decentralized Capsule units. Continuous, point-in-time, vital and lifestyle-describing data coexist in the DHT.

The potential applications of the combination of a distributed network of sensing points like the CAPSULA Health Pods and a DHT technology can be several and somewhat disruptive, in prevention strategies, in epidemiological analyses, in fast checkups in clinical settings, and many others.

Currently some exploitation activities are dedicated to the evaluation of the effectiveness of treatments and/or therapies, response to medications or lifestyle changes, to the cost-effectiveness analysis in the implementation of medical and/or lifestyle solutions in the market, to the cost-effectiveness analysis in identifying the population for a clinical trial, for precision public health based on anticipating the needs of the individual and capable of responding productively.

The development challenges are in the realization of AI models capable of aggregating data so as to formulate personalized recommendations and suggestions or alerts in real time and for a wider list of pathologies, as well as in the integration with a set of digital therapeutics in the vision of the future e-Medicine.

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