

Assessing Well-Being in Spain in the Post-COVID Era: A Population Study Using Mobile Sensors and Experience Sampling

Oresti Banos

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: oresti@ugr.es*

Carlos Bailon

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: cbailon@ugr.es*

Miguel Damas

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: mdamas@ugr.es*

Carmen Goicoechea

*Mind, Brain and Behavior
Research Center (CIMCYC)
University of Granada
Granada, Spain
email: carmengoico@correo.ugr.es*

Hector Pomares

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: hector@ugr.es*

Ciro Rodriguez

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: crleon@ugr.es*

Claudia Villalonga

*Research Centre for Information and
Communication Technologies (CITIC-UGR)
University of Granada
Granada, Spain
email: cvillalonga@ugr.es*

Abstract—The coronavirus outbreak has impacted severely the well-being of populations all around the world. All of a sudden, people had to shift to remote work and social distancing measures, which resulted in profound changes to daily routines, causing stress, anxiety, and depression. Hence, it is important to understand the effects of COVID-19 on the well-being of populations, in order to make informed decisions on public health interventions and policy recommendations. This paper presents the first population study conducted within the context of the POSTCOVID-AI project, which combines mobile sensing and artificial intelligence techniques to shed new light on the impact of COVID-19 on the well-being of the Spanish population. The aim of this article is to present the methodological framework, data collection, and preliminary results generated for this study, as well as the future directions towards the achievement of the goal of the project.

Index Terms—COVID-19; smartphones; sensors; experience sampling; well-being.

I. INTRODUCTION

The outbreak of the coronavirus disease (COVID-19) has had a profound impact on the well-being of populations around the globe. The unexpected shift to remote work and social distancing measures resulted in significant changes to daily routines, causing stress, anxiety, and depression in many individuals. The pandemic has also illustrated clear disparities

in our societies, with certain populations, such as those living in poverty, marginalized communities, and essential workers, being disproportionately affected. Additionally, the economic consequences of the pandemic have also led to financial stress and insecurity for many households.

After a few years, the pandemic has been brought generally under control, mostly thanks to the widespread use of diagnostic tests [1], administration of vaccines [2] and the remarkable efforts of healthcare workers and scientists. Nonetheless, it is of much importance to understand the direct and indirect effects of COVID-19 on the well-being of populations. In particular, studies on the impact of the pandemic on well-being can provide, for example, insights into its long-term consequences, such as post-traumatic stress disorder and other mental health conditions [3]. Likewise, this type of studies can also enlighten us to have a better understanding on other important social consequences, like increased feelings of loneliness and isolation for many individuals, particularly for older adults and those living alone [4].

Spain was one of the countries hardest hit by the COVID-19 pandemic, with a high number of cases and deaths reported in the first wave of the pandemic [5]. The Spanish government implemented strict lockdowns and social distancing measures, which had a significant impact on the daily lives of individuals

and families. The Spanish economy was also greatly impacted by the pandemic, with high levels of unemployment and financial insecurity reported.

According to recent studies, the Spanish population experienced a range of negative impacts on their well-being as a result of the COVID-19 pandemic. One study found that the pandemic led to increased levels of stress, anxiety, and depression among the Spanish population, particularly among those who were directly affected by the illness, such as healthcare workers, and those who lost loved ones [6]. Another study reported that the lockdowns and social distancing measures resulted in increased levels of loneliness and social isolation, which can have long-term consequences for mental health [7]. In addition to the psychological effects, the economic consequences of the pandemic have also had a significant impact on the well-being of the Spanish population. Some studies reported that the pandemic has resulted in increased levels of poverty, particularly among marginalized populations, such as immigrants and single-parent families [8].

Great efforts have been made both in Spain and globally to comprehend better the consequences of the pandemic. Several studies have been conducted to that end, normally by means of one-shot surveys. Some works particularly relied on the use of digital questionnaires, which could be filled in via a web browser [9] or a mobile app [10], [11]. More sophisticated approaches adding mobile sensing features have been also developed to measure diverse social and behavioural indicators for small population samples [12]. Many such studies took place during the early phases of the COVID outbreak, particularly during or right after the lockdowns. Nonetheless, many more efforts are needed, especially now and in the years to come, to track the evolution of the well-being of the population. In light of this necessity of follow-up data on the effects of the pandemic, we contribute with POSTCOVID-AI, a project aimed at providing a longitudinal and holistic description of relevant factors associated to population well-being during the post-pandemic era. The project overarching goal is to build an AI-driven system to automatically and continuously monitor and analyse population-level indicators relating to physical activity, social interactions, and emotional states, among others, as well as their links to general well-being. In this paper, we present the overall idea behind POSTCOVID-AI and the first population study conducted within the project using the developed digital tools. Moreover, initial results and findings derived from this study are briefly outlined.

The remainder of the paper is as follows. Section II describes the POSTCOVID-AI intelligent system. Section III describes the study conducted and the preliminary results are shown in Section IV. The main conclusions and next steps are outlined in Section V.

II. POSTCOVID-AI

POSTCOVID-AI is a novel framework that employs real-time acquisition and analysis of social, behavioral, and emotional data to assess the impact of the post-COVID-19 context

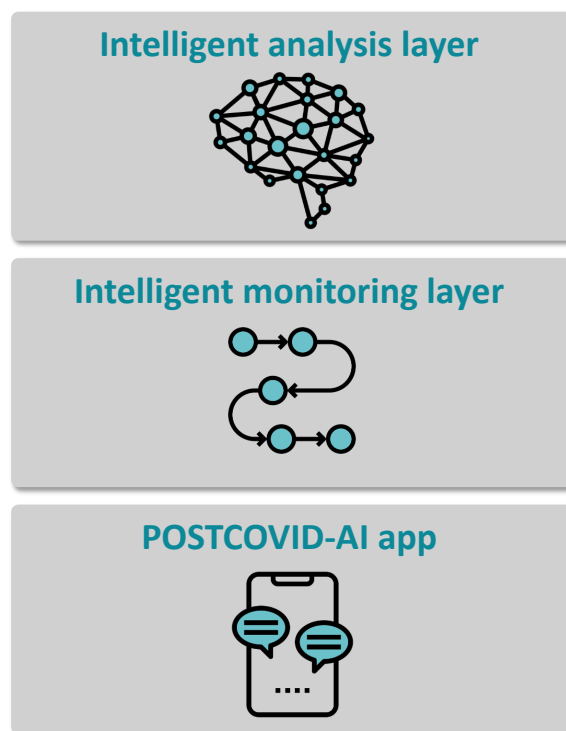


Fig. 1. POSTCOVID-AI high-level architecture.

on the well-being of the Spanish population. Leveraging the widespread use of smartphones among most segments of the population, POSTCOVID-AI continuously and anonymously monitors social, behavioral, and emotional data at both the individual and group levels. The framework combines digital sensing and artificial intelligence techniques to process raw, anonymous, and mobile big data into meaningful longitudinal representations of the social, behavioral, and emotional states of the population. These representations are then used to identify relevant patterns and tipping points that may impact well-being, as well as to predict its future evolution.

POSTCOVID-AI relies on a two-layered methodological framework and a mobile app, schematically presented in Fig. 1.

The POSTCOVID-AI app is designed to gather both objective and subjective data from individuals in real-time to monitor the impact of post-COVID-19 context on the well-being of the population. This is achieved via the integration of built-in smartphone sensors and digital questionnaires. Objective data is collected passively using the smartphone's built-in sensors, such as the light sensor to monitor sleep patterns, accelerometry to monitor activity levels, audio level to measure environmental noise, and Bluetooth/WiFi/GSM to measure interactions with others. The app also uses Experience Sampling Methods (ESMs) to collect self-reported data related to health status, emotions, and subjective well-being. The collected data includes demographic information, COVID-19 related information, emotional, social, behavioral, and well-being data, providing a comprehensive view of the social,

behavioral, emotional, and well-being states of each individual. The data is anonymised and securely transferred to a central data center for aggregation, harmonization, and analysis. The vast amount of data collected by POSTCOVID-AI app enables the use of innovative machine learning and artificial intelligence methods to generate new knowledge and insights into the impact of this and similar pandemic on people's well-being.

The intelligent monitoring layer comprises all the mechanisms for gathering, aggregating and harmonising (i.e., cleaning, transforming and normalizing) the data collected anonymously via the POSTCOVID-AI app. The dataset harmonisation task prepares the recorded data for processing. It includes the labelling, coding, adaptation, cleansing and wrangling of the data so that they can be processed by the analytical routines implemented in the intelligent analysis layer. This task also ensures the full anonymisation of the data for its public sharing. As a result, a comprehensive big dataset of harmonised mobile data is produced.

The intelligent analysis layer sophisticatedly processes the harmonised mobile big dataset in order to generate more interpretable contextual and factual information describing the social, behavioural and emotional situation of the individuals, thus creating a multivariate longitudinal dataset. To that end, machine learning techniques are used, such as clustering algorithms (e.g., principal component analysis, deep clustering networks) to group and select statistically relevant and non-redundant mobile data features. Advanced classification algorithms (e.g., support vector machines, convolutional neural networks) are applied to translate these data features into categorical and numerical indicators describing social, behavioural and emotional states. As an example, body motion registered via the phone accelerometer sensor is transformed into physical activity labels of the type "sitting", "walking" and the like. As a result, a collection of rich time series variables or indicators is generated, which quantify aspects such as the overall mood or activity performed at home vs. outdoors, during daytime vs. night-time, in weekdays vs. weekends, etc. The resulting unique multivariate longitudinal dataset is continuously and automatically analysed via artificial intelligence algorithms to generate new knowledge and evidence on how past and present events are affecting and will affect the population's well-being. More specifically, multivariate pattern mining techniques (e.g., vector autoregressive integrated moving average, dynamic programming change point detection) are used to determine individual and population level tendencies and change points, such as a positive a trend in the number of hours spent at home or a decrease in the sleeping hours linked to a negative trend in the general state of mind. All these analytical findings are then mapped to the reported individual and population well-being.

III. POPULATION STUDY

The participant sample for this study was sourced through a market research company that established a panel of individuals meeting the specific requirements of the study. The selection process employed a quota stratified sampling

methodology to ensure representation of the Spanish population in terms of gender, age, location, and annual income.

Before the study began, candidates were provided with a detailed information sheet that outlined the study's parameters, including its duration and start date, the number of surveys to be completed, and the frequency of their completion, as well as data privacy considerations. The rewards for participating were also outlined, with a minimum of 80% completion rate of the daily surveys required to receive the reward.

All study procedures were conducted in accordance with relevant ethical guidelines and regulations. The study was approved by the Ethical Committee of the University of Granada under reference number 2214/CEIH/2021. Prior to participating, all individuals provided informed consent and confirmed that they were at least 18 years old. Participation in the study was strictly voluntary and all data collected was anonymous and confidential. The study adhered to the ethical standards outlined in the Declaration of Helsinki.

A total of 110 individuals completed the minimum required registration period (i.e., November 15, 2021 to December 15, 2021). During the study, 7 participants withdrew, but they were promptly replaced with other individuals with similar characteristics. The participants were composed of 53 (48.2%) females and 57 (51.8%) males, with ages ranging from 18 to 70 years (mean±std age=44.3±16.1). Annual net income was classified according to the criteria established by the Spanish Statistical Institute (INE). To ensure representation of the diverse Spanish population, the Nielsen Geographic Zones criteria were used. Of the 110 participants, 77 (70%) completed 80% or more of the surveys.

For the data collection, the study participants were required to install the POSTCOVID-AI app on their smartphones, enter the identification number provided by the recruitment company, grant the necessary permissions for the app's proper functioning, and provide their digital informed consent to participate in the study. As a part of the enrollment process, participants were asked to complete an initial survey, which included demographic and COVID-19 related information, as well as questionnaires aimed at measuring their well-being.

Once enrolled, the app initiated the passive data collection through the smartphone's sensors, including physical activity recognition, and indicators of social activity such as connection type, screen usage, WiFi networks, ambient light, and noise. Moreover, the self-reported emotional data was collected using the ESMs implemented through the app. The app pushed notifications to participants at six designated times per day, randomly distributed between 7:00-8:00, 10:00-11:00, 13:00-14:00, 16:00-17:00, 19:00-20:00, and 22:00-23:00. The notification persisted for one hour before disappearing. Upon opening the notification, the app prompted participants to complete the corresponding survey, which was then transmitted to the data storage server. In addition to the daily surveys, the app prompted participants to complete weekly questionnaires on their socio-economic, health, and well-being status, to monitor any changes over time. Table I outlines the different data types, variables, and indicators collected via the phone.

TABLE I
OVERVIEW OF THE DATA COLLECTED IN THE POPULATION STUDY.

Data type	Variable	Instruments or Indicators
Sensor	Activity recognition	Detected physical activities
	Wifi	Connections to WiFi networks
	Connectivity	Type of connections with the network
	Light	Ambient light measurements
	Noise	Ambient noise measurements
	Screen	Smartphone screen status
Initial Survey	Participant’s characteristics	Questions on socio-demographic and COVID-19 related data
	Psychological measures	International PANAS Short Form (I-PANAS-SF)
		General life satisfaction and seven domain of life
		Flourishing Scale (FS)
		Patient Health Questionnaire – 9 (PHQ-9)
		Generalized Anxiety Disorder Scale (GAD-7)
		Brief Resilience Scale (BRS)
Acceptance And Action Questionnaire – II (AAQ-II)		
Daily Survey	Affect	Valence
		Energetic Arousal
	Tense Arousal	
Emotional event	Report on any remarkable situations at the emotional level	
Weekly Survey	Follow up variables	Questions on socio-demographic and COVID-19 related data
		General life satisfaction and seven domain of life

IV. PRELIMINARY RESULTS

The dataset obtained in the initial POSTCOVID-AI study, which will be publicly released soon, encompasses a diverse array of variables, as described above. Among the most salient data is the mood of the study participants. Following the preprocessing of mood data collected from daily surveys, we identified 57 participants with an adequate number of responses, constituting at least 80% of the 180 total responses recorded over the course of the month-long study. This will allow us to calculate indices of psychological well-being. The sample comprised 30 male participants (53%) and 27 female participants (47%). The mean age of participants was 44 years with a standard deviation (SD) of 17 years. The youngest participant was 18 years old and the oldest was 70 years old.

In terms of the psychological characteristics of the participants, based on the questionnaires administered at the start of the study, we compared the results to mean scores of the general pre-pandemic population as reported in prior studies. Specifically, our participants had a mean score of 5.95 (SD = 4.85) on the Generalized Anxiety Disorder Scale - 7 (GAD-7), which indicates a mild level of anxiety. The mean score of the general population in Spain prior to the pandemic was 3.54 (SD = 3.32). On the Patient Health Questionnaire - 9 (PHQ-9), our participants had a mean score of 6.86 (SD = 4.72), reflecting a mild level of depression. The mean score of the general population prior to the pandemic was 2.91 (SD = 3.52). All the responses of each participant for the GAD-7 and the PHQ-9 are shown in Fig. 2 and Fig. 3 respectively.

These findings suggest that our participants exhibit slightly elevated levels of both anxiety and depression compared to those reported in previous studies of the general population prior to the pandemic. These results are consistent with those obtained in another study involving almost 2000 participants conducted during the pandemic in Spain, with a mean GAD-7

score of 5.86 (SD = 5.24) and a PHQ-9 score of 6.50 (SD = 5.65). This supports the validity of the data and reiterates the mental health impacts of the pandemic that have been documented in multiple studies. Our group’s aim is to carry out further studies to validate these results.

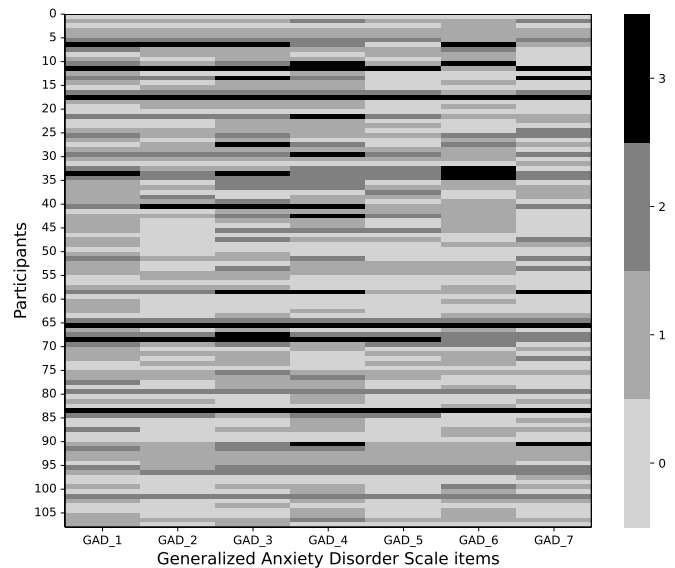


Fig. 2. Generalized Anxiety Disorder Scale (GAD-7) responses of each participant. The seven items address how often participants have been bothered by any of the following problems: GAD 1 - "Feeling nervous, anxious or on edge"; GAD 2 - "Not being able to stop or control worrying"; GAD 3 - "Worrying too much about different things"; GAD 4 - "Trouble relaxing"; GAD 5 - "Being so restless that it is hard to sit still"; GAD 6 - "Becoming easily annoyed or irritable"; GAD 7 - "Feeling afraid as if something awful might happen". Each item of the scale (GAD x) is scored with a 0, 1, 2, or 3 value.

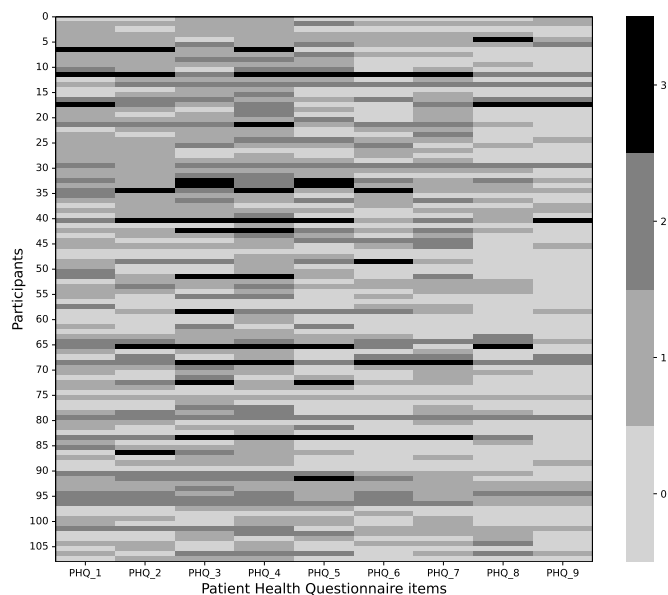


Fig. 3. Patient Health Questionnaire (PHQ-9) responses of each participant. The nine items address how often participants have been bothered by any of the following problems: PHQ 1 - "Little interest or pleasure in doing things"; PHQ 2 - "Feeling down, depressed, or hopeless"; PHQ 3 - "Trouble falling or staying asleep, or sleeping too much"; PHQ 4 - "Feeling tired or having little energy"; PHQ 5 - "Poor appetite or overeating"; PHQ 6 - "Feeling bad about yourself - or that you are a failure or have let yourself or your family down"; PHQ 7 - "Trouble concentrating on things, such as reading the newspaper or watching television"; PHQ 8 - "Moving or speaking so slowly that other people could have noticed? Or the opposite - being so fidgety or restless that you have been moving around a lot more than usual"; PHQ 9 - "Thoughts that you would be better off dead or of hurting yourself in some way". Each item of the scale (PHQ x) is scored with a 0, 1, 2, or 3 value.

V. CONCLUSION

The COVID-19 pandemic has had a profound impact on the well-being of populations around the world, with the Spanish population being no exception. The pandemic has resulted in increased levels of stress, anxiety, depression, loneliness, and financial insecurity, among other negative impacts. Nonetheless, further research is needed to fully understand the long-term consequences of the pandemic on the well-being of populations.

In this work, we introduced POSTCOVID-AI, an on-going project that aims to continue monitoring the effects of the pandemic on the population well-being. In doing so, the project ambitions to objectively inform governments, health organizations, and communities to help them implement interventions and policies that address the psychological and economic consequences of the pandemic, and support the most vulnerable populations.

A first population study has been conducted in Spain showing the potential of the proposed approach. At this time, the project team is undergoing the curation of the collected data, which will be made open access soon. A preliminary analysis of the data confirm that both anxiety and depression hold after the most severe phase of the pandemic, thus confirming the need to keep on tracking the well-being of the population, with

the overarching goal of supporting individuals and families as they navigate this challenging time.

ACKNOWLEDGMENT

The project leading to these results has received funding from "la Caixa" Foundation under the project code SR20-00668. The authors want to express their gratitude to all the participants of the study.

REFERENCES

- [1] R. W. Peeling, D. L. Heymann, Y.-Y. Teo, and P. J. Garcia, "Diagnostics for covid-19: moving from pandemic response to control," *The Lancet*, vol. 399, no. 10326, pp. 757–768, 2022.
- [2] D. M. Altmann and R. J. Boyton, "Covid-19 vaccination: The road ahead," *Science*, vol. 375, no. 6585, pp. 1127–1132, 2022.
- [3] A. Kumar and K. R. Nayar, "Covid 19 and its mental health consequences," pp. 1–2, 2021.
- [4] T.-J. Hwang, K. Rabheru, C. Peisah, W. Reichman, and M. Ikeda, "Loneliness and social isolation during the covid-19 pandemic," *International psychogeriatrics*, vol. 32, no. 10, pp. 1217–1220, 2020.
- [5] L. Redondo-Bravo, M. J. S. Moros, E. V. M. Sánchez, N. Lorusso, A. C. Ubago, V. G. García, P. S. Villanueva, A. P. Azón, J. G. Bescós, A. L. Boone *et al.*, "The first wave of the covid-19 pandemic in spain: characterisation of cases and risk factors for severe outcomes, as at 27 april 2020," *Eurosurveillance*, vol. 25, no. 50, 2020.
- [6] R. Rodríguez-Rey, H. Garrido-Hernansaiz, and S. Collado, "Psychological impact and associated factors during the initial stage of the coronavirus (covid-19) pandemic among the general population in spain," *Frontiers in psychology*, vol. 11, p. 1540, 2020.
- [7] M. Martínez-García, E. Sansano-Sansano, A. Castillo-Hornero, R. Femenia, K. Roomp, and N. Oliver, "Social isolation during the covid-19 pandemic in spain: A population study," *Scientific Reports*, vol. 12, no. 1, p. 12543, 2022.
- [8] J. C. Palomino, J. G. Rodríguez, and R. Sebastian, "The covid-19 shock on the labour market: Poverty and inequality effects across spanish regions," *Regional Studies*, pp. 1–15, 2022.
- [9] N. Oliver, X. Barber, K. Roomp, K. Roomp *et al.*, "Assessing the impact of the covid-19 pandemic in spain: large-scale, online, self-reported population survey," *Journal of medical Internet research*, vol. 22, no. 9, p. e21319, 2020.
- [10] C. Bailon, M. Damas, H. Pomares, D. Sanabria, P. Perakakis, C. Goicoechea, and O. Banos, "Smartphone-based platform for affect monitoring through flexibly managed experience sampling methods," *Sensors*, vol. 19, no. 15, pp. 1–23, 2019.
- [11] C. Bailon, C. Goicoechea, O. Banos, M. Damas, H. Pomares, A. Correa, D. Sanabria, and P. Perakakis, "Covidaffect, real-time monitoring of mood variations following the covid-19 outbreak in spain," *Scientific Data*, vol. 7, no. 1, pp. 1–10, 2020.
- [12] K. Konsolakis, O. Banos, M. Cabrita, and H. Hermens, "Covid-behave dataset: measuring human behaviour during the covid-19 pandemic," *Scientific Data*, vol. 9, no. 1, pp. 1–15, 2022.