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Seismocardiography with Smartphones: No Leap from Bench to Bedside (Yet)

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Abstract. For a decade, seismocardiography (SCG) on smartphones has been an interesting topic within the technical community, but mobile applications for this topic are rare on the market. The transition from laboratory to bedside application seems to have not yet been completed. To possibly increase the chances of a successful implementation, the added value of the method needs to be addressed clearly and backed up by research. The authors address the following aspects. 1. To improve comparability, standardization is required, 2. adequate validation processes in clinical settings will build trust, but foremost, 3. the field of application should be critically evaluated to identify the most meaningful and reasonable benefit of this method.

Keywords. smartphone, seismocardiography, transition

1. Introduction

The heartbeat felt on a body's surface is a representation of vibrations that result from the heart's muscular tension and relaxation, blood flow and recoil through the greater vessels. Seismocardiography (SCG) is a method that records these vibrations and correlates them with cardiac function [1]. SCG could be used as a non-invasive diagnostic tool for cardio-vascular conditions and monitoring procedures. Since the 1960s accelerometers have been used to measure the characteristic signals. With the rise of the smartphone industry in the early 2000s, the Micro-Electro-Mechanical Systems (MEMS) technology led to smaller and cheaper accelerometers in general. This effect is assumed to be correlated with an increase in SCG research [2]. Accelerometers became integral components for smartphones (and other smart technology) and were utilized for manifold research inclusive SCG studies. The goal of this paper is to snapshot the current market for smartphone apps using accelerometers for diagnostic purposes regarding SCG and the state of the art in the medical and technical literature according to the topic and to give a short review of the findings.

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2. Method

2.1. Literature Research

A literature search was conducted on the 22.02.2022 in the literature databases (PubMed, IEEE Explore and ACM) based on the PRISMA standard [3]. For procedural support, the web based Rayyan® content management system for systematic reviews (Rayyan® Systems, Inc., Cambridge, Massachusetts, USA) was utilized. The keywords “seismocardography” AND (boolean operator) “smartphone” were utilized for research. Only articles from 2000 to 2022 (in English or German) were considered to capture the emergence of smartphone technology during this period. The abstracts of the identified articles were blindly reviewed by two individuals. Duplicates were removed. Articles were excluded that dealt with the wrong population (animals), the wrong technology (no smartphone), or the wrong method (PPG; activity tracking; location tracking; sleep tracking; tremor). The selected articles were analysed according to the aspects shown in Table 1. The review results were compared for differences. In case of a deviate opinions of the raters, the aspects were discussed.

Table 1. Items and expressions applied for the literature research.

Item	Expression
Study type	viewpoint; review; feasibility; explorative; comparative; other
Sensor system	none; accelerometer, gyroscope; combination; other
Endpoints	heart rate; heart rate variability; pulse transit time; cardiac myocardial function; cardiac valve actions; respiration rate; stress level; other; n.a.
Population	healthy; ill; both; n.a
Field of application	health promotion/fitness; prevention; diagnostic; therapeutic; other; n.a.
Indication	one; atrial fibrillation; myocardial infraction; cardio-vascular disease; other; n.a.
Research	yes; no
Setting	bench; bedside; both; n.a.
App availability	not available; available for research; available on the market; n.a.; unknown
Mobile operating system	iOS®; Android®; other; n.a.; unknown

2.2. Semi-Automatic Retrospective App Store Analysis (SARASA)

We performed a semi-automatic retrospective App Store analysis (SARASA) following a standardized protocol published in detail here [4]. The SARASA process comprises a keyword-based filtering and metadata-based description, review, and ranking steps that were applied to a dataset retrieved from the Apple® App Store® (Apple® Inc., Cupertino, California, USA). The basis for this study’s SARASA application was a readout of all apps listed in the “Medical” and “Health & Fitness” store categories of the Apple® App Store® Germany that took place between 12.03.2022 and 13.03.2022. To apply SARASA, the keywords “ballisto*”[2] OR (boolean operator) “seismo*” OR “accelero*” were used for filtering the app store descriptions. The app description texts for the matching apps were reviewed by two reviewers. Apps were excluded following the same exclusion criteria used for the literature research.

[2] Seismocardiography is a variation of Ballistocardiography (BCG) that measures the energy driven shift of the body mass center of gravity. Seismocardiography focuses more on the heart as organ.

3. Results

3.1. Literature Research

20 articles were identified, one duplicate match was deleted, and another article was excluded (animal experiment). 13 journal articles and 5 conference articles (n=18), including 1 viewpoint, 1 review and 16 feasibility (5 with comparator ECG) studies were included in the analysis. 2 articles were published in biomedical journals, 16 in technical journals, the publication date lying between 2012 and 2021. Except the viewpoint and the review article, all articles were associated with conducted research. The laboratory setting (bench) dominated in 16 studies. 10 articles solely described the use of the built-in accelerometers; in another 8, the accelerometers were used in combinations with a gyroscope or additional sensors. Apps were used in 11 articles (iOS: 5; Android: 4; unknown: 2), of which 2 apps are available in app stores[3]. 9 apps were developed by the researchers but had not been made publicly available. In 2 meta-articles (viewpoint and review), no apps were utilized. All articles explored the diagnostic purpose as field of application. 3 articles focused on atrial fibrillation (AFib), 1 on myocardial infarction (STEMI), and 1 on both indications plus coronary artery disease. In most feasibility studies, the endpoints were mixed: heart rate variability (HRV), heart rate (HR) or/and heart rhythm were in the focus of 13 publications, whereas 4 publications centred on myocardial function, 3 on the Pulse Transit Time (PTT), and 1 additionally dealt with respiratory rate or stress level. 11 studies included healthy subjects as opposed to sick patients in 3 studies, and another 3 dealt with both healthy and sick subjects (one included no human subject).

3.2. Semi-Automatic Retrospective App Store Analysis (SARASA)

At the beginning of the App Store® readout, there were 96.615 apps listed in the "Medical" and "Health & Fitness" categories of the German store front of the Apple® App Store®. Altogether, 96.534 apps were excluded from our analysis (22.036 apps did not provide a German or English store description text, and 74.580 did not match any of the three keywords). The resulting 81 apps (13 medical, 44 health/fitness, 24 other) were manually screened for an applied SCG or BCG method. 78 apps were excluded due to mismatch (no use of accelerometer: 2; seismology: 1; no further information on purpose: 1; for activity tracking: 39; for localisation tracking: 11; pedometer: 2; sleep tracker: 4; tremor detection: 7; other: 11). However, 2 apps were included for deeper analysis as shown in Table 2. Both were commercially available. 1 app depended on an external accelerometer sensor to be deployed under the bed mattress. The respiration rate as well as cardiac parameters (HR, HRV) were recorded. Only one app uses the in-built accelerometers for HR analysis. In the description texts, there was no indication that any of the apps or developers were related to any scientific research projects or research institutes of the literature results.

[3] A hand search for these apps in the Apple® App Store® Germany was unsuccessful. These apps may have been discontinued due to the fast life cycle of apps in general. In Google's Play® Store (Google® LLC, Mountain View, California, USA), however, one app was still available.

Table 2. Results of the SARASA. Description of three apps identified. None referenced to a research project from the literature research. Names and brands of the app are omitted for reasons of neutrality.

No	Description	Store Categories	Medical Device
1	Detection of the heart rate by utilizing in-built accelerometer. Smartphone is meant to be hold in the hand during the measurement.	Health & Fitness; Education	no
2	AI-based contact-less health monitor with remote monitoring and alert system. Analysis heart rate, respiratory rate, sleep. Uses an external accelerometer placed under the mattress.	Health & Fitness; Lifestyle	unknown
3	Heart rate and respiratory rate collected by an external sensor worn on the chest.	Health & Fitness; Medicine	yes

4. Discussion

The literature research covering > 20 years showed some interest in applying SCG concepts on smartphones by the technical community. Nevertheless, only 3 apps of that kind were available on the App Store®[4]. None of these apps was affiliated with the research. In the following, we will discuss possible reasons why the transformation has not happened in the last two decades.

The advantages of smartphone SCG (low cost, availability, easy application, non-invasiveness) are described well and the field of application (diagnostics), and endpoints (e.g., heart rate) have already been identified. Nevertheless, this seems not to raise enough interest in the health care professional (HP) community. The algorithmic driven detection of the heart rate, heart rate variability and respiratory rate is in the focus of most publications and apps found in the App Store. However, the same cardiovascular information could also be retrieved using other sensors integrated in the smartphone. For instance, photoplethysmography (PPG), which utilizes the smartphone camera in combination with the in-built light source (or sensors dedicated specifically to this purpose), is already established in health care and provides heart rate measurement as well as automated diagnosis of heart rhythm disorders [5]. Compared to SCG, the PPG method is more convenient to use, and measurements are less affected by common disturbances (vibrations through breathing, talking) [6]. Moreover, the HP community may be reluctant to smartphone SCG as there is a gap in clinical evidence through clinical trials with a sound design and appropriate sample size. Some authors criticize a lack of standardization to harmonize acquisition protocols for SCG on smartphones (population characteristics, sensor location, filter and analysing concepts, sampling rates, comparison with “gold standard” techniques) and ask for extensive validation [7].

From the technical perspective, additional aspects need to be considered that lead to uncertainties in measurements. Accelerometers vary between devices and manufacturers. A comparison at the sensor level alone is thus often only possible based on reviewing the respective data sheets. Furthermore, today’s digital accelerometers are highly complex and extensively configurable systems (e.g., with respect to resolution, output data rate, internal filters, pre-processing, etc.). The developers of apps in this context commonly do not care about (or may even be not aware of) these hardware-specific details at first, since often, the mobile platforms offer programming interfaces (APIs) that encapsulate

[4] As SARASA is not available for Google Play® Store, a non-standardized preliminary manual search was conducted on 15.03.2022 using the above-mentioned search terms, which resulted in no matching app dedicated to SCG or BCG.

access to the underlying hardware. But even with standardized API based access to the sensors, varying degrees of sensitivity of the sensors regarding the measurements (and potential interference) must be considered. Latencies introduced for technical reasons, as well as due to the operating system, can also influence the measurement [8].

5. Limitations

Due to the chosen keywords, the literature research was limited. It is known to the authors that there is a vast amount of literature on the topics of BCG and accelerometery, but for the purpose of correlating the findings with smartphone technology, the search was narrowed down accordingly. A method of systematic research of description texts in the Google Play® store (similar to the SARASA based evaluation of Apple's App Store) was not available and was thus not conducted. For this store, only a manual search was performed. Therefore, the results regarding the Google Play® Store are limited and possibly incomplete.

6. Conclusions

Using smartphones to explore the possibilities for diagnostic application of SCG is a popular practice within the technical community. However, these endeavours are not reflected by the mobile applications available in the app stores. To possibly improve the process of bringing the technology from laboratory settings to health care practice, further research into smartphone-based SCG is needed that addresses the added value of the technology. For improving comparability, standardization is also essential. Research-backed validation processes in clinical settings will also boost trust, but foremost, the field of application needs to be critically appraised to identify the most meaningful and reasonable benefit of this method.

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