BeMonitored: Monitoring psychophysiology and behavior using Android in phobias

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Abstract It is of the utmost importance that researchers can recreate, as accurately as possible, real-life conditions in psychological studies. However, that is not always possible. Given that phobias are rather context-specific, their study is the ideal candidate to assess the feasibility of using a mobile and wearable device for obtaining physiological and behavioral data. In this article, we propose BeMonitored, a smartphone-based solution to support more ecologically valid monitoring of psychological experiments. BeMonitored delivers customizable, specific context-dependent audiovisual stimuli and uses external resources connected via Bluetooth or a smartphone's own resources, while capturing the participant's behavior, physiology, and environment. We used BeMonitored in a spider phobia case study and showed that spider phobics differed from control participants in face motion, captured by the smartphone camera. Moreover, our results also revealed heart rate differences between spider and neutral stimuli in phobic participants. The presented results emphasize the usefulness of smartphones for phobia monitoring. Considering their intrinsic characteristics, smartphones may

constitute the natural evolution from the lab to more realistic contexts.

Keywords Psychophysiology · Behavior · Spider phobia · Online monitoring · Mobile device

Specific phobias are common mental disorders and cause a substantial clinical burden (LeBeau et al., 2010). Spider phobia, in particular, is amongst the most prevalent forms of specific phobia (Agras, Sylvester, & Oliveau, 1969) and involves persistent and intense fear of spiders, as well as avoidance behavior regarding every context in which a confrontation with spiders is anticipated (American Psychiatric Association, 2013). Although animal phobia may be considered as having limited clinical relevance, this circumscribed anxiety disorder (Soares, Esteves, & Lundqvist, 2015; Soares, Esteves, Lundqvist, & Öhman, 2009) offers a valuable scientific model for investigating psychophysiological reactions (e.g., heart rate) and behavioral changes (e.g., avoidance) (for reviews, see Öhman & Mineka, 2001; Öhman, Soares, Juth, Lindström, & Esteves, 2012).

One of the central tenets of several cognitive-behavioral models of anxiety disorders is to attribute avoidance behavior as a maintenance factor of anxiety (e.g., Beck, Emery, & Greenberg, 1985). Avoidance either can be reflected in a complete refusal to confront the phobic stimulus (e.g., a spider in the case of spider phobics) or can involve safety behaviors, such as head movements away from such stimuli. Thus, observing behavior is highly informative for both the diagnosis and assessment of treatment efficacy. The behavioral approach/avoidance test (BAT) is one of the most common behavioral observation methods in specific phobia (Antony & Barlow, 2011). BAT involves the confrontation of the

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phobic individuals with their feared object while several aspects of behavior (overt and covert) are being measured (e.g., proximity to the object and psychophysiological responses) (Hood & Antony, 2012).

Although capturing and quantifying physiology and behavior in realistic environments is very relevant in psychological science (Lang, Greenwald, Bradley, & Hamm, 1993), most studies have been performed in highly controlled settings, thus neglecting the relevance of the context and environment in the studied phenomena. The benefits of laboratory studies are undeniably relevant, but they do not portray real-life scenarios. However, with the advent of both wearable and mobile devices, some of the main technical difficulties found outside the laboratory (i.e., logistics, lack of mobile setups) can be surpassed and new scenarios for data gathering outside the lab considered, allowing a quantifiable and realistic-context follow-up.

Recent technological developments in the areas of biomedical sensors, mobile devices, and wireless telecommunications allow new solutions to measure, communicate, and process information in real time and anywhere (Brás, Fernandes, & Cunha, 2013; Colunas, Fernandes, Oliveira, & Cunha, 2011; Ribeiro, Colunas, Marques, Fernandes, & Cunha, 2011). Good examples are mobile devices, in particular the smartphones that are becoming a ubiquitous resource, with a huge potential in the psychology field. Yet, validation studies are still lacking (Bless, Westerhausen, Kompus, Gudmundsen, & Hugdahl, 2014; Miller, 2012). Smartphones merge several important properties that have great potential: their cost, when compared to typical laboratory settings (see, e.g., Lee et al., 2012); their availability, allowing a better coverage of the target population; and their adaptability to the environment—to context and participants' behaviors (through targeted application development)—thus providing valuable feedback and assessment, for instance, as a treatment outcome. They can also act as a stimulus delivery system—namely through static images, video, and audio—while relying on sensors to collect precise, objective, and ecologically valid data from real settings (e.g., motion, location, and psychophysiology). A few recent studies have already addressed the validity of technology use for assessments of psychological states (Andersson et al., 2009; Botella, Bretón-López, Quero, Baños, & García-Palacios, 2010; Botella et al., 2011; Picard & Liu, 2007; Stopczynski et al., 2014), and in particular of mobile systems as a portable and inexpensive solution (Botella et al., 2010, 2011; Picard & Liu, 2007; Stopczynski et al., 2014). However, studies investigating the validity of monitoring devices including psychophysiological signals, such as electrocardiography (ECG), are still very much in its infancy.

In this article, we propose BeMonitored, a system supported on a mobile device. BeMonitored intends to explore the use of mobile and wearable systems in the assessment and study of

psychological disorders outside the lab. BeMonitored can deliver context-aware stimuli (e.g., time, GPS location) based on both audio and video, while monitoring both behavior (e.g., face motion and activity using the accelerometer) and physiological variables (e.g., ECG, as in the present configuration using an external wearable device; Ribeiro et al., 2011).

As a proof of concept for BeMonitored, we focused on phobias—more specifically, spider phobia. As has been reported in the literature, the exposure to a phobic stimulus by a phobic person triggers an avoidance response (e.g., Öst, 1985). Since it is triggered by very clear and specific ecological stimuli, it is the ideal type of disorder to study the impact of using a mobile monitoring solution. Mobile monitoring could provide solutions to quantify the reaction to phobic stimuli in the assessment of the phobia level or in the treatment follow-up—all in a more realistic and ecological context. Participants were monitored and physiological and behavioral variables were collected, such as ECG, face tracking, video, and audio (i.e., in a multimodal approach), in an indoor setup in order to evaluate the value and reliability of smartphones as a means to monitor phobia.

Materials and method

Participants

The study involved a group of 30 university students at the University of Aveiro, Portugal, who volunteered to participate. All participants filled out the Fear of Spiders Questionnaire (Klorman et al., 1974). On the basis of the questionnaire scores, we assumed that individuals with scores above the 75th percentile were potentially phobic, and those scoring below 25th percentile were considered as a control, nonphobic group. The participants' group score was 13 ± 8 (mean $\pm$ standard deviation), the score for the 75th percentile was 20, and that of the 25th percentile was 7. From the initially 30 individuals who filled out the questionnaire, only seven (two males and five females) fulfilled the inclusion criteria or were available to perform the test—four potential phobics (f2, f5, f6, and f7) and three controls (f1, f3, and f4). The selection procedure to create the high-fear groups resulted in participants with fear levels in the phobic rank, but did not include a formal DSM-V diagnosis of animal phobia (American Psychiatric Association, 2013). The participants had normal or corrected-to-normal vision, did not suffer from any mental or neurological disorder, and were medication free.

The study was approved by the Ethics Committee of the University of Aveiro, Portugal, and both the guidelines of the Declaration of Helsinki and the standards of the American Psychological Association were followed. Participation in the experiment was based on written informed consent,

including the right to end participation at any time. Participants were rewarded with course credits.

Experimental setup and protocol

During the data collection, the smartphone was placed in front of the user, in order to acquire video frames of the participant's face, with the smartphone's front-facing camera, while presenting video stimuli (Fig. 1). To avoid setup configuration problems and ensure that the participant's face was detected regardless of height, the distance to the device, or even the context in which the device was used, the BeMonitored application was developed to include a calibration process to ensure the individual's correct position. The user-worn ECG electrodes and a photoplethysmography (PPG) sensor in order to acquire physiological data. During the calibration phase, the system also extracted the initial heart rate.

A video was presented in each session, during which head/eye movements and heart rate were monitored. The volunteers were exposed to a total of 150 s of video: 10 s with a textual sequence, 35 s with the control1 segment, 70 s with spiders, and 35 s with the control2 segment. The setup used is depicted in Fig. 1.

For each volunteer dataset, we split the data into three groups: control1 (first neutral video), spider (video containing spiders: active), and control2 (second neutral video). The dependent variables were the heart rate, head movement in the x and y axes, and the fixational stability of head movement. The last variable was calculated as

$$P(t) = x_dist^2(t) + y_dist^2(t), t = 1, \dots, N, \quad (1)$$

where x_dist (y_dist) was the distance from the current midpoint eyes position in the x (y) axis to the baseline eyes position, and N was the length of the data collection record.

The segments were compared within each volunteer dataset (paired statistical analysis), using a Wilcoxon signed-rank test (comparing the segments' medians), and also using an F test (comparing the segments' variances). We considered $p < .05$ as marking the significance level. A Bonferroni correction was implemented for multicomparison analysis.

BeMonitored architecture

The BeMonitored system has two main logical blocks—the acquisition box and the smartphone, depicted in Fig. 2. The acquisition box is responsible for the acquisition of physiological information collected from the human participants (1). The smartphone runs the BeMonitored application, which receives the incoming information in the signal acquisition module (2). This module updates the data display and stores the raw data. The signal processing unit (3) is responsible for processing the incoming signals from the acquisition box (1) and performs the relevant event detection. BeMonitored relies on the multimedia resources of the smartphone to acquire both audio and video-image information using the smartphone cameras, and later the video data are processed by the image processing unit (4).

The main user interface is provided by the BeMonitored application responsible for coordinating the several modules during synchronous data acquisition and storage. To ensure that all acquired and processed data are synchronized, all data are archived jointly with a timestamp in the memory store (5). A .txt format file is used to simplify data exporting and human readability. Besides allowing online monitoring of the main information in the smartphone display (6) during acquisition, BeMonitored (when not acquiring a session) also provides basic interfaces for session management, review, and exporting.

Fig. 1 BeMonitored: Components and sample use during a session in a spider phobia study. Note that the participants faced the smartphone but did not hold it, in order to avoid damage to the equipment due to extreme responses of the phobic person

Fig. 2 BeMonitored block diagram: The main components are the acquisition box (a) and BeMonitored, running on a smartphone (b). BeMonitored, besides supporting the acquisition and processing of data

during the monitoring session, also supports basic session management, review, and exporting functionalities

BeMonitored system

The implementation of BeMonitored is based on the Android OS, and a Samsung Galaxy S3 phone was used as the main deployment smartphone. We used the wearable RTABP system (Ribeiro et al., 2011) to acquire ECG and PPG at a 500-Hz sampling frequency, transmitted to the smartphone using a Bluetooth connection. Although this equipment was developed in house, the system is prepared to collect ECG signals from other equipment.

Once parsed from RTABP, the ECG data are processed using an implementation of the QRS detection algorithm by Hamilton/Pan–Tompkins (Hamilton & Tompkins, 1986; Pan & Tompkins, 1985) to calculate the heart rate (HR). This algorithm has already been implemented and tested in the DroidJacket system (Colunas et al., 2011). On the basis of HR, we performed a detector for tachycardia events that triggered an alarm whenever the HR values were higher than 100 bpm (Timby, 2009). The detection of the event triggered an intent at Android OS level that generated an audiovisual alarm, translated in the device vibration with a distinct pattern.

Behavior: Face tracking, audio, and video

To monitor behavior, we relied on the video and audio capabilities of the smartphone. BeMonitored simultaneously collects, processes, and stores both audio (environment sound and voice) and video from the phone’s front-facing camera. To accomplish the online video processing, we opted to acquire sequences of individual frames instead of a video stream. Although the sampling frequency is lower (three frames per second), it allows for processing online and full tracking of the face motion on the basis of the extraction of the eyes position for each acquired frame.

Each captured frame is preprocessed: flipped (rotation of 270 deg) and subsampled to a power-of-two size (currently to 24), which returns an image that is 1/4 the width/height of the original with 1/16 the number of pixels, to optimize the

memory footprint and processing time. The face is detected using the Android OS’s native face detection algorithm, also allowing the identification of the eye position (whenever possible). The middle point between the two eyes is used to estimate the position of the eyes, which is used as our face-tracking solution (Fig. 3).

BeMonitored also creates a record for each participant and session containing personal (photo, name, e-mail) and session-specific information (date, duration of the experimental session) (see Fig. 4a). The record includes all calculated parameters, namely pictures taken, faces detected or not detected, average, higher and lower HR, and events (e.g., eyes midpoints and HR), with the respective timestamps (lower and higher values) (Fig. 4d). This information is stored in an internal application database using SQLite, which can be accessed and analyzed later.

All acquired data (video frames captured, the audio file, and physiological data streams) are stored on the device memory. A file for each session is created with the processed data (eyes midpoints and HR values).

Fig. 3 Face-tracking example using eye midpoint estimation. Using an initial position (a), the face tracker estimates the face displacement during the session (b)

Fig. 4 BeMonitored user interface. Here are some representative snapshots of the BeMonitored user's interface: (a) record management, including session review and data export; (b) video calibration screen, to ensure that the participant is in front of the smartphone; (c) snapshot from the spider segment video; (d) online/offline review screen, presenting the

participant's face on top, the initial and current heart rate (72 and 84, respectively) and a graph of the face position during the session. Vertical lines represent two protocol condition changes. On the bottom is a chart presenting the face motion across time

Data acquisition

Each session is defined by a specific video (the stimulus) and a set of video-dependent timestamps (presented in the online display, Fig. 4c) in order to tag relevant events or protocol transitions. This description is contained in an uploaded XML file and can be customized according to the aim of the session.

During a BeMonitored session, there are three main stages: calibration, baseline, and the session protocol. The calibration process is performed at the start of every acquisition. At this stage, an online face-tracking process starts, using the phone's

front camera. The user sees him-/herself on the screen, and with the help of a feedback rectangle, he/she adjusts the position of the head. This procedure ensures that the system is able to capture the volunteer's face (Fig. 4b). During the calibration phase, the system starts the physiological (currently ECG) data collection. Overall, this protocol stage lasts 1 min and establishes the baseline for the HR and the head/eye position measurements.

In order to establish a baseline for future analysis, the first 10 s of the video stream are presented to the user with a textual sequence. During this period, the system makes an average of

Fig. 5 Dispersion of face-tracking movement (fixational stability) in relation to initial position) for the seven volunteers, considering the control1, spider exposure, and control 2 segments. The phobic participants are Subjects 2, 5, 6, and 7. Subject 6 is an extreme example; during the session, he/she felt high discomfort and tried not to

focus on the video in the spider segment, with that response being translated to a high variability in spider segment. Each boxplot represents the 75 % percentile, median, and 25 % percentile for the face-tracking movement

Table 1 Medians and percentiles 25 and 75 are presented in the table for all participants, in the format median [percentile25, percentile75]

	control1	spider	control2
f1	83.00 [81.00, 83.27]	81.00 [78.00, 83.00]	83.54 [83.00, 85.00]
f2	72.30 [65.94, 80.01]	78.95 [73.63, 83.33]	72.30 [68.18, 77.94]
f3	125.00 [122.40, 128.30]	109.72 [96.00, 113.86]	93.00 [91.71, 95.82]
f4	125.00 [125.00, 127.58]	96.00 [84.26, 120.00]	81.84 [79.38, 82.76]
f5	57.00 [57.00, 57.72]	57.00 [56.00, 57.60]	56.00 [56.00, 57.00]
f6	93.75 [88.24, 99.85]	97.09 [86.52, 108.23]	95.55 [89.55, 105.63]
f7	71.00 [69.00, 73.00]	78.00 [73.00, 85.00]	66.00 [65.00, 68.00]

the first 30 midpoints of the eyes coordinated to get the baseline (3 frames/s = 30 shots) for the initial face position.

After the calibration and baseline stages, the video starts to be displayed and the behavior (face position) and physiological data to be acquired. During this stage, the acquired data are used to extract the online signal and video-related parameters. The test and the acquisition process end when the video also ends.

Data archiving and exporting

Besides storing data in the Android file system, we also decided to enable export ability of the data to the cloud to a common, online folder, to serve as an offline storage/analysis resource. Currently, we are using Dropbox and have deferred to it all the data transfer and synchronization, to distance both the application and the user from the data transfer process. The export process implies an explicit export option from the BeMonitored user. The selection of Dropbox was based on the good native support for both Android and other major OSs.

Results and discussion

This article's major goal is to present the BeMonitored software as a new tool for behavioral and physiology data collection in ambulatory conditions. To accomplish this goal, we collected and analyzed data (fixational stability and HR) in order to support the hypothesis that presenting the fear stimulus on a smartphone induces both behavioral and physiological alterations in the participant.

The data acquired and processed by the monitoring application revealed an alteration in the behavior of all volunteers while they were exposed to spiders. The fixational stability was significantly different between the control1 and control2 segments ($p < .05$), except in one nonphobic volunteer (f1). When comparing the spider with the control1 segment, a similar result was obtained—significant differences ($ps < .05$) for all volunteers except one nonphobic subject (f1), indicating a behavioral response change when spiders were shown. A significant difference ($p < .05$) was also observed between the spider and control2 segments, in all except three (f1 [nonphobic] and f6 and f7 [phobic]) volunteers. Our results also showed that the variance of the fixational stability in the spider segment

Fig. 6 (a) Clustering using the K-Medians method, relating the control1 and spider segments; (b) dispersion diagram of the data of each participant

Fig. 7 (a) Clustering using the K-Medians method, relating the control1 and control2 segments; (b) dispersion diagram of the data of each participant

was higher than the variance in the control2 segment ($p < .05$), except in the nonphobic volunteers (f1, f3, and f4) and f7 (the boxplots in Fig. 5 allow a similar interpretation).

Regarding the HR responses (Table 1), we found a significant difference between the two control segments except in two phobic volunteers (f2 and f5, $ps < .05$). A significant difference was apparent in almost all volunteers ($p < .05$; except in f5 and f7 [phobic]) when comparing the control1 and spider segments. This may have been motivated by the fact that these participants were aware that they would be confronted with spiders, which might have altered their baseline anxiety (e.g., HR values). The observed variance in the spider segment was higher than the variance in the control1 segment (i.e., there was an activation, $p < .05$), in all except two phobic participants (f2 and f7). Moreover, the increase of variance in HR and in fixational stability suggested that

individuals displayed a specific response, both psychological and behavioral, after the exposure to spiders.

The clustering algorithm K-Medians was used to study the relation between the data segments and dispersion diagrams. Initially, the data were analyzed using a configuration with two clusters ($K = 2$), in order to identify the two groups (nonphobic and phobic). However, by using this configuration, one participant constituted a cluster, which was justified by his/her extreme reaction to the stimulus. Therefore, and since we intended to separate at least the nonphobic participants, we decided to include an extra cluster, in order to group participants with the same characteristics. Consequently, we used a configuration with three clusters ($K = 3$), thus grouping nonphobic, probable phobic, and extreme reactions. The three clusters identified (Cluster 1, Cluster 2, and Cluster 3) are represented in the Figs. 6a, 7a, and 8a.

Fig. 8 (a) Clustering using the K-Medians method, relating the control2 and spider segments; (b) dispersion diagram of the data of each participant

The analysis of the clusters suggested a possible discrimination between the phobic and nonphobic groups. Considering control1 versus spider (Fig. 6a and b), Cluster 2 contained data from f7 (phobic), Cluster 1 data from f2 and f6 (both phobic), and Cluster 3 contained the remaining data (phobic and nonphobic).

In relation to control1 versus control2 (Fig. 7a and b), Cluster 3 contained the data from f7 (phobic); Cluster 1 contained data from f2 and some from f7 (both phobic); and Cluster 2 contained the remaining data (mixing phobic and nonphobic data). Finally, in control2 versus spider (Fig. 8a and b), Cluster 2 contained data from f2, f4, and f6 (f4 is nonphobic); Cluster 3 contained data from f7 (phobic); and Cluster 1 was composed of the remaining participants' data (collapsing phobic and nonphobic).

By analyzing Figs. 6a, 7a, and 8a, it was evident that participant f7 was always differentiated from the other volunteers, representing in some cases an independent cluster (Figs. 6 and 8).

Overall, even considering the limited number of participants, the results suggest that by using these clusters it might be possible to distinguish spider-phobic from control participants using the fixational stability captured by the smartphone's camera. One possible justification for the obtained results may be that, for control participants, the spider stimuli were evaluated as innocuous, and therefore did not significantly influence their behavioral and physiological responses. On the other hand, the phobic participants showed a distinct behavioral response, which was consistent with the extensive literature on fear and phobias (e.g., Öhman & Mineka, 2001). In fact, the fear or the discomfort experienced by those individuals when confronted with the stimuli were translated into an avoidance response, as has been mentioned in the literature (Antony & Barlow, 2011; Hood & Antony, 2012; Wilhelm & Grossman, 2010).

The sample size constitutes a limitation in the extrapolation of the results, since it is not representative of a phobic population. The overall pattern of results from the present study shows the potential usefulness of smartphones in phobia monitoring, regardless of the small sample size. Due to the inherent characteristics of smartphones, they may indeed constitute a potent instrument that may enable a natural evolution from lab monitoring to outside monitoring of several disorders. However, the evolution from the indoor to the outdoor setup will only be possible after ensuring smartphones' physical integrity in the face of extreme reactions during the exposure to phobic stimuli.

Conclusion

In this article, we proposed BeMonitored, an affordable smartphone-based solution to support more ecologically valid

monitoring of psychological experiments. BeMonitored delivers customizable, specific, context-dependent audiovisual stimuli and is able to capture the participant's behavior, physiology, and environment by using external resources connected via Bluetooth or the smartphone's camera and audio. BeMonitored produces synchronous data for each session in an accessible and readable text format. Although BeMonitored was initially intended to be fully autonomous, we extended it with the ability to explicitly export the data from the application directly to the cloud using Dropbox (e.g., a Research folder on the desktop). Currently, we are proceeding with validation of BeMonitored to release it as a freely available support tool. We aim to provide an information system back office for data management, as well. BeMonitored also provides basic session management, namely for demographics, and supports offline review of all related information for a given session (acquired data and participants' demographics).

We found significant variations of HR during the spider events and showed that spider phobics could be differentiated from control participants using solely the face motion captured by the smartphone camera. Although further tests are needed, due to the limited number of participants, BeMonitored has proven to be a viable system that by design can be further extended to provide other physiological and behavioral parameters.

Although our focus was on spider phobia, BeMonitored could be applied to other phobia-related assessment and monitoring, especially in cognitive-behavioral therapy scenarios (e.g., Öst, 1985).

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