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Digital phenotypes for mindfulness and anxiety found by smartphone APP

Fenótipos digitais para mindfulness e ansiedade encontrados por aplicativo de smartphone

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RESUMO

A pesquisa em telemedicina possibilitou a captação de medidas fisiológicas para encontrar biomarcadores do comportamento humano durante o uso de *smartphones* chamados fenótipos digitais. A identificação e avaliação desses biomarcadores para diagnóstico da saúde fornece subsídios a uma área afim da telemedicina, a medicina de precisão. Foi desenvolvido um aplicativo para celular chamado *Neuropesquisa*, que possui recursos voltados a encontrar esses biomarcadores enquanto os usuários preenchem escalas psicológicas para saúde mental. O objetivo foi correlacionar *mindfulness*, ansiedade e tempo de reação e rastrear possíveis fenótipos digitais dessas pessoas. Realizou-se um estudo observacional, de delineamento correlacional, transversal e remoto com 364 adultos pelo *Neuropesquisa*. Foram encontradas correlações positivas e significativas entre *mindfulness* e tempo de reação, e negativas e significativas para ansiedade e tempo de reação. Concluiu-se que *Neuropesquisa* foi capaz de identificar fenótipos digitais dentre os constructos avaliados, de relevante importância para medicina de precisão e saúde mental.

Palavras-chave: Ansiedade. Aplicativos móveis. Atenção plena. Medicina de precisão. Telemedicina.

ABSTRACT

Research in telemedicine has made it possible to capture regulatory measures to find biomarkers of human behavior during smartphone use called digital phenotypes. The identification and evaluation of these biomarkers for health diagnosis provide gains for an area related to telemedicine, precision medicine. It was developed a mobile application called *Neuropesquisa*, which has features to find these biomarkers while users complete psychological scales for mental health. The aim was to correlate mindfulness, anxiety and reaction time, and track possible digital phenotypes of users. This was an observational study, with a cross-sectional, correlational, and remote design with 364 adults, through *Neuropesquisa*. There were positive correlations between mindfulness and reaction time, and negative correlations between anxiety and reaction time. It was concluded that *Neuropesquisa* was able to identify digital phenotypes among the considered constructs, of relevant importance for precision medicine and mental health.

Keywords: Anxiety. Mobile applications. Mindfulness. Precision medicine. Telemedicine.

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INTRODUCTION

The context of the covid-19 pandemic stimulated scientific research and the remote development of digital tools. In the area of mental health promotion, telemedicine has enabled assistance in diagnosis, prevention and monitoring of physiological measures[1,2]. In this sense, applications using sensors available on smartphones allow a naturalistic approach, with a large number of users, real-time feedback and continuous and detailed data capture for the study of human behavior and health[3].

Through the analysis of data from these sensors, it is possible to identify digital biomarkers of human behavior when using wearable technologies and smartphones. These biomarkers provide a set of physiological, psychological and even pathological information particular to the user called the digital phenotype. In the field of mental health, digital phenotypes have already been found for patients with symptoms of anxiety and alcohol use[4], as well as for depressive, stressful, and mood behaviors through typing patterns on keyboards connected to smartphones[5,6].

Considering the world mental health report from the World Health Organization (WHO), cases of anxiety increased by 25%. In Brazil, there are about 18.6 million people with anxiety disorders, which represents the highest prevalence in the world. The WHO suggests that this is one of the consequences of the pandemic caused by the Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2). The impediment to access to adequate treatment and the interruption of those who had already started had a strong impact on the promotion and prevention of mental health, which was reflected in the number found by the international organization[7]. Anxiety can trigger disorders, such as generalized anxiety, which presents symptoms that are difficult for the patient to recognize and quantify, but demonstrate a common behavior of psychomotor agitation, which can be characterized by digital phenotypes[8,9].

Mindfulness is a state of attention achieved by a set of techniques that lead the practitioner to maintain sustained attention to focus without repressing the flow of thoughts, feelings and sensations. As a result, exercisers report decreasing distractions throughout the day. With a particular neurobiology, mindfulness is recognized in scientific research as an effective psychological practice for self-regulating stress, anxiety, pain management and strengthening mental health[10].

A randomized clinical trial sought to compare and determine whether the mindfulness technique for stress reduction is not inferior to escitalopram (a first-line psychotropic drug for the treatment of depression and anxiety). In this study, which lasted eight weeks and was followed up between 12 and 24 weeks after the interventions, 208 participants were assigned to two groups, of which 102 received the intervention with mindfulness and 106 with escitalopram (dose adjusted to the individual needs). The results no inferiority of mindfulness to escitalopram[11]. A current systematic review points to mindfulness practices as effective strategies for reducing the symptoms of anxiety disorders, as well as promoting people's quality of life[12].

The literature on digital phenotypes acquired by the effect of mindfulness is scarce, but a protocol for a future clinical trial was recently published that intends to understand digital phenotypes of stress and insomnia in caregivers of elderly with dementia who received mindfulness-based interventions[13]. Current telemedicine, even with the possibilities of virtual consultations, has not yet fully explored the tools of remote technologies to improve the health of patients[1,2].

One area for which telemedicine provides many subsidies is precision medicine, which aims to address the patient's health and disease from gene variability to changes in lifestyle that affect their expression, adapting a more accurate response to treatment. One of the goals is to promote health diagnoses to the user according to the results of their digital phenotypes. The evaluation of data on a large scale, in real time and in the user's natural environment has been placed as a required route for new advances in biomedical sciences. These results go beyond the information acquired in a single virtual medical assessment, and may suggest others that contribute to the robustness of the patient's assessment. With the increasing adoption of smartphones and the sensors contained in them, there is an increasing possibility of extracting digital phenotypes. Creating possible solutions to find and evaluate these phenotypes is urgent for the mental health area, especially for psychiatric and neurological disorders[14].

Smartphone applications can be created to trigger sensors that make it possible to track digital phenotypes, including GPS, accelerometer, bluetooth, microphone, SMS recording, number of calls, time the cell phone screen remains on and others. The capture of data acquired by these resources allows to obtain general user information, such as location, level of physical activity and in social networks, sleep and how much thy use the cell phone[15]. Other measures can be implemented such as reaction time to a question or cognitive tests that provide clues about the person's mental health, such as the random number test.

The accelerometer is an inertial sensor that measures the rate of change of acceleration due to gravity from the smartphone's three orthogonal axes (x,y,z). Its output is given in m/s^2 or gravitational units (g); positive or negative, depending on the position of the smartphone. A similar sensor in these devices is the gyroscope, differing in that it captures the angular velocity and that its output is in radians per second (rad/s). It is one of the main resources for studying human behavior based on smartphones, demonstrating robust associations between physical activity and physical and mental health[3]. It is also used to identify and predict emotions in digital phenotypes, such as happiness and anger[16].

Reaction time or latency is the time that the individual takes to answer a given task; the speed of decision-making reflects implications of the subject's cognitive processing and psychological states[17]. For example, the state of stress affects perception and the ability to perform motor tasks, resulting in greater decision-making latency[18]. Anxiety involves excessive inhibitory control, causing shorter latency[19]. The state of mindfulness, on the other hand, decreases latency, due to the improvement in attention, characteristic of the state[20].

The random number generation task (RNT) is a direct measure of the functioning of attention and executive functions, such as working memory, strategizing, numerical judgment and inhibitory control, all related to the prefrontal lobe. Human beings are poor generators of random numbers, so the sequence of numerical randomness directly reflects cognitive functioning. Redundancy in this task correlates with neuropsychological problems that attenuate these aforementioned executive functions. Conversely, the creation of a good random number arrangement is indicative of good mental health[21,22].

Considering that data capture features for the digital phenotype, such as accelerometer, gyroscope and reaction time, can be captured while volunteers fill out self-report psychological scales about their mental health, a psychophysiological research application for cell

phones was developed. The objective is to find digital phenotypes relevant to the mental health of the respondents. It also included an RNT.

In this article, we sought to find out whether there are digital phenotype patterns that correlate anxiety, mindfulness and reaction time measured by the response time of the items of the psychological scales provided online through the developed application, Neuropesquisa. As it registers a large number of different sensors per second, a huge amount of data was obtained. Thus, a preliminary analysis checked the correlation between response time, given by the time spent touching the cell phone screen when questions arising from psychological scales were presented. The rest of the data are analyzed using artificial intelligence techniques and made available in other articles in the future.

METHODS

THE *NEUROPESQUISA* APPLICATION

Neuropesquisa is a free application designed for Android smartphones and is available on the Playstore. Its objective is to collect data from the accelerometer, gyroscope and reaction time, from the cell phone, while users respond to psychological scales that measure mindfulness, stress, anxiety, depression, satisfaction with life and openness to experience. After completing the scales, the application generates a random number generation task, ending with questions about the positioning of the cell phone in the hands, described in detail below (Figure 1).

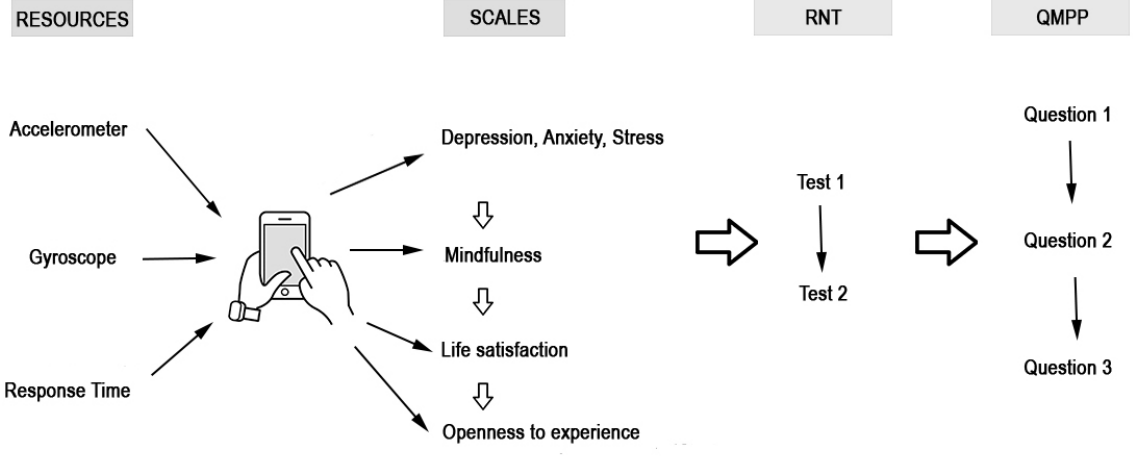

Figure 1. Features of the *Neuropesquisa* application.
Source: prepared by the authors.

The Neuropesquisa application gathers information with three types of resources: accelerometer, gyroscope and response time. The collection starts with the first question in the "Scales" section and continues until the last question in the "Questions about mobile phone positioning" (QMPP) section. The completion of the scales is done according to the order of the figure 1 whose names indicate the construct measured in the scale. At the end of this step, the user is forwarded to the two random number generation tasks (RNT), where the user is asked to do test 1 and then test 2. Finally, the user moves on to the QMPP section, where they fill in the three sequential questions about the positioning of the cell phone in their hands.

When entering the application, the user creates a fictitious identity (the initial letters of the full name) and agrees with the terms for disclosure and participation in the research contained in the Informed Consent (IC). Next, the user fills in the sociodemographic data (SDD) and move on to the step with two options: go to the questionnaires (suggested option) or provide a statement. When starting the first question of the first questionnaire, the application simultaneously activates the accelerometer and the gyroscope until the completion of the steps and then sends the data to the researchers. The capture is made every 10 milliseconds for the x,y,z axes of the accelerometer and gyroscope, and every 1 second of the reaction time.

The scales in the app were: Depression, Anxiety and Stress Scale (DAAS-21), Five Facets of Mindfulness Questionnaire (FFMQ-BR), Satisfaction With Life Scale (SWLS-BP) and Openness to Experience Factorial Scale (OES). Next, two random number generation tasks were suggested: A) "Now type a series of ten numbers in the freest and most spontaneous way possible, avoiding repeating, unless you feel like doing it"; and B) "Finally, enter a series of ten numbers as randomly as possible".

Finally, the user answers three multiple-choice questions about how they were holding the cell phone:

1) You answered the questionnaire using which hand(s)? The answer options are: a) I mainly used my right hand; b) I mainly used my left hand; c) I mainly used both hands.
2) What position were you in most of the time when you answered the questionnaire? The answer options are: a) I was lying down; b) I was sitting; c) I was standing.
3) How was your cell phone most of the time when filling out the questionnaires? The answer options are: a) I've been holding the cell phone in my hand(s); b) The cell phone was supported and lying on a horizontal surface (table, bed, etc.); c) The cell phone was leaning against a vertical or diagonal surface (wall, headboard, tripod, etc.).

RESEARCH CHARACTERIZATION

This was an observational, remote research, with a cross-sectional, correlational, quantitative design. It was based on the assessment of psychological constructs through psychological scales and, simultaneously, through psychophysiological measures triggered by the application.

SAMPLE CHARACTERIZATION

Participants were summoned by social networks, by articles on websites and television programs. The IC (as directed by resolution 466/2012 of the CNS) and the SDD were filled out shortly after the volunteer entered their initials in the application. The project was approved by the Research Ethics Committee of the Health Sciences Center, Federal University of Paraíba under opinion number 4,735,002. Data were collected throughout the month of July 2021

A total of 383 people of both sexes responded to the survey. For this study, we considered respondents between 18 and 68 years old, who did not have cardiovascular diseases, did not make frequent use of substances and did not present any characteristics that could bias the measurement of responses. People younger than 18 years and who incompletely completed the survey were excluded from the studies ($n = 19$), with a total of 364 adults aged between 18 and 68 years participating ($M = 29.4$; $SD = 8.88$). Women, single and students, predominated in the study, as listed in Table 1.

Table 1. General characteristics of the study participants

	Variable	n	Total	Proportion
Gender	Female	250	364	68.7%
	Male	113	364	31%
	Other	1	364	0.3%
Marital status	Single	243	364	66.8%
	Married	107	364	29.4%
	Widowed	2	364	0.5%
	Divorced	12	364	3.3%
Occupation	Student	154	364	42.3%
	Worker	172	364	47.3%
	No occupation	32	364	8.8%
	Retired	6	364	1.6%

Source: prepared by the authors.

PROCEDURES

During the disclosure, participants received instructions on how to install and follow the steps in the application to the questionnaires, completely filling in the information. It is worth noting that the Neuropesquisa application is part of a larger project aimed at identifying digital phenotypes in various categories of mental health; therefore, in the present study, only part of the data was used. The following were evaluated: 1) total time each participant took to complete from the first to the last question of the application: the five scales, the two tests of random numbers and the three questions about the positioning of the cell phone; 2) "Anxiety" factor of the Depression, Anxiety and Stress Scale (DASS-21); and 3) Five Facets of Mindfulness Questionnaire (FFMQ).

INSTRUMENTS

The next stage of the application consisted of completing the psychological scales. The ones used in this research were: Depression, Anxiety and Stress Scale (DASS-21); Five Facets of Mindfulness Questionnaire (FFMQ-BR); Satisfaction With Life Scale (SWLS-BP); and Openness to Experience Factorial Scale (OES).

The FFMQ, which considers mindfulness as a multidimensional construct, consists of a 39-item Likert scale questionnaire from 1 to 5 (never or rarely true to almost always or always true). It evaluates the level of mindfulness in five components: a) observation; b) description; c) act with awareness; d) non-judgment of internal experience; e) non-reactivity to internal experience[23]. The first three aspects refer to the state of attention, and the last two, to the performance of mindfulness.

The DASS-21, on the other hand, is an instrument aimed at measuring the symptoms of stress, anxiety and depression, validated for the Brazilian Portuguese language. The model of this scale is based on the idea that physiological dysregulation of the hypothalamic-pituitary axis causes affective disorders (and subtypes) that would fall within a spectrum between depression, anxiety and stress[24].

In turn, the Brazilian version of the Satisfaction With Life Scale (SWLS-BP) is a five-item scale, with a 7-point Likert scale, known as a good measure of cognitive judgment of subjective well-being, based on the respondents' own values. It has been used in over 4,000 studies, is brief and covers all ages. In addition, it correlates, according to the score, with positive affects (enjoyment/fun, cheerful, happy, optimistic and satisfied) or negative (angry/hostile, depressed, frustrated, unhappy and worried/anxious)[25].

The OES is the openness to experience factorial scale validated for Brazil with 42 items on a 7-point Likert scale. This major personality factor is linked with intellectual curiosity, exploration behavior, aesthetic and artistic sensitivity, imagination, creativity and appreciation of non-traditional ideas and patterns. Genes related to this factor have already been discovered, and, from a neuroscientific point of view, individuals with high scores in openness to experience also demonstrate high activity in the dopaminergic system and in the dorsolateral prefrontal cortex[26].

DATA ANALYSIS

The R Project for Statistical Computing package, version 4.1.2 (The R Foundation for Statistical Computing & Institute for Statistics and Mathematics, 2021), of the R programming language, was used for the descriptive and inferential analysis of the data. In the first, the frequency and sample distribution were verified, and in the second, non-parametric non-linear correlation tests and partial correlation tests were used.

RESULTS

Correlations between mindfulness, anxiety and reaction time were performed controlling for age and gender variables (Table 2). The reliability of the instruments for the sample was analyzed using Cronbach's alpha, as well as the sample median, standard deviation and Spearman correlation matrix for the three constructs.

Cronbach's alpha was calculated for the five facets of mindfulness in general (overall FFMQ): $\alpha = 0.846$ ($M_d = 2,95 \pm 0,53$), for the "Observe" facet $\alpha = 0.774$ ($M_d = 3,12 \pm 0,87$), $\alpha = 0.707$ for the "Non-reactivity" facet ($M_d = 2,42 \pm 0,76$), $\alpha = 0.800$ for the "Act with awareness" facet ($M_d = 3,18 \pm 1,07$), $\alpha = 0.795$ for the "Describe" facet ($M_d = 3,12 \pm 0,94$), $\alpha = 0.859$ for the factor "Non-judgmental" facet ($M_d = 2.75 \pm 1.03$). Regarding the "Anxiety" facet ($M_d = 12.00 \pm 5.44$) of the DAAS-21, $\alpha = 0.707$. As "reaction time" ($M_d = 20.29 \pm 23.58$) is not a psychological construct, but a psychophysiological response, Cronbach's alpha was not calculated.

When comparing "Reaction time" with "Anxiety", the correlation was negative, while "Reaction time" with "Mindfulness" presented positively correlated factors (Table 2). For "Mindfulness", in addition to the overall FFMQ, the facets "Act with awareness" and "Non-reactivity" were significant. Importantly, the described correlations were weak.

Table 2. Spearman Rank Correlation Matrix between total response time of the scales, anxiety and the Five Facets of Mindfulness according to age and gender (n= 364)

	1	*2*	*3*	*4*	*5*	*6*	*7*
Reaction time							
1 Time in minutes	1						
FFMQ Scale							
2 Overall FFMQ	0.126*	1					
3 Observe	0.052	0.341***	1				
4 Non-reactivity	0.106*	0.464***	0.351***	1			
5 Act with awareness	0.115*	0.668***	-0.100	0.021	1		
6 Describe	0.008	0.669***	0.248***	0.272***	0.240***	1	
7 Non-judgmental	0.100	0.528***	0.308***	-0.051	0.519***	0.140**	1
DASS-21							
8 Anxiety	-0.147**	-0.445***	0.149**	-0.045	-0.519***	-0.193***	0.527***

(1-8) = Correlation coefficients. * $p < 0.05$. ** $p < 0.01$. *** $p < .001$.
Source: prepared by the authors.

When overall FFMQ was correlated with the other mindfulness facets (Table 2), a positive and moderate correlation was found for all mindfulness facets, and negative for "Anxiety".

In the "Observe" facet (Table 2), there were weak, positive correlations with the "Describe" facet, and moderate correlations with the "Non-reactivity" and "Non-judgmental" facets. Regarding "Anxiety", the correlation was weak and positive.

The "Non-reactivity" facet was weakly correlated with the "Describe" facet, significantly (Table 2). "Act with awareness" had a weak, positive correlation with the "Describe" facet, and a moderate correlation with "Non-judgmental". When compared to "Anxiety", it had the same strength as "Non-judgmental", but significantly. The "Describe" facet (Table 2) was weakly, positively correlated with the "Non-judgmental" factor, and weakly, negatively correlated with "Anxiety". Facet "Non-judgmental" was positively correlated, in a moderate way, with "Anxiety".

DISCUSSION

The resource for exploring digital phenotypes used in this research was the reaction time of all answers filled in the questionnaires. As expected, high anxiety scores reflect excessive inhibitory control and consequently shorter latencies and total response times[19]. Even though it is a weak correlation, it is clear that the reaction time can provide evidence of a digital phenotype for this construct.

Mindfulness can be compared in the same way, as only two of the five facets were significant. On the other hand, a positive correlation with reaction time has not yet been reported in the literature for digital phenotypes, and these results corroborate the mindfulness effects of improved attention and more aware decision-making; thus, longer reaction times are to be expected[20].

The mindfulness facets that were significant, "Act with awareness" and "Non-reactivity", are directly linked with decision

making and inversely with anxiety. Non-reactivity is a characteristic derived from the efficiency of inhibitory control, in order to exclude intrusive thoughts and select the most adaptive insofar as attention can be focused on the current activity (act with awareness)[27,28]. This demands a longer reaction time[20].

It was expected that all mindfulness facets were correlated with each other[28]. The correlations between "Act with awareness" and "Observe", and "Non-reactivity" and "Non-judgmental" were negative, but non-significant, which does not affirm an antagonism between the facet. In general, mindfulness facets were negatively correlated with anxiety, as reported in the literature[27]. The "Act with awareness" facet, even non-significant, is negatively correlated with anxiety. However, "Observe" and "Non-judgmental" were positively correlated with anxiety.

Unlike the other facets, "Observe" is not entirely consistent with mental health predictions in the assessment of the present moment that this facet proposes. According to experience, a lot of observation (in the sense of a lot of eye deviations) can be a correlate of anxiety, which justify the positive correlation between the "Observe" facet and anxiety presented in Table 2[27,29,30].

The "Non- judgmental" facet is intended to measure the experience of refraining from self-criticism, but typically the initial training to develop the habit of non-judgment leads to the apprehension of evaluative thoughts that can trigger anxiety. This is what seems to happen according to the moderate and positive correlation between not judging and anxiety present in Table 2. Furthermore, this factor is more negatively associated with stress and depression than with anxiety[27].

FINAL CONSIDERATIONS

Digital phenotypes can be biomarkers of mental health in smartphone users. With the increasing accessibility and high frequency of use of these devices, telemedicine becomes more expansive, as psychophysiological data can be remotely collected and in a naturalistic environment. These biomarkers found in the patient's routine through behavioral expression when handling the cell phone can now be combined with the initial assessment at the physician's office, contributing to a more robust diagnosis by precision medicine.

In the present study, digital phenotypes of anxiety and mindfulness were found when the response time values were correlated when answering the questionnaires of the respective constructs. More specifically, the participants' reaction time, assessed by the speed with which they completed the scales, proved to be able to reflect, better than by chance, their degree of anxiety and mindfulness. These findings are relevant because it is one of the first studies to identify a valid correlate between a digital phenotype and the degree of mindfulness of mobile application users. The results support the hypothesis that the digital phenotype can be used to validate important aspects of the psychological health of individuals who are generating data for better evaluation of precision medicine.

Our findings also indicate that the Neuropesquisa application is efficient in finding digital phenotypes of psychological constructs; therefore, it is an important tool for prevention and promotion of mental health.

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