# Smartphone-Enabled mHealth Sensorics for Digital Assistance of Human Autonomic Resilience to Stress

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***Abstract*—Quality of life largely depends on the ability of a person to resist stress, what refers to the concept of resilience to stress. The priority groups are older and frail people, disabled people and people under strain conditions. The autonomic resilience, along with the motor and cognitive resilience, is regarded as one of the major components of resilience. In frail people, autonomic resilience is substantially reduced. In this concept position paper, we explore human autonomic sensorics when an mHealth system provides digital assistance in autonomic functioning of a person during her/his daily activity. The core of our concept is a smartphone which can used in person's daily activity for monitoring such critical markers of the human autonomic function as orthostatic hypotension during transition from supine or sitting to standing position. A smartphone has potential to sense both blood pressure and heart rate during events of postural transition. The developed mHealth concept aims at digital support of the autonomic activity of a person in his/her daily life. The provided information encourages the person for better performance and results.**

## I. INTRODUCTION

Quality of life largely depends on the ability of a person to resist stress, what refers to the concept of resilience to stress during person's daily activity. The priority groups are older and frail people, disabled people and people under strain conditions, as well as young people and people living in urban areas [1, 2]. Human resilience is related with the following three functions of human.

a) Motor function: the movement activity.

b) Cognitive function: the thinking process.

c) Autonomous function: the internal body processes.

The IoT-enabled mHealth technology supports effective monitoring the performance of these human functions [3, 4]. The autonomic resilience, along with the motor and cognitive resilience, is regarded as one of the major components of resilience. In our previous work, we studied the motor resilience [5] and cognitive resilience [6]. In this paper, we continue our research on the concept of smartphone-enabled mHealth sensorics for digital assistance of human resilience to stress. We explore human autonomic sensorics when an mHealth system provides digital assistance in autonomic functioning of a person during her/his daily activity.

In our concept, the core of the system is a smartphone which can used in daily activities of life for monitoring such critical markers of frailty in the autonomic function as orthostatic hypotension (reduce blood pressure due to decreased baroreceptor sensitivity) during transition from supine or sitting to standing position. Then the markers are used for evaluating the human resilience to stress.

In general, the developed mHealth concept aims at digital support of the activity and performance of a person in his/her daily life. The concept assumes that a smartphone can construct a personal smart space where internal and external sensors provide status information on the motor, cognitive, and autonomous function [4]. This study is limited with the case with the autonomous activity. We discuss the opportunities of smartphone-enabled monitoring of the autonomous function in respect to digital assistance of people in resilience to stress.

In respect to the autonomous function, an important opportunity of a smartphone is its potential to monitor both blood pressure and heart rate based on movement-related sensors. Inertial Motion Units (IMUs) are sensors that measure movement in multiple axes. Accelerometers are sensors that measure a changing acceleration on the sensor. Gyrometers are sensors that measure changing angular motion. Such sensors are basic components to measure the human autonomic function based on "movement" implications, similarly as it happens in measurement of the cognitive function [6].

The digital assistance uses the collected measurements, which provide the base to "make insight" to person's autonomous function and its consequences to the health. The person has a digital tool to observe and analyze own health. The provided information (services) assists the daily activity. The provided information encourages the person for better performance and results, so supporting the resilience to stress and making higher the quality of life (QoL). Note that such information is useful for physicians, but our concept primarily oriented to the case when the person is the key consumer of the information.

The rest of this paper is organized as follows. Section II provides a wide literature review in healthcare to discuss the terms of human resilience, human vitality, and frailty. Section III discusses the reasons of smartphone-enabled sensorics for digital support of human resilience to stress. Section IV considers possible cases of using a smartphone as a monitoring tool of digital support for the human autonomic frailty and resilience to stress. Section V summarizes the key findings of this concept study.

## II. Problem Review: Human Resilience, Frailty, and Vitality

The phenotypic approach to socio-medical problems is attracting increasing attention from health professionals and physicians due to the growing need to monitor and evaluate human performance under certain biomedical conditions, primarily aging, stress, and disability. Among the phenotype-oriented concepts currently being studied are "resilience", "frailty" and, to a lesser extent, "vitality".

### *A. The Terms*

Vitality is a kind of subjectively estimated "life force", "internal capacity", "liveliness", "vigor", "strength" or "feeling full of energy", which has several determinants such as positive mindsets and emotions, purposeful living and good social connections, physical activity and mobility [7, 8]. In this sense, the notion of vitality is close to the concept of Qi (or vital energy) in Chinese philosophy and medicine [9]. Such features cannot be readily described in terms of physiological mechanisms and, correspondingly, measured in conventional units of measurement. In a sense, these concepts are rather socio-psycho-medical than physiological [10]. Nonetheless, vitality, resilience and, especially, frailty can be assessed with questionnaires and certain measures [11].

The concept of resilience is generally close to the concept of viability, although it has a different meaning. Resilience is understood as a person's ability to withstand (adapt) life stresses (troubles, misfortunes, failures, etc.) or "bounce back" from stressors [12]. The inability to withstand stressors can lead to certain medical conditions, primarily stroke, myocardial infarction, stomach ulcers, depression, anxiety, and apathy. Therefore, the main goal of resilience is to cope with stressors and prevent their negative consequences. Some people are more resistant to life stress, while others are less. To better understand the idea of resilience, it would be useful to use the concept of *frailty*.

Frailty refers to a state of functional multisystem failure characterized by several distinct *external* signs (symptoms), primarily 1) weakness (dynapenia) 2) slowness (e.g. slow walking speed), 3) low physical activity ("low energy"), 4) unintentional weight loss (due to sarcopenia and not only) and 5) fatigue (exhaustion). The term "frailty" and its properties are actively discussed in latest medical research, e.g., see [13-18].

Frailty is associated with increased vulnerability and reduced ability to tolerate physiological stress, including recovering capacity from a stressor. In that sense, the state of frailty is generally opposite to the state of resilience, and therefore can be used to indirectly assess resilience. Due to comorbidities, such marker as polypharmacy may be added to the list of frailty symptoms [19]. Sociodemographic (age, sex, education), nutritional and psychological factors also contribute to frailty.

Pathophysiologically, frailty is associated with chronic inflammation and chronic pain, which are expressed as abnormal immune, metabolic and hematologic markers [20]. Thus, due to thoroughly established parameters and markers frailty looks promising to indirectly (inversely) evaluate resilience to stress in focus groups. In general, phenotypic approach allows evaluating such features as "ability", "capability", and "potential" without strict comprehension of actual physiological mechanisms of these features, and frailty.

### *B. Markers of Physical Frailty (PF)*

The physical (motor) dimension of frailty, such as mobility (or the ability to change location in the environment that is move between two locations) or motility (the ability to move) presumably are the best suited to assess frailty, because physical abilities are the most "external" (explicit). The aforementioned motor characteristics of frailty are physical by their nature and, therefore, easy to measure.

To example, weakness (dynapenia) is measured as force (N) of hand grip, slowness - as walking speed (m/s, km/h), weight - as body mass (kg), and physical activity - as metabolism (kcal/hour) or number (rate) of stepping (actigraphy), fatigue – as decline in performance (in movements per time unit). The introduction of the concept of frailty allows applying conventional measuring physical and physiological equipment or inventing novel facilities and instruments.

Indeed, in our earlier study in this field, we presented a list of motor tests and tasks that are widely used in motor physiology and neuroscience to characterize the motor system and, potentially, measure weakness [5]. Among these, are Walking Speed test, TUG-test, Trail-Walking test, 2-, 6- and 10-minute Walking test, backward walking, tandem stepping, maximal step length, miniBEST, Sit-to Stand tests, socks task, and many more.

The analysis of these tests and tasks allowed identifying some measures which allow distinguishing between normal and frail motor activity. For example, study [21] recommends 7,0 kg of muscle mass per $m^2$ for men (5,7 kg/m2 for women) as measured by bioimpedance analysis, handgrip strength >26 kg for men (>18 kg for women), and gait speed at >0,8 m/s as normal ones. Similarly, study [22] recommends speed 1,24 m/s as a cutoff point for gait speed in the elderly. Normally, healthy older old people (over 80 years) walk at a speed 0,96 m/s [22]. Stepping pace in older men at the age 70 years was estimated as 103 steps/min with step length 66 cm and with step time 0,58 s [23]. Older non-frail women walk at 112 steps per min.

Thus, the average walking speed for the elderly is approximately around 1,0 m/s. Correspondingly, within 2 minutes older people can walk >134 m [24], and within 6 minutes - > 392 m. These tests and tasks can be suitably combined with mHealth methods for frailty/resilience evaluation [5, 6].

### *C. Markers of Cognitive Frailty*

Cognitive frailty (CF) "…is characterized by reduced cognitive reserve, but is different from the physiological brain aging. At the same time, it is noteworthy that, under different circumstances, cognitive frailty may also represent a precursor of neurodegenerative processes…" [25, p. 726]. Also, "…cognitive frailty" as a heterogeneous clinical manifestation characterized by the simultaneous presence of both physical frailty and cognitive impairment…" [25, p. 726]. Thus, according to this definition, CF generally refers to decline in mental abilities and is closely associated with the PF.

To identify CF, a comprehensive cognitive assessment exploring memory performance as well as other cognitive functions (i.e. executive functions). Several cognitive tests and instruments were proposed such as speed of processing test, the Montreal Cognitive Assessment test (MoCA), the Mini Mental State Examination (MMSE) and the Alzheimer's disease Assessment Scale-cognitive subscale (ADAS-Cog). MoCA and MMSE are most frequently used as screening tools for CF [19]. CF is a multi-domain condition; it includes impairment in attention, information processing speed, memory and execution domains [19]. In addition, CF and PF are closely associated with each other and are usually concurrent in a frail individual [25, 19]. Altogether, this prompts application of motor-cognitive tests to assess frailty.

In our earlier study we suggested to apply certain stimulus-reaction (SR) and finger tapping tests FTT), which are widely used in assessing the motor-cognitive performance in aged people and people with Parkinson's disease, for the use as biomarkers of CF in a smartphone. In particular, simple reaction time (SRT) can be used to assess the stimulus detecting time, and choice reaction time CRT) would help evaluating the decision-making function, while FFT allows assessing execution ability (motor time) [6].

*D. Other manifestations of frailty*

However, besides the motor (physical) and cognitive signs, frailty is associated with several autonomic symptoms (dysautonomia) [26]. The autonomic nervous system and corresponding visceral organs are responsible for supplement and storage of energy what is known as "autonomic provision of motion". Besides the physical (motor) domain, cognitive, and autonomic, frailty includes social and psychological dimensions [19]. Altogether, frailty can be descripted as a phenotypic syndrome which includes several external signatures (symptoms or markers) with established cut-off normal range. Then a question comes: what kind of sensorics must be figured out to collect such data?

*E. How one can identify frailty?*

Currently, there are two major approaches to collect physiological data – in the laboratory (or in-hospital) and field setting. Within another dimension, the physiological data on the body functioning can be collected

1) Invasively, i.e. blood or cerebral liquor sampling, which means penetration trough the defensive barriers (skin, mucosa) to the internal environment.

2) Non-invasively, i.e. saliva and urine sampling or electrophysiological investigation, which mean collecting data from the surface of skin or mucosa without penetration. Non-invasive methods refer to so-called "dry" physiology.

As the invasive sampling requires penetration through skin or mucosa, it is painful and stressful. For that reason they are the least relevant for monitoring bodily functions or characteristics. Surface self-adhesive or wearable sensors (for example, electrocardiography or electroencephalography, accelerometers) are less annoying, but can also be stressful. Even wearing such an advanced sensor as "smart clothes" informs the subject that he/she is participating in the experiment.

The in-lab setting can be regarded as a "gold standard" approach because it allows controlling the process of data collection and is supported by excellent laboratory scientific equipment. From the other side, staying in the laboratory still means to stay within the experiment. That inevitably influences the outcome as the experimental setting provokes stress. Indeed, "… simply being in the field—no matter how physically challenging the task being performed—does influence physiology." [27, p. 10].

For that reason we would exclude the "smart clothes" techniques, textile and wearable sensors from further consideration because wearing them inevitably means participating in experiment.

For the same reason we avoided discussing varied smartphone applications which represent a kind of self-administered measurement (auto-measurement), because self-experimenting does influence physiology [28], it often fails and require discipline and persistence [29].

We presume that the best way to collect data is to collect them totally insensibly which means that the subject do not feel him/herself as being immersed into the experiment. The only possibility to follow such requirement is to use a household appliance (device) which is:

1) Widely spread in all possible focus groups of people, including aged and disabled people.
2) Always at-hand.
3) Highly personal.
4) Suitably primed for integration to the Internet, the mHealth and AI technologies [30].

To our opinion only a smartphone and its basic functions would have helped collecting data on a person with minimum inference with him/her. Therefore, there were two major aims to the study:

1) To identify autonomic frailty signatures which potentially can be measured with the smartphone basic functions and find ways to integrate them with mHealth methods.
2) To identify basic smartphone functions which are already primed for assessment of autonomic frailty.

In other words, we aim at further instrumentalization (adaptation) of a smartphone for frailty monitoring in addition to our earlier studies [5, 6]. The digital assistance uses the collected measurements, which provide the base to "make insight" to person's autonomous function and its consequences to the health. The person has a digital tool to observe and analyze own health. The provided information (services) assists the daily activity. The provided information encourages the person for better performance and results, so supporting the resilience to stress and increasing QoL.

## III. Smartphone-Enabled Human Sensorics

In general, the developed mHealth concept aims at digital support of the activity and performance of a person in his/her daily life. The concept assumes that a smartphone can construct a personal smart space where internal and external sensors provide status information on the motor, cognitive, and autonomous function [4]. Various sensors are increasingly used to collect physiological information on the body functioning.

Wearable (accelerometers, gyroscopes) and self-adhesive sensors are used to assess motion and neuromuscular function. For example, electromyographic self-electrodes are already used to monitor the condition of neuromuscular system in subjects with Parkinson's disease to evaluate levodopa treatment or deep brain stimulation [31] or epilepsy type 1 [32]. Accelerometers and actigraph units are widely used to assess motion in older people [33], in frail people [34].

Wearable and portable GPS technologies are used to monitor mobility in people with neurodegenerative diseases [35] and dementia [36], to detect falls [37], and monitor daily physical activity [38, 39]. "Smart" clothes (electronic textiles or e-textiles) also draw significant attention from healthcare practitioners [40]. E-textiles are used to assess the level of stress [41] and motion [42, 43]. Usually, smart clothes help monitoring several parameters, such as heart rate, respiratory rate, temperature, motion and skin sympathetic reaction, which are critical to stress assessment.

Both wearable and e-textile sensors are becoming ever more sophisticated. Still, they are "sensed as being sensors" by users. This means that the experimental setup still influences the physiological state of the subject.

Smartphones are comparable with e-textiles or wearable inertial sensors by sensing functionality. For example, a smartphone is equipped with IMU (inertial measuring unit) and can be used to assess gait and balance in subjects with Parkinson's disease [44, 45] or post-stroke patients [46]. Currently, accelerometers and GPS applications are the most popular in mHealth applications of a smartphone [47].

Note that a smartphone is perfectly primed for integration in Internet of Things (IoT), smart spaces (SmS), and Ambient Intelligence (AmI) [3]. The mHealth system serves as at-home Laboratory for personal use by a given person [4]. In addition, a lot of applications are available to assess varied bodily functions [48, 49]. Altogether, a smartphone seems to be very promising tool to assess frailty and to provide digital assistance for resilience to stress.

## IV. Possible mHealth Implementation

Let us consider possible ways to use smartphone-oriented sensors to assess the frailty and the autonomous resilience level.

### *A. Markers of Autonomic Frailty*

One of the most readily seen symptoms (markers) of autonomic frailty is orthostatic hypotension (OH) that is inability to hold normal BP after postural transition from sitting (or supine) to standing position [50-53] due to insufficient baroreceptor sensitivity [54]. Lowered BP in standing position often results in dizziness, blurred vision and falls [50] what in general is known as orthostatic intolerance.

Heart rate and heart rate variability (HRV) are also affected in frail people [55, 56]. Namely, rest heart rate is decreased and numerous HRV parameters are specifically modified in frail people. From the physiological point of view, all orthostatic tests evaluate the baroreflex sensitivity (BRS) as shown in Table I. In case of OH, the baroreflex activity is reduced.

Thus, there are the following two well-established markers for autonomic frailty.

1) orthostatic hypotension
2) heart functioning characteristics

They measure HRV and heart rate (either during OH or per se). These markers are detected and evaluated with definite physiological tests.

### *B. Screening tests and cutoff values for autonomic tests*

OH is evaluated with help of several orthostatic tests - Active Standing Test (AST), Sit-to-Stand test (SST), and Head Tilt Test (HUT) also known as Tilt Table test (TTT) [57]. The HUT appears as a passive OH test, requires special rotating table which allows changing position of the body in the frontal plane from horizontal to vertical [58] and even upside down. This method is regarded as accurate but is performed only in the laboratory (hospital) environment, and requires much resource (the rotating table, qualified staff, and BP measuring device). In addition, HUT is a time-consuming method [57].

The remaining tests (AST and SST) are active by their nature as they must be performed by subjects by their own. The SST test is usually used to evaluate performance capacity of a subject and van be conducted in a form of Five Time SST what not exactly corresponds to the purpose of evaluating the OH.

In that respect, AST is the most relevant method to evaluate OH. This method is active because the subject performs active transition from the horizontal (supine) position to the vertical (standing) one by him/herself. Accordingly, SST represents a more easy-to-perform version of AST (active transition from the sitting to standing position). Such active "verticalization" provokes transient decrease in the arterial blood pressure (BP) following the decrease of the venous return due to counteraction of gravitation force. As a result, less venous blood returns back to the heart (the right atrium) which results in the transient decrease of BP.

The decrease of BP, in turn is sensed by baroreceptors of the carotid artery and aorta, which further triggers autonomic reaction to it (vasoconstriction and increase in heart rate) [Lanier et al., 2011]. More specifically, OH "… is defined as a decrease in systolic blood pressure of 20 mm Hg or a decrease in diastolic blood pressure of 10 mm Hg within three minutes of standing when compared with blood pressure from the sitting or supine position" [59, p. 527].

As of now, BP and, correspondingly, OH cannot be directly measured with a smartphone. Still, OH can be monitored with help of finger arterial pressure [60]. However, such special wearable devices stay beyond the scope of the present study.

The heart rate and HRV may serve as surrogate markers of OH in frail and pre-frail people [61, 59; 62] what promises adaptation of smartphone basic functions to this task. The HRV characteristics (time- and frequency-domain, and nonlinear parameters) informs on the balance between the activity of nervous, humoral, and metabolic factors, and between sympathetic and parasympathetic divisions of the nervous systems [63].

In parallel with BP, the heart rate (HR) is modified during orthostatic tests. For example, HR drops by 10% of base line value to 40 beats per minute [57].

The equivalence between frailty measures and physiological tests and modalities is found in Table I.

TABLE I. EQUIVALENCE BETWEEN FRAILTY MEASURES, PHYSIOLOGICAL TESTS AND PHYSIOLOGICAL MODALITY

| Autonomic frailty measure (screening tool) | Physiological test | Physiological modality |
|---|---|---|
| Reaction to standing, change in arterial blood pressure (mm Hg) and heart rate (beats/min) | Active standing test (AST), Sit-to-Stand test (SST), Head Tilt Test (HUT) | Baroreflex sensitivity (BRS) |
| Heart rate variability (time and frequency domain, non-linear parameters) | Heart rate variability (HRV) | Relative activity of nervous, humoral and metabolic factors, sympathetic and parasympathetic nervous systems |

Thus, several autonomic tests are relevant to assess autonomic frailty in older people, namely – AST, SST, and several measures can be used for that, primarily, HR and HRV. As for blood pressure, it cannot be currently measured with a smartphone. However, wearable sensors integrated with a smartphone via an application can be figured out.

### *C. Assessing the Autonomic Performance with a Smartphone*

As we have already pointed in our earlier studies [5, 6], the best approach to evaluating motor and cognitive reactions is to conduct them within the framework of activities of daily life (ADL), with only minimal awareness of the subject (user) that tasking is going on. The major problem with the laboratory and even field measurements is that subjects involuntarily would try to perform as good as possible [64]. This is true also for self-administered and self-conducted testing. Therefore, Must be maximally" embedded" into the real ADL.

Smartphone accelerometers are capable of recognizing heart rate [65]. The heart produces vibration during the pumping cycle. On the surface of the body this vibrations are presented as a kind of "earthquake" which can be sensed by ballistocardiography and seismography methods [66; 67].

Besides the cuff-based BP monitoring, cuff-less devices are rapidly entering the consumer market for personal nonclinical use [68]. The cuff-less sensing of BP can be based on 3-axis accelerometers [69], which are already present in smartphones.

Altogether, potentially smartphones can be used as measuring devices both for BP and HR monitoring with help of their basic functions, namely, accelerometers.

During ADL, people perform a lot of varied movements, including locomotion and posture transition. Namely, people perform standing from sitting or supine position, which well correspond with AST and SST tests. We presume that integration of BP or HR (or both) measuring with a program which is capable of sensing specific postural transitions would help inventing a smartphone-based application to monitor autonomic frailty.

## V. CONCLUSION

The developed mHealth concept aims at digital support of the activity and performance of a person in his/her daily life. The concept assumes that a smartphone can construct a personal smart space where internal and external sensors provide status information on the motor, cognitive, and autonomous function. This study was focused on the case with the autonomous activity, and we discuss the opportunities of smartphone-enabled monitoring of the autonomous function.

First, in older people the autonomic frailty is mainly presented by such signature as orthostatic hypotension. It manifests itself as reduced blood pressure and heart rate after transition from supine or sitting to standing position. These postural transitions correspond with such physiological autonomic tests as active standing test and sit-to-stand test, which, in turn, can be regarded as events of the activities of daily life. Second, smartphones already have technical prerequisite to sense either blood pressure cuff-less and heart rate during postural transitions in a form of 3-axis accelerometers. Third, smartphones are the best primed for integration into mHealth systems due to connection to the Internet.

In sum, our study concludes that a smartphone has strong potential to serve as a phone-based sensorics for digital support of human autonomic resilience to stress.

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