Psychophysiological Assessment of Stress under Ecological Settings: A Systematic Review

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Abstract

Stress can negatively impact one's health and well-being, however despite the recent evolution in stress assessment research methodologies, little agreement still exist about stress conceptualization and assessment. In an attempt to summarize and reflect on this evolution this paper aimed to systematically review research evidence of ecological approaches on psycho-physiological stress assessment. Thus, a literature search of electronic databases was conducted spanning 22 years (1990 – 2012) and 55 studies were reviewed. Studies were considered for inclusion if they contemplated both psychological and physiological measures of stress under ecological settings. This review focused on five themes: methodologies terminology; research population; study design; measurement and technology. Findings support the need to use a common methodology terminology in order to increase scientific rigor. Additionally, there seems to be an increasing tendency for the use of these methods by multidisciplinary teams among both clinical and non-clinical populations aiming to understand the relationship between stress and disease. Most of the studies reviewed contemplated a time-based protocol and different conceptualizations of stress were found resulting in the use of different subjective measures. Findings reinforce the importance of combining subjective and objective measures while also controlling for possible time or situation dependent confounders. Advances in technology were evident and different assessment techniques were found. The benefits and challenges of ecological protocols to assess stress are discussed and recommendations for future research are provided, aiming to overcome previous limitations and advance scientific knowledge in the area.

Keywords: stress assessment, ecological approaches; psychological and physiological measures, systematic review

Psychophysiological Assessment of Stress under Ecological Settings: A Systematic Review

Stress is a wild and well-known term, commonly used by the general population across different settings of life (Maracine, 2010). According to Lazarus and Folkman (1984) stress occurs when pressure exceeds one's perceived ability to cope, resulting from a transaction between the individual and the environment, including the individual's perceptions, expectations, interpretations, and coping responses. Stress involves a complex physiological response aimed to help the person deal with the perceived threat (Sapolsky & McEwen, 1986). Despite the fact that several attention has been dedicated to the study of stress over the years, little agreement still exists among the academic community with respect to its conceptualization and assessment (Monroe, 2008). Traditional stress assessment methods in Psychology are often reliant on retrospective designs, are cross-sectional in nature and use only self-report measures. As suggested by Segerstrom and O´Connor (2012) data collected may be plagued by memory biases or distortions associated with time delays, challenging the validity and reliability of the reports. In support of this idea, several studies revealed significant discrepancies between real-time assessments and retrospective recall. As an example, Hufford, Shiffman, Paty, and Stone (2001) suggested that participants are more likely to report experiences that have more personal meaning, occurred more recently, are unusual in meaning, or consistent with their current mood. Laboratory designs are one commonly used solution to the limitations presented above, since they avoid retrospective report problems and can add the rigor of an experimental design (Smith & Stone, 2003). Additionally, laboratory designs also allow physiological stress responses monitoring (Zanstra & Johnston, 2011). However, it is important to bear in mind, that

laboratory baseline conditions may not represent real-world conditions. This can be explained by the inherent artificial conditions, which are likely to increase the risk of biasing results. In agreement with this idea, Monroe (2008) suggested that laboratory research assessing stress rarely, if ever, includes aspects of the social environment which is an important part of the stress concept. According to Zanstra and Johnston (2011) stress reactions should be investigated in relation to discrete and objective stressful situations. Additionally, considering that stress is an interdisciplinary topic, interdisciplinary research methods are needed in order to fully understand the concept (Goldstein & Kopin, 2007).

In an attempt to overcome previous research limitations, the 21st century science recommends research methods such as Experience Sampling Method (ESM, Larson & Cskszentmihalyi, 1983), Ecological Momentary Assessment (EMA, Stone & Shiffman, 1994) and Ambulatory Assessment (AA, Fahrenberg, Myrtek, Pawlik, & Perrez, 2007) to investigate a variety of behaviors, experiences, and conditions, including the experience of stress. ESM is an ecologically-valid methodology, developed to understand the dynamic process of person-context interactions. Participants in ESM are signaled with a device (e.g. pager) at random times within a fixed time period and booklets where they are required to report their activity, mood and/or thoughts (Kimhy et al., 2010). In 1994 a new approach was proposed denominated EMA (Stone & Shiffman, 1994). Following technological development trends the assessment goals of EMA have expanded beyond self-reported subjective states to the monitoring of physiological conditions. AA is another commonly used term in the literature and is often referred to the monitoring of physiological processes through the use of computer-assisted procedures, sometimes accompanied by diary self-reports of subjective states or contexts (Trull & Ebner-Priemer, 2009). Although a definition of the different research

approaches can be found in the literature, the terms are used interchangeably as being conceptually the same. Recently, Trull and Ebner-Priemer (2013, p. 4.2) suggested that "AA represent a methodological umbrella that encompasses increasingly computerized or digitized methods of experience sampling, ecological momentary assessment, and continuous psychophysiological, biological, and behavior monitoring". However, the same authors in 2009 appealed for the use of EMA as an "umbrella" term that attempts to integrate all these assessment traditions with similar goals. Hence, it is clear that there are a variety of terminologies used to denominate assessment of real world activities. As suggested by Fahrenberg (2006), this multiplicity of terms may be due to a disclosure of the author's personal interests in emphasizing their own contribution, or it can be a result of commercial memberships or claims. Despite the lack of agreement in the use of a common terminology, the methodologies share some similar features and are essentially modern day tools, allowing for a within-person assessment in natural environments, and contemplating an idiographic approach (Trull & Ebner-Priemer, 2009). For the purpose of the current systematic review the term ecological approaches will be used to refer to all real world assessment methods, including ESM, EMA and AA.

Considering the relationship between stress and physical illness (Jansson, Wallander, Johansson, Johnsen, & Hveem, 2010) an important advantage of these holistic stress approaches is the opportunity to objectively investigate the cognitive processes and behaviors leading to the physical illness. In other words, ecological approaches allow a further understanding of the relationship between subjective psychological and objective physiological parameters of stress and health conditions (Yoshiuchi, Yamamoto & Akabayashi, 2008). Thus, several studies have been conducted with clinical (e.g. Kimhy et al., 2010) and non-clinical populations (e.g.

Sausen, Lovallo, Pincomb, & Wilson, 1992) in order to better understand this relationship and its influence on health outcomes. Furthermore, these approaches provide an interesting opportunity to study daily life events (Fahrenberg et al., 2007) across medicine (e.g. Kalpakjian, Farrel, Albright, Chiodo, & Young, 2009) and psychology fields (e.g. Bishop et al., 2003) combining multidisciplinary teams.

Regarding the techniques used by ecological approaches to assess psychological measures of stress, some examples were found such as paper diaries (e.g. Barnet, Steptoe, & Gareis, 2005), daily phone interviews (e.g., Almeida, Wethington, & Kesseler, 2002), and electronic diaries (e.g. Kimhy et al., 2010). Due to the fast technological advances more complex and sophisticated protocols have emerged recently (Shiffman, Stone, & Hufford, 2008) matching closely to the population needs and study aims. As an example a study by Kuntsche and Labhart (2013) assessed psychological measures of stress using a new Internet-based, cell phone-optimized assessment technique (ICAT). This method allows a baseline assessment combined with text messages sent to the participants' personal cell phones providing a hyperlink to an Internet-stored cell phone-optimized questionnaire. This innovative and flexible way of collecting data reduces recall bias and can be applied in various disciplines.

In what concerns to the physiological measures of stress, the most commonly used are cortisol (e.g. Collip et al., 2011), Heart Rate (HR), Heart Rate Variability (HRV) (e.g. Dockray et al., 2010) and Blood Pressure (BP) (e.g. Ewart & Johnson, 2004). Regarding methods used to collect physiological measures of stress under ecological conditions these include Salivette (e.g. Collip et al., 2011), ambulatory BP and HR monitors (e.g. Muraoka, Carlson, & Chemtob, 1998) and more recently wearable T-shirts incorporating ECG (e.g. Kaiseler, Rodrigues, Ribeiro, Aguiar, & Cunha, 2013). When contemplating physiological measures of stress, attention should

be drawn to confounders' variables such as physical activity levels and posture, since these are directly related with cardiac activation and can possibly bias results (Schwerdtfeger, Konermann, & Schonhofen, 2008). In an attempt to overcome this challenge, new methods such as accelerometry or actigraphy, including novel technologies were proposed as a possible resource to control for confounders variables (Wilhelm & Grossman, 2010). Another important aspect to consider when assessing stress under ecological conditions is the design of the study. Particularly, ecological approaches designs can be divided into event-based sampling and time-based sampling schemes, varying according to the study purposes (Shiffman et al., 2008). The main difference between these two sampling schemes is that in an event-based scheme a recording is made each time a predefined event occurs, whereas in the time-based sampling a recording is solicited based on a time schedule, often based on random time intervals, without a predefined focus (Shiffman et al., 2008). A combination design can also be used, when the researcher is interested in the conditions that are associated with a target event (Bolger, Davis, & Rafaeli, 2003).

Research on ecological assessments of stress has been privileged by the rapid technological development and benefits from multidisciplinary expertise across different life settings allowing for 24h continuous monitoring of physiological data, without interfering with subjects daily life (Houtveen & Geus, 2009). An important aspect to consider is measurement synchronization that allows for the temporal associating of psychological stress measures and physiological data, offering unique opportunities to fully understand the stress experience (Kimhy et al., 2010). In support of this argument Wilhelm and Grossman (2010) suggested that when conducting "multichannel studies" with different measures it is important to highlight the need for these measures synchronization.

Acknowledging the importance of stress ecological studies in contemporary life and their contribution to the development of knowledge, it seems crucial to reflect on the current methodological challenges of this task. This need seems to be reinforced by novelty of the research area, which results in a growing number of studies across disciplines aiming to assess similar stress conceptualization but using different terminologies, methods, techniques and designs, limiting development of knowledge. For this purpose, the current systematic review aims to summarize, evaluate and synthesize previous research assessing stress in ecological settings combining both psycho-physiological measures. For this purpose, the current paper reviewed over 22 years of research in this area across the disciplines of medicine and psychology. This systematic review will not only contribute to the development of knowledge in this area but will also provide research recommendations for future studies.

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Method

Search strategy

Eight electronic databases (Medline with full text; Psyarticles; Psycritiques; Psybooks; Psychological and Behavioral Science Collection; Psyinfo; Socindex with full text; Fonte Académica) in Ebsco were searched in addiction with the Society for Ambulatory Assessment (SAA) database (http://www.ambulatory-assessment.org/typo3/ambulatory/index.php?id=35). The search in Ebsco was conducted using the keyword “stress” combined with each one of the following terminologies: “Ecological Momentary Assessment”; “Experience Sampling Method”; “Ambulatory Monitoring”. The years of publication were limited between 1990 to December 2012. All articles were searched in SAA database, between 2006 to 2012. The methodology used for systematic review was based on the guidelines defined by

Chalmers and Haynes (1995), Lloyd Jones (2004) and Mulrow (1995). Lloyd Jones (2004) recommended sifting papers in 3 stages such as review them by title, then abstract and finally by full text, excluding those at each step that did not satisfy the inclusion criteria. Due to the difficulty of identifying studies relevant to the research question by only reviewing their title, this criterion was not used in the current review. Instead, all papers were reviewed by abstract and then by full text to determine whether they met the inclusion criteria. One thousand, eight hundred and three references were removed after reading their abstract. A total of 322 articles were screened, 270 of which were excluded. Furthermore, the reference lists of all papers were also checked for relevant studies, and another 8 studies were screened, 5 of which were excluded. In total, 55 studies were included in this systematic review (Figure 1). Each article considered for inclusion was reviewed independently by the first two authors and if differences were found, the article was reconsidered. The two authors agreed on 51 out of the 55 reviewed articles (93%) reported. In the cases of disagreement, discussion was followed with the third authors and a decision was made.

[Figure 1 near here]

Inclusion criteria

Studies were considered for inclusion if they provided both psychological and physiological measures of stress under real world conditions and were published as full papers. As suggested by Knipschild (1995) studies published as abstracts or conference proceedings were excluded. Studies that did not assess stress in real world settings were also excluded. It is worth noting that not all included studies considered stress assessment as a primary goal, since in some cases this aim was assessed on a post-hoc basis.

Results

The initial search resulted in a total of 2125 papers, of which 55 articles deemed potentially relevant. A total of 1813 were excluded for not assessing stress; 149 articles were excluded due to lack of physiological measures; 19 due to lack of psychological measures; 12 were development only in laboratory settings, 27 were not empirical studies and 50 were duplicated. The selected studies were displayed into several themes. These include 1) the terminology used for the methodologies, 2) type of research aim, 3) study design, 4) measurement (psychological and physiological) and 5) technology. Findings are displayed in Table 1.

[Table 1 near here]

1. Terminology used for methodologies:

Different terminologies were found across the reviewed studies. As an example, 38 studies used Ambulatory terminology, 9 used EMA and 6 used ESM. Additionally, when searching in the SAA database, since no keywords were used, other different terminologies were found, these included Momentary diary assessment (1), Momentary assessment (1), Interval-sampling Methodology (1), Momentary experience sampling (1) and 3 studies did not use any particular terminology.

2. Research population

The reviewed studies aimed to address particular clinical questions among both clinical and non-clinical populations. Out of the 55 studies reviewed, 39 were conducted among non-clinical population and 16 studies were conducted among subjects with particular clinical conditions such as Posttraumatic stress disorder (PTSD)

(5), asthma (1), psychotic disorders (3), borderline personality disorder (1), medically unexplained symptoms (1), nondipping phenomena (1), chronic muscle pain (1), spinal cord injury (1) and 2 with a specific population, pregnant women.

3. Study design

This systematic review has found different ecological sampling and assessment schemes. As an example, 52 studies used time based-protocols, from which 36 used a time-based protocol with fixed intervals, 15 used random intervals and 1 used both time and random intervals. An event based protocol was found in 1 study. Seven studies recorded physiological data continuously.

4. Measurement

Different stress conceptualizations were found across studies, leading to different ways of measuring the concept. Particularly, when analyzing psychological measures of stress, studies used emotion, affect or mood measures (25), event-related stress (12) interpersonal stress (3), psychosocial and social stress (5), chronic stress (4), acute stress (1), pressures (1) and perceived stress over a stressor (9). When analyzing physiological measures of stress, the most commonly used measures were BP (35), HR (29), cortisol (18) and HRV (6). Additionally, other complementary biological and physiological markers were used such as physiological stress, using locomotor activity (1), steps counting (1) and physical activity (1); airflow assessment (1) and respiration (1), error related negativity (1), carotid artery atherosclerosis (2), intima-medial thickness (1), urine (specific gravity and ketones) (1) and plasma fibrinogen (1). When considering synchronization of measures, out of the 55 papers, 38 synchronized both physiological and psychological measures of stress.

5. Technology

Out of the 55 studies reviewed, 43 used diary techniques, from which 25 used paper diaries, and 19 used electronic diaries. All studies included the complementary use of questionnaires. In what concerns to psychological stress assessment, 11 studies used only questionnaires (cross-sectional design), and 29 collected psychological stress data on a daily basis using diary based measures. Out of these 29 studies, 15 included daily diaries and complementary questionnaires to assess stress. Regarding physiological measures, out of the 55 studies reviewed, 41 used ambulatory BP and HR monitors (41), life shirt system (1), salivette (13), saliva swabs (2), saliva tubes (1), aliquots (1) and straws (1). Additionally, some studies have also used other complementary biological and physiological measurement equipment including mini-wright peak flow meter (1), portable capnometer (1), electroencephalographic recording and signal processing (1), magnetic resonance imaging (1) and B-mode ultrasound (1). Furthermore, reviewed studies used a variety of additional technology to prompt subjects for assessments such as audible devices like electronic pagers (1), digital wristwatches (6), and alarms (1). Finally, 6 studies also used technology to assess physical activity levels such as pedometer (1), accelerometer (3), physiomodul (1) and actiwatch (1).

Discussion

The aim of this paper was to evaluate and synthesize previous research assessing stress using an ecological approach and combining psycho-physiological measures. An overview of these innovative psycho-physiological stress assessment methods will be discussed, focusing on the benefits of these research approaches, and reflecting on the associated challenges. Findings will be discussed following the results section structure:

1) the terminology used, 2) the research population, 3) the study design, 4) stress measurement considerations and the 5) technology used.

Firstly it is worth reflecting on the existence controversy across the terminology used for the methodologies. As an example, a study by Stiglmayr et al. (2008) investigating the interaction of dissociative symptoms and subjective assessments of stress within participants over time, referred the "use of EMA, also known as ambulatory assessment or experience sampling method" (p. 140). As mentioned above, despite the similarities, there are differences across these methodologies that should be considered (Trull & Ebner-Priemer, 2009). It is believed that this limitation restricts conclusions in the understanding of what exactly each method aims for and what research measures should be contemplated. Additionally, when conducting a search across the SAA database we found that other terminologies were used to address the same type of methodology (e.g. Interval-sampling methodology, Momentary experience sampling). This terminological confusion can impair scientific rigor. Thus, it is important to find consistency in the terminologies in order to choose the correct term that best fits this type of methodology. Results showed that the majority of studies (38) found in the current systematic review used the ambulatory terminology (AA). According to Wilhelm and Grossman (2010) AA has progressed more rapidly in medical application, when compared to the psychology field. Thus, a possible explanation for the use of this terminology (AA) across most of the reviewed studies may be the fact that most of these studies were multidisciplinary in nature, concentrating in the disciplines of medicine and psychology across the health and organizational settings.

Secondly, when analyzing the research population, the majority of ecological approaches studies (39) seem to be conducted among non-clinical populations. These

findings support previous recommendations suggesting the importance of studying stress from a prevention perspective (e.g. Holt-Lunstad, Birmingham, & Light, 2008). Furthermore, ecological approaches seem also to be appropriate and useful among clinical populations. As an example, an ambulatory psychophysiological study, with a multidisciplinary team conducted by Ebner-Priemer, Kuo, and Schlotz (2008) among patients with Bipolar disorder, used a combination of physiological and psychological measures to understand the relationship between psychological distress and affective dysregulation. The authors found that conflictive emotions were related to psychological distress and psychological distress was related to physiological arousal (HR). Indeed, multidisciplinary ecological approaches provide accurate information about physiological and psychological symptoms and their relationship with health conditions in clinical and non-clinical populations (Yoshiuchi et al., 2008).

Thirdly, regarding the study design, the majority of studies (52) were time-based. These findings support Shiffman et al. (2008) suggestion that time-based sampling is usually concerned with ongoing experiences that can be assessed within the course of a typical period and aim to characterize experience in a more broadly and inclusively way. On the other hand, according to the same authors, rare or highly specific experiences are difficult to be evaluated by using a time-based design and should be studied using an event-based design. Event-based schemes are focused on particular discrete events in which assessments are prompted by the occurrence of a predefined event of interest to the investigator. As an example, a study conducted by Sausen et al. (1992) aiming to investigate psychological stress in medical students, conducted assessments only before, during, and after specific events such as the lecture and examination day. It is important to highlight that future studies contemplating event-based schemes should pay special attention to compliance, since it may be

difficult to assess or verify whether occurred events were entered or not, or if entries were made for events that did not occur (Shiffman et al., 2008). Additionally, it is also important to consider also the risk that the participant may not reliably identify relevant events and event-based responses should not be overgeneralize to the person's general experience (Bolger et al., 2003). Ecological study designs have different schedules or intervals that should be theoretically and/or empirically guided. Thus, in this review there are designs with fixed schedules (e.g. Barnett, Steptoe, & Gareis, 2005), variable (e.g. Carels, Sherwood, Szczepanski, & Blumenthal, 2000) or combined (e.g. Entringer, Buss, Andersen, Chicz-Demet, & Wadhwa, 2011). As suggested by Bolger et al. (2003) when using a fixed-time schedule, one of the greatest challenges is to decide the suitable spacing of intervals between the assessments. Thus, long intervals may error natural cycles, exclude important events and also contribute to the risk of biased recall. On the other hand, intervals that are too short may miss slower processes (e.g., day-to-day changes), so they are more suitable to be used when assessing processes that change quickly (e.g. mood) and may also increase participant's burden (Iida, Shrout, Laurenceau, & Bolger, 2012). Alternatively, researchers may use variable or mixed schedule designs that allow the possibility to randomly sample moments, which may reduce the potential for biased reports (Bolger et al., 2003). According to Shiffman et al. (2008), when using time-based assessment schedules, especially with variable intervals, ecological studies should include some method of signaling subjects when an assessment is scheduled.

Fourthly, when considering stress measurement it is important to address how stress is defined, according to the literature, definitions of stress can differ in the extent to which they valorize stressful events, responses or individual assessments of situations (Cohen, Kessler, & Underwood Gordon, 1995). When considering psychological stress

measures, some limitations can be found. As an example, in the reviewed studies conducted by Kamarck et al. (2004; 2007) one of the limitations addressed was the subjectivity of the reports, since they involved a cognitive appraisal and inferences from the participant. Additionally, in a reviewed study conducted by Buckley, Holohan, Greif, Bedard, and Suvak, (2004), the authors highlighted that psychological measurements were limited to "yes" or "no" answers as to whether participants felt "stressed". However, these single one item answers do not provide a complete assessment of the concept, since other dimensions of stress are not being contemplated. It seems crucial to appeal for the complementary use of objective physiological data, considering the complexity of the stress concept. In the reviewed studies, BP, HR, Cortisol and HRV were the most commonly used measures, known as being robust indicators of the stress response. However, caution should be drawn when analyzing this data during real world settings since "variation in physical activity and posture, social interaction and ingestion across the assessment can mask more subtle emotion effects on dependent variables" (Wilhelm & Grossman, 2010, p.566). In order to overcome this limitation, some traditional studies relied on self-reported physical activity, excluding physiological data from the analysis for times when physical activity was reported. In agreement with this idea, 24 studies in this review rely on self-report measures to indicate the activity and the contextual information, after or during each record. As an example, a study conducted by Brondolo et al. (2009) with 73 city traffic agents, aiming to investigate trait hostility and cardiovascular reactivity in potential stressful situations, assessed mood and BP variables. In order to address control variables that can influence BP readings, the authors included in the ambulatory diary additional questions including participants' activities, location, and posture at the time of each cuff inflation. Although an attempt was made to control confounder variables in this study, the method

used may be simplistic and unreliable, since the exact time of the changes in behavior are dependent on the participant availability/willingness to record the data. Hence, in order to control these confounder variables, several modern tools (Houtveen & Geus, 2009) discussed in the following paragraph should be considered. Additionally, as pointed by Wilhelm and Grossman (2010) the synchronization of data is a very importance aspect when aiming to fully understand the impact of stress responses. In this review, out of the 55 reviewed studies, 38 synchronized psychological and physiological measures of stress. The same authors suggested that ecological approaches should employ a synchronization timing signal to all devices, since no available ambulatory solution currently exists for this purpose.

Finally, regarding the use of technology, 19 studies used electronic diaries as a technique for psychological stress data assessment. Tough, we found that some of the reviewed studies (23) still used paper and pencil format diaries. However, these may be more prone to a potential risk of retrospective completion of entries and completing entries in advance (Beckham et al., 2005). To overcome these limitations, Boody and Smith (2008) recommended the use of electronic diaries, since most ambulatory studies using electronic devices have conceived methods of self-reminder, prompting participants' to respond and releasing them of the need to worry for the appropriate times for response (Trull & Ebner-Priemer, 2013). Additionally, Bolger et al (2003) suggested that most recent technologies allow to integrate diary reports with physiological measures. Thus, regarding physiological data, new modern methods are emerging, allowing the measurement of physiological stress indices as participants undergo their daily life. As an example, in a reviewed study conducted by Kimhy et al. (2010) aiming to measure concurrent stress and arousal in individuals with psychosis during daily functioning in natural environment, an ESM with electronic diaries and a

wearable Life-shirt system to assess stress and psychosis were used. The methodology allows continuous and simultaneous assessments and provides the opportunity to understand dynamic variations in stress, arousal, and psychosis with an accurate, high time resolution measurement. This new technology was initially used in the medicine area, but today this equipment is even more elaborated, non-invasive and easy to use, suitable for applications in other areas, such as psychology (Fahrenberg et al., 2007). An important aspect to consider when assessing stress physiological data is the influence of confounders variables such as physical activity and posture levels. In order to overcome this limitation, modern technological recording devices should be used. As an example, a study conducted by Pieper, Brosschot, van der Leeden and Thayer (2007) with 73 teachers aiming to understand cardiac effects during worry episodes and stressful events, used an ambulatory HR and HRV device including a accelerometer, aiming to identify and remove episodes with high physical activity that can bias stress physiological data. Despite this need, only 7 studies were found recording physical activity with technology. The limited number of studies found that used this technology, may be explained by the fact that sophisticated analysis software and equipment are required to analyze this data, which can be a limitation for research teams (Wilhelm and Grossman, 2010). To address this limitation a variety of low-cost devices and software possibilities can be found (http://www.ambulatory-assessment.org).

This review should be considered in light of some limitations, such as lack of statistical appliance or software to analyze data, and conclusions are exclusively based on published studies. Regardless of its challenges, the present review provides strong support for the use of ecological approaches contemplating both psycho-physiological measures for stress assessment investigation, due to their capacity to capture experiences (e.g., stress) in a way that traditional designs cannot. These methodologies

permit to obtain more accurate and detailed data, as participants are usually able to provide greater detail about their experiences, reducing errors and retrospective bias, without interfering in daily life flow (Vannier & O´Sullivan, 2008). Moreover, data has strong ecological validity, combining daily tasks with self-report information and physiological data (Hoppmann & Riediger, 2009). Furthermore, in agreement with Youshiuchi et al. (2008) ecological approaches lead to more profitable findings about the relationships between psychosocial factors and stress-related diseases when using wearable devices to assess physiological and behavioral data in natural settings.

Concluding, current findings suggested that literature in ecological approaches is vast and involves controversial theoretical and methodological issues. Our findings suggest that AA terminology is the most commonly used terminology to denominate ecological approaches of psychophysiological assessment, and should be used in the future as a standard assessment terminology in this area. Additionally, findings suggest that there is a multidisciplinary research approach to this area, in an attempt to fully understand the impact of stress on psychological and physical health. Acknowledging the fact that the design of an ecological study is a challenging task, future studies designs including assessment schedules or intervals should always be theoretically and/or empirically guided. Furthermore, accurate and reliable measurements of stress should be supported by both psychological and physiological data, preferably synchronized and including control technologies for possible confounder variables affecting physiological data. Hence, findings suggest that ecological approaches combining psychophysiological measures of stress, offer a promising promise avenue for future prevention and/or rehabilitation stress research, by offering a unique opportunity to obtain a detailed examination of stress causes and impact while maintaining natural context conditions.

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1 Asterisks indicate studies included in systematic review

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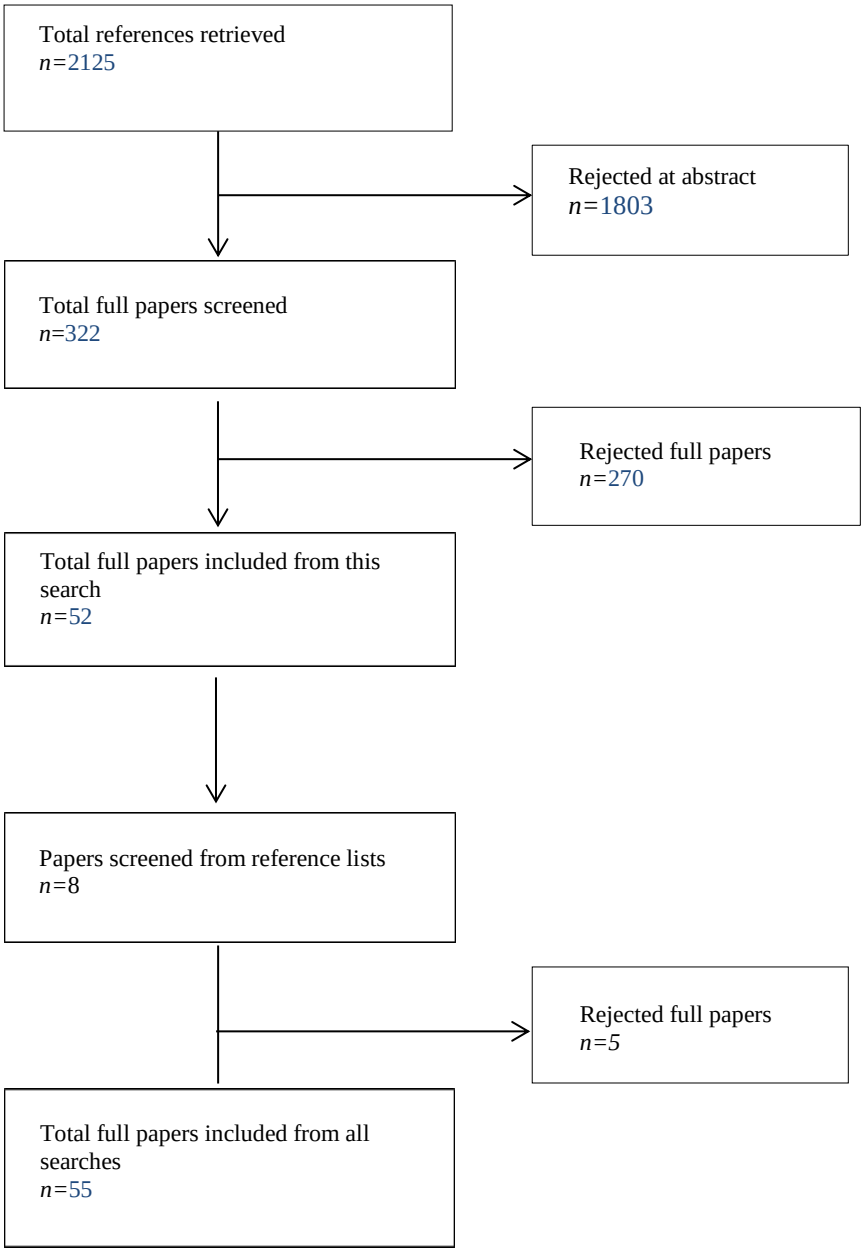
Figure 1. Summary of study selection and exclusion – all literature searched.



807 *Table 1.* Summary table of the reviewed studies using ecological approaches on stress assessment

Authors	Aim of the study	Research population	Study design	Measurement		Stress measurement synchronization	Technology	Terminology used for the methodology
				Psychological	Physiological			
Barnett et al. (2005)	Estimate the relationship between marital-role quality and 3 psychobiological stress indicators	105 middle-age adults	Time – based (fixed intervals) during 1 day	Subjective stress; Marital-role quality; negative affect	Cortisol, BP	Yes	Paper diaries; SpaceLabs 90217; Salivette	Momentary Experience Sampling; AM;
Beckham et al. (2005)	Investigate the association between smoking and situational cues	63 smokers with PTSD and 32 smokers without PTSD	Time – based (random intervals) during 1 day	Mood states (feeling distressed); PTSD symptoms; psychopathology	HR; BP	10 minutes before	Paper diaries; Accutracker II	AM
Beckham et al. (2000)	Investigate the relationship between daily diary affect ratings and ambulatory CV activity	117 male Vietnam combat veterans (61 with PTSD and 56 without PTSD)	Time – based (fixed intervals) during 12 to 14 hours	PTSD symptoms; psychopathology; mood states (stressed)	HR; BP	10 minutes before	Paper diaries; Accutracker II	AM
Bedford et al. (2011)	Examine whether negative eating/body attitudes were associated with cortisol and ABP	120 non-obese, healthy women aged 19 –35	Time – based (fixed intervals) during 1 day	Eating and body attitudes; perceived stress	Cortisol; HR; BP	No	Aliquots; Spacelabs 90207	AM
Benotsch et al. (1997)	Compare ABP and investigate interpersonal daily stress as a possible mediational mechanism	48 students pre-selected for high and low hostility scores	Time – based (quasi random intervals) during 2 days	Perceived social support; hostility; daily interpersonal stress	HR; BP	No	Paper diaries; Accutracker II	AM
Bishop et al.	Test de demand-	118 police	Time – based	Occupational stress	BP; HR	Yes	Electronic diaries;	AM; EMA

(2003)	control model for coronary disease	patrol officers	(fixed intervals) during a morning shift	(job demands; decisional control)			Accutracker II; BP monitors	
Brondolo et al. (2009)	Investigate trait hostility and CV reactivity to potentially stressful social interactions	73 (39 women) New York City traffic enforcement agents	Time – based (fixed intervals) during 1 day	Mood; Hostility; state affect; Quality of interactions	BP; HR	Yes	Paper diaries; Suntech Accutracker II	EMA
Buckley et al. (2004)	Examine the relationships between diagnostic status, basal CV activity, and CV reactivity to stress	2 groups:19 with chronic PTSD and 17 without PTSD	Time – based (fixed intervals) during 1 day	Personality and behavior traits, PTSD symptoms; depressive symptomatology; state and trait anxiety, affective distress	HR; BP	Yes	Electronic diaries; Dinamap automated BP monitor; Dynapulse 5000A	AM
Campbell et al. (2006)	Investigate between peak expiratory flow rate (PEFR) and high frequency heart rate variability (HFHRV) during periods of negative affect and physical activity associations	53 patients with mild to moderate asthma	Time- based (fixed intervals) with continuous monitoring of HRV during 1 day	Asthma self-efficacy; mood (stressed; frustrated, sad, tense)	Airflow assessment; HFHRV	Yes	Paper diaries; Timex wristwatch; Polar R–R monitor; Mini-Wright Peak Flow Meter	AA
Carels et al. (2000)	Examine the relationship between marital distress and BP during daily life	50 married employed women	Time – based (random intervals) during 1 day	mood (angry, sad, stressed, frustrated, tense, happy, in control) marital distress	BP; HR	Yes	Paper diaries; Accutracker II	AM

Collip et al. (2011)	Investigate whether HPA axis functioning is altered in individuals at above average genetic risk for psychotic disorder	60 siblings of patients with a psychotic disorder and healthy comparison group (N=63)	Time – based (random intervals) during 6 days	Event stress; psychotic symptomatology; negative affect, Trait psychosis liability; childhood trauma	Cortisol	Yes	Paper diaries; Digital wristwatch; Salivette	ESM
Compton et al. (2007)	Examine individual differences in error-related self-regulation predict emotion regulation in daily life	47 participants	Time-based (fixed intervals with a frequency of one per day) during 14 days ERN was recorded continuously	Personality; stress; anxiety	ERN	No	Electroencephalographic Recording and Signal Processing	ESM
Conley and Lehman (2012)	Examine CV activity when an academic stressor was occurring and when an academic stressor was not occurring.	99 undergraduate students	Time – based (fixed intervals with a frequency of one per day) during 4 days	Stress events; anxiety; depression	BP; HR	No	Electronic diaries; Spacelabs Healthcare	AM
Dennis et al. (2007)	Investigate gender differences regarding the association between smoking and situational cues	63 smokers with PTSD and 32 without PTSD.	Time – based (fixed intervals) during 1 day	Psychopathology; affect; PTSD symptoms; restlessness; worry; hunger	HR; BP	Yes	Paper diaries; Accutracker II	AM
DeSantis, et al. (2007)	Identify potential physiological pathways to racial	255 adolescents	Time – based (fixed intervals) during 3 days	Negative emotion; chronic stress; episodic life stress;	Cortisol	Yes	Paper diaries; programmed watch; Saliva swabs	ESM

	disparities in health outcomes			personality				
Doane and Adam (2010)	Understand momentary/daily changes in loneliness or chronic, ongoing feelings of isolation and loneliness with HPA axis activity	108 participants	Time – based (fixed intervals) during 1 day	Mood (stressed); anxiety; stress (chronic and episodic); loneliness trait	Cortisol	Yes	Paper diaries; Actiwatch Score; Straws; Mechanical Kitchen Timer; Straws;	EMA (Momentary diary method)
Dockray et al. (2010)	Validate DRM affect ratings by comparison with contemporaneous EMA ratings	94 women aged 21-54 years working at University college London	Time – based (fixed intervals) during 2 days	Happiness, tiredness, stress, anger/frustration	Cortisol; HR; HRV	Yes	Paper diaries; DRM online entries; Saliva swabs (the other instruments were not described here)	EMA; DRM
Dollan et al. (1992)	Understand coping styles in the relation between real-life stress and BP	20 male college students	Time – based (random intervals) during 2 typical school days 1 with an examination	mental effort; emotional stress, anger, coping	BP; HR	Yes	Paper diaries; Accutracker 102	AM
Ebner-Priemer et al. (2008)	Investigate the relation between psychological distress and components of affective dysregulation	50 BPD and 50 healthy controls	Time - based (fixed intervals) during 1 day with continuous monitoring of ECG	Psychological distress; emotions	HR; PA	Yes	Electronic diaries; Vitaport II;	AM
Entringer et al. (2011)	Assess whether EMA of cortisol sampling improves the ability to predict the length	25 healthy pregnant women	Time – based (EMA random intervals and fixed sampling design for measures of	Negative affect (stressed)	Cortisol	No	Electronic diaries; Medication Event Monitoring System; Salivette	EMA

	of human gestation		cortisol) during 4 days					
Ewart and Jorgensen (2004)	Test Social Competence Model on adolescents who completed the SCI and later underwent ABP monitoring	187 Black and White adolescents	Time – based (fixed intervals) during 1 day	Social Competence; Social Impact; stress; interpersonal skills, styles and strivings	BP	No	Paper diaries; Dinamap Vital Signs Monitor:ECG; Accutracker DX monitor; Interview audiotapes	AM
Giesbrecht et al. (2012)	Assess the plausibility of cortisol as a biological link between maternal psychological distress during pregnancy and fetal development	83 women (gestational ages 6—37 weeks)	Time – based (quasi random intervals) during 3 days	Mood; psychological distress; daily stress; depression; anxiety; stress history	Cortisol;	Yes	Electronic diaries; Salivette	EMA
Habets et al. (2012)	Examine the association between pituitary volume, real-life stress reactivity and genetic liability for psychotic disorder	20 patients with psychotic disorder, 37 non-psychotic siblings of these patients, and 32 controls	Time – based (random intervals) during 6 days	Psychotic symptoms Event stress; Social stress; Emotional stress;	Cortisol	Yes	Paper diaries; MRI scans; Freesurfer stable release v5.0. digital wristwatch; Salivette; GIANT	ESM
Hallman and Lyskov (2012)	Investigate autonomic nervous system regulation, PA and perceived stress and energy during daily activities	23 subjects with chronic muscle pain in the neck–shoulders (trapezius myalgia) and 22 symptom-free controls	Time-based (fixed intervals) and HRV continuous monitoring during 1 day	Perceived stress; energy; pain	HRV; PA	Yes	Paper diaries; Bipolar electrocardiogram; Intelligent Device for Energy Expenditure and Activity	AM

Hanson and Chen (2010)	Explore the relationship between childhood family environments, daily stress and daily biological outcomes	87 participants, ages 19 to 25	Time – based (fixed intervals) during 7 days	Childhood family psychosocial environment; daily stress; sleep	Cortisol	No	Paper diaries; Actiwatch; Salivette; MEMS 6 TrackCap Monitor	None
Holt-Lunstad et al. (2009)	Examine the competing predictions regarding the directional influence of parental status and its interaction with gender	198 married males and females	Time – based (random intervals) during 1 day	Dyadic adjustment; depression; perceived stress; sleep quality; satisfaction with life	BP	No	Accutracker II	AM
Holt-Lunstad et al. (2008)	Examine the influence of marital status, relationship quality, and network support on measures of psychological and CV health.	204 married and 99 single males and females	Time – based (random intervals) during 1 day	Marital quality; network support; mental health; depression; satisfaction with life; perceived stress	BP	No	Accutracker II	AM
Hoppmann et al. (2006)	Examine the relationship between the personal relevance of daily activities with respect to self-set work and family goals and affective and	53 dual-earner couples with preschool children	Time-based (fixed intervals) during 6 days	Personal goals; goal relevance of daily activities; affect quality	Cortisol	Yes	Electronic diary; Salivette	Interval-sampling methodology

	neuroendocrine stress reactions							
Houtveen and van Doornen (2007)	Examine the relationship between MUS and peripheral stress physiology	74 participants with heterogeneous MUS were compared with 71 healthy controls	Time – based (fixed intervals) during 1 day	Momentary experienced somatic complaints; mood	Cortisol; HR; Cardiac autonomic activity; Respiration	Yes	Electronic diaries; VU-AMS; Capnometer; Salivette	AM
Kalpakjian et al. (2009)	Examine the diurnal variation of salivary cortisol in adults Spinal Cord Injury and the effect of stressors on cortisol and mood	51 persons: 25 persons with Spinal Cord Injury and 26 without.	Time – based (random intervals) during 2 days	Stress and mood	Cortisol	Yes	Paper Diaries; Salivette; electronic pager	EMA (includes ESM as a structured diary technique)
Kamarck et al. (2012)	Examine associations between the perception of ongoing psychological demands by EMA and 6-year changes in carotid artery atherosclerosis .	270 initially healthy participants	Time-based (fixed intervals) during 3 days	Psychosocial stress	IMT, BP	Yes	Electronic diaries; B-mode ultrasound; Accutracker DX	EMA
Kamarck et al. (2007)	Examine correlates of 3-year carotid artery disease progression using longitudinal design	335 healthy individuals	Time – based (fixed intervals) during 6 days	Job strain; Psychosocial stress	BP; HR; Carotid Artery Atherosclerosis	Yes	Electronic diary; Accutracker DX; B-mode ultrasound scanner	EMA
Kamarck et al. (2004)	Evaluate the role of psychological	337 healthy adults	Time – based (fixed intervals)	Perceived stress ; Depression; Hate	BP; Carotid Artery	Yes	Electronic diaries; Accutracker DX;;	EMA

	demands and decision latitude as correlates of subclinical carotid disease		two 3-days period	and anger; Job strain	Atherosclerosis		B-mode ultrasound scanner	
Kamarck et al. (2003)	Examine the correspondence between laboratory measures of CVR and within-person changes in CV activity during daily life	335 Healthy adults	Time – based (fixed intervals) during 6 days	Mood; psychosocial demands (Negative affect; Arousal; Task demand; Decisional control; Social conflict)	HR; BP	Yes	Electronic diaries; Accutracker DX; Two-lead EKG; impedance cardiography; IBM 486 PC	AM
Kimhy et al. (2010)	Test the feasibility and validity of a novel methodology designed to measure concurrent stress and arousal	20 patients with psychosis	Time – based (random intervals) during 2 days and 36 hours of arousal continuous monitoring	Subjective stress (negative mood) anxiety; loneliness; irritation; sadness; happiness/relaxation ;	HR	Yes	Electronic diaries; Holter monitor; Lifeshirt system	ESM ; AA
Kneipp et al. (2007)	Examine psychosocial stress, salivary cortisol, 24-hr ambulatory BP and HR and health among single mothers before and after exiting Temporary Assistance for Needy Families (TANF)	40 single mothers before and after exiting TANF	Time – based (fixed intervals) during 1 day	Psychosocial stress; depression; general health;	Cortisol; BP	No	Paper diaries; Salivette; Spacelabs Medical 90207; alarm	AA
Kudielka, et al. (2007)	Understand Circadian cortisol	102 healthy permanent day	Time-based (fixed intervals) during 2	health status, sleep, vital exhaustion,	Cortisol	No	Sallivette	None

	profiles and psychological self-reports in shift workers with and without recent change in the shift rotation system	and night shift workers (comparison groups) and former permanent day and night shift workers	morning shifts, 2 evening shifts, and up to 3 night shifts, followed by 1–4 days off.	perceived chronic stress, effort–reward imbalance and overcommitment.				
Linden et al. (2008)	Investigate the nondipping phenomenon	62 patients (30 nondippers)	Time – based (fixed intervals) during 1 day	Anger, hostility, coping, depression, anxiety and perceived stress	BP; HR	No	Spacelabs 90207	AM
Luecken et al. (2009)	Examine stress sensitization and inoculation models of the impact of early parental death on stress exposure and reactivity in late adolescence/young adulthood	91 late adolescents/young adults (43 early bereaved, 48 non bereaved).	Time – based (fixed intervals) during 1 day	Parental caring; depression; anxiety trait; stress; positive and negative affect	BP	Yes	Electronic diaries; Suntech Oscar II ABP monitors	AM
Maina et al. (2011)	Examine the association between two job stress models—the job strain and the effort-reward imbalance model—and ambulatory BP monitoring	100 call handler operators	Time – based (fixed intervals) during 2 days	Perceived stress; job strain	BP; HR	No	Paper diaries; BP One OPCB Monitor	AM
Muraoka et al. (1998)	Examine the CV correlates of PTSD using 24-hr ABP and HR	11 veterans with PTSD and 7 without PTSD.	Time – based (random intervals) during 1 day	PTSD symptoms; depressive symptoms; mood (stress; anxiety and	HR; BP	Yes	Paper diaries; Accutracker II	AA

	monitoring			anger)				
Parshuram et al. (2004)	Examine the workload and the level of fatigue and physical stress	11 senior fellows	Continuous monitoring during 35 shifts	Workload stress; fatigue	HRV; Physical stress (steps); urine (specific gravity and ketones)	No	Pedometer; Marquette Series 8500 recorders MultiStix 10 SG	AM
Pieper et al. (2007)	Hypothesize that increased HR and decreased HRV occurs not only during stressful events but also during episodes in which stress is cognitively represented	73 teachers	Time – based (fixed intervals) during 4 days	Job strain; trait worry; depression; anxiety; hostility	HR; HRV	Yes	Electronic diaries ; VU-AMS device with an accelerometer	Momentary Assessment; AA
Piferi and Lawler (2006)	Investigate the relationship between giving and ambulatory BP	96 undergraduates	Time – based (fixed intervals) during 1 day	Tendency to give social support; perceived stress; socially supportive behaviors; self-esteem; self-efficacy; depression	BP; HR	Yes	Paper diaries ; DynaPulse 5000A	AM
Rau (2006)	Examine the relationship between work-related stress and hypertension	126 healthy men employed in white collar jobs	Time – based (fixed intervals) during 1 day	Work related stress, relaxation-related experiences; Disturbed ability to relax; vital exhaustion	BP	No	BOSO TM2420; Physiomodul	AM
Richman et al. (2010)	Examine the impact of perceived discrimination on ABP and daily level affect during	63 participants	Time – based (random intervals) during 1 day	Perceived discrimination; hostility; neuroticism; affective states (stressed)	BP; HR	Yes	Electronic diaries; AccuTrackerII ABP	AM

	social interaction							
Sausen et al. (1992)	Examine hemodynamic responses to systematic variations in occupational stress using ABP monitors	44 healthy male medical students	Event-based	Psychological stress (mood)	HR; BP	Yes	Accutracker BP and HR monitor; Dinamap vital signs monitor	AM
Schlotz et al. (2006)	Examine the associations of specific task-related stressors and negative affective states on salivary cortisol and explores the mediating and moderating role of state negative affect and trait anxiety, respectively.	71 participants	Time – based (fixed intervals) during 2 days	Subjective stress; state affect; trait anxiety	Cortisol	Yes	Electronic diaries; Salivette; Medication Event Monitoring System	None
Schoenthaler et al. (2010)	Examine the effect of psychosocial stressors on Masked Hypertension .	240 unmedicated black and Latino(a) adults with optimal office BP readings (≤120/80 mm Hg)	Time – based (fixed intervals) during 1 day	Daily interpersonal stress	BP; HR	Yes	Electronic diaries; OMRON HEM 704; Suntech; Accutracker II	AM
Schwerdtfeger et al. (2008)	Examine the psychobiological correlates of self-efficacy	Study 1:58 school teachers Study 2: 50	Continuous monitoring during a day	Study 1: self-efficacy; perceived stress; burnout; affect	Study 1: HR; HRV; Locomotor activity	No	Study 1: Three-dimensional Accelerosensor; VARIOPORT-b;	AM

		school teachers		Study 2: self-efficacy; Physical complaints	Study 2: saliva cortisol		ECG Study 2: Salivette	
Smith et al. (2012)	Measure the momentary experience of social-evaluative threat, concerns about physical appearance, and confidence in abilities, and related these factors to concurrent variation in ABP	94 married, working couples	Time-based (random intervals) during 1 day	Negative affect (stressed)	BP	Yes	Electronic diaries; Oscar 2 - Suntech monitor	AM
Steptoe et al. (2005)	Show that positive affect is associated with reduced neuroendocrine inflammatory, and CV activity	116 men and 100 women	Time–based (fixed intervals) during 1 day	Positive affect; Stress; Control; Tiredness; Psychological distress; Psychopathology	Cortisol; BP; HR; Plasma fibrinogen	Yes	Paper diaries; Space Labs 90217 monitor; Salliva tubes; Portapres-2	AM; ESM
Steptoe et al. (2000)	Analyze associations between CV Stress Reactivity and BP and HR in everyday life	102 female and 60 male school teachers	Time – based (fixed intervals) during 1 day	Pressures	HR; BP	Yes	Paper diaries; BPM – spacelabs 90217; A&D UA-751 electronic sphygmomanometer ,Bedfont portable smokerlyzer	AM
Tobe et al. (2007)	Evaluate whether job strain and marital cohesion continued to be	248 participants	Time-based (fixed intervals) during 1 day	Job strain; marital cohesion	BP	No	Spacelabs Medical	AM

	associated with ABP in a longitudinal design							
Uchino et al. (2006)	Examine the association between age and daily stress processes that might have implications for CV disease	428 middle-aged to older adults	Time-based (random intervals) during 1 day	Negative affective states (feeling stressed)	BP	Yes	Paper diaries; Accutracker II	AA

Note. AA- Ambulatory Assessment; AM – Ambulatory monitoring; BP – Blood Pressure; BPD – Borderline Personality Disorder; CAPS – Clinical Administrated PTSD- Post-Traumatic Stress Disorder; CV – Cardiovascular; DRM – Day Reconstruction Method; ERN – Error-related negativity; EMA – Ecological Momentary Assessment; MRI -Magnetic Resonance Imaging GIANT - General Image Analysis Tools; HPA - Hypothalamic-pituitary-adrenocortical HR- Heart Rate; HRV – Heart Rate Variability; IMT - Intima-Medial Thickness; MUS – Medically Unexplained Symptms; PA – Physical Activity; PDA – Personal Digital Assistant; PTSD- Posttraumatic Stress Disorder; SFC- Self-focused-coping SCI – Social Competence Interview