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The Role of Ambulatory Assessment in Psychological Science

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Abstract

We describe the current use and future promise of an innovative methodology, *ambulatory assessment* (AA), that can be used to investigate psychological, emotional, behavioral, and biological processes of individuals in their daily life. The term AA encompasses a wide range of methods used to study people in their natural environment, including momentary self-report, observational, and physiological. We emphasize applications of AA that integrate two or more of these methods, discuss the smart phone as a hub or access point for AA, and discuss future applications of AA methodology to the science of psychology. We pay particular attention to the development and application of *Wireless Body Area Networks (WBANs)* that can be implemented with smart phones and wireless physiological monitoring devices, and we close by discussing future applications of this approach to matters relevant to psychological science.

Keywords

ambulatory assessment (AA); mobile health (mHealth); smartphone; wireless body area network (WBAN)

Research in psychological science primarily uses retrospective survey methods (collecting self-report data from questionnaires or interviews) and laboratory-based methods (measuring psychological or biological responses as well as reaction times to standardized stimuli presented under controlled conditions). However, these tried-and-true methods are limited in a number of ways, including total reliance on individuals' retrospective self-report, the skill of the interviewer or rater, and the artificial setting of the assessment. Above all, these methods may not provide a representative and unbiased sample of an individual's emotions, thoughts, and behaviors as they unfold in daily life.

In this article, we describe the current use and future promise of an innovative methodology, *ambulatory assessment* (AA). The term AA encompasses a wide range of methods used to study people in their natural environment, including momentary self-report (e.g., experience sampling [ESM; Csikszentmihalyi & Larson (1987)], ecological momentary assessment [EMA; Stone & Shiffman, 1994] using electronic diaries), observational (e.g., audio- or video-recording; activity monitoring), and physiological (e.g., cardiac and respiratory

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activity assessed using physiological sensors worn by participants) (Trull & Ebner-Priemer, 2013). Note that ESM, EMA, and AA are often used interchangeably, although their historical antecedents and original aims differ (Shiffman, Stone, & Hufford, 2008; Stone & Shiffman, 1994; Wilhelm, Perrez, & Pawlik, 2012). AA is the broad term encompassing all the methods mentioned above. ESM emphasizes random sampling schemes and often uses paper-and-pencil diaries and beepers, while ecological momentary assessment is most often associated momentary self-report using electronic diaries. Our use of AA is also consistent with the name of the primary organization of daily life research methods investigators, the *Society for Ambulatory Assessment* (SAA; http://www.ambulatory-assessment.org/).

Data from AA methods can characterize and test dynamic psychological processes, including emotions, cognitive styles and expectations, behavior patterns, and physiological correlates of daily life. Importantly, AA addresses many of the limitations of retrospective survey or laboratory methods (Trull & Ebner-Priemer, 2013). In particular, AA methods can provide real-time (or near real-time) assessments which minimize retrospective and heuristic biases that are known to systematically distort past experiences and events. For example, the "peak-end" rule suggests that recollection of emotional events is influenced heavily by its most intense point and by the end-point state (Fredrickson & Kahneman, 1993). Collecting momentary assessments over relatively shorter periods of time can therefore attenuate this bias because recollection is minimized. In addition, the collection of many assessments over time provides a temporal dimension to the monitoring of psychological constructs, especially crucial in the case of processes like emotion that are known to be dynamic, to fluctuate over time, and to change as a result of both external and internal influences. Finally, obtaining assessments in individuals' natural environment improves external validity, allowing one to observe and evaluate potential influences on psychological processes which are often experimentally eliminated or controlled in the laboratory (for examples of laboratory artifacts in psychology, medicine, and biology see Foulsham et al., 2012; Pickering et al, 1988; Rattenborg et al., 2008, respectively).

Although AA methods include momentary self-report, observation, and physiological approaches, most of the existing AA research literature uses only one of these methods. By far, the majority of studies use momentary self-report to assess individuals' experience in daily life. Even these studies can help challenge or revise psychological theories, like the finding that higher anxiety for mathematics in girls is reported in retrospective questionnaires but not in everyday life assessments of math lessons or tests (Goetz et al., 2013). Other examples include the finding that binge eating is both preceded and followed by increases in negative affect, counter to predictions by the affect regulation model (Haedt-Matt & Keel, 2011); alcohol use is associated with both positive and negative affect in clinical samples (Jahng et al., 2011); and desire for sleep, sex, and leisure activity in everyday life is rated stronger than that for "addictive" behaviors like using tobacco or alcohol (Hofmann, Vohs, & Baumeister, 2012). To date, compliance rates for completing momentary self-reports have been impressive, even among those with serious and chronic mental health conditions (see Trull & Ebner-Priemer, 2013). Furthermore, there are examples of AA momentary self-reports providing more explanatory power than traditional survey and retrospective methods (e.g., Wichers et al., 2010).

In addition to momentary self-report, many studies assess activity levels of individuals in daily life. For example, recent reviews of AA studies in the field of psychopathology and clinical psychology indicate that objectively measured daytime activity level (using accelerometers) is significantly lower in those with depression, and daytime activity levels significantly increase as function of treatment of depression (Burton et al., 2013).

Notably, more and more studies are beginning to combine AA data collection methods so that individuals' self-reports can be mapped onto their physiological activity, situational context, behavioral activity, and interpersonal experience. By combining momentary self-reports and accelerometry data, for example, Dunton et al. (2013) found that children reported feeling more energetic both before and after greater objectively-measured physical activity in their natural environment, and children who were more physically active demonstrated more stable levels of both positive and negative affect. Combining momentary self-reports and global positioning system (GPS) data, Epstein et al. (2014) found, contrary to expectations, recovering opioid and cocaine abusers reported less stress and negative mood while in more impoverished and disordered neighborhoods. Likewise, self-reported substance craving was negatively related to the adversity of the neighborhood. These findings challenge the idea that all individuals view and experience neighborhoods in the same way, and suggest that one experiences less discomfort in "familiar" surroundings (i.e., neighborhoods characterized by more disorder and drug activity). Finally, Huffziger et al. (2013) collected momentary self-report and momentary cortisol data over a two day period in a sample of remitted depressive patients and healthy controls. The authors found momentary rumination was associated with higher cortisol activity over the day in both groups, whereas lower momentary mood predicted higher cortisol levels only in the healthy controls. Remitted depressed individuals' reports of lower mood did not significantly affect cortisol levels, suggesting a decoupling of affective and neuroendocrinological processes in these patients.

Findings such as these suggest that methods and devices that can collect multiple types of momentary data are likely to be preferred and used in future studies, because they provide a more ecologically valid description of processes, and influences on these processes, as they unfold in daily life (Goodwin, Velicer, & Intille, 2008). Furthermore, measuring the "momentary self" from the perspective of multiple domains (e.g., subjective, behavioral, biological) is more likely to reveal important connections between these domains and to inform theories stipulating certain biological and physiological underpinnings of the "experiencing self" and psychological processes (Connor & Barrett, 2012).

In addition to facilitating the testing of theories that focus on psychological processes and mechanisms, it is also important to note that the method itself may help generate and promote new theories, given that AA provides insight into the "film of life" that is not possible with other methods (e.g., see Greenwald, 2012). Below, we highlight the utility of the smartphone in AA studies, because it can collect multiple types of data as well as serve as a hub for sensor networks that can collect and transmit data in real-time.

The Smartphone in Ambulatory Assessment

A recent Pew survey (January, 2014) indicated that 58% of American adults now own a smartphone. Worldwide, it is predicted that by 2014 there will be about 1.8 billion smartphone users (Portfolio Research, 2011). A smartphone can be used like an electronic diary to prompt and log self-reported momentary responses in ambulatory assessment. However, there are many more powerful functions unique to the smartphone that can aid AA. Today's state-of-the-art smartphone has a powerful processing capacity, large memory storage capacity, the ability to multi-task, a range of connectivity possibilities with other devices, many built in sensors, the potential to link with external sensors, GPS capabilities to track location and time, digital cameras and video-recorders, and audio input/output and recording (Miller, 2012). Because of this versatility, the smartphone has become the central hub or access point for ambulatory assessment.

Wireless networks of miniaturized body sensors with a central access point, which are called *Wireless Body Area Networks (WBANs)* or *body sensor networks (BSNs)*, appear particularly promising. Smart phones, as the single access point, can be used to prompt participants and record self-reported responses to standardized queries (and through internal sensors can intuit both behavior and context). The smart phones interact with the wireless devices (using Bluetooth) collecting, for example, cardiac and respiratory activity. Real-time analyses of the body signals can trigger surveys when physiological or behavioral events of interest are detected (Ebner-Priemer et al., 2013).

To date, there are relatively few WBAN studies in the psychological science literature, although we expect this to change. Recent reviews highlight a number of systems that have been developed to monitor vital signs (e.g., cardiac activity, respiration, body temperature), activity and gait, and body position/posture, for example (Latre et al., 2011; Ullah et al., 2012). It is easy to envision how these and other systems could be applied to topics relevant to psychological science. For example, data from WBAN systems will allow us to test psychological theories of emotion and behavior by providing time-intensive and precise measurement of a variety of potentially influential person-level factors that may interact with environmental demands or situational contexts (Intille, 2012). In addition, monitoring potentially confounding variables will be possible. Finally, it is possible to use data from WBAN systems to trigger interventions aimed at modifying or preventing problematic behaviors or responses. Specifically, algorithms can be developed to identify potential problematic states (and locations) that may put an individual at risk for engaging in dysfunctional behavior. Digital interventions (e.g., texts, audio-recordings, video-recordings) can be programmed to be administered in such high risk situations or episodes. For example, Gustafson et al. (2014) reported on a randomized clinical trial that examined the effect of a smartphone-administered intervention to support the recovery of patients leaving residential treatment for alcohol use disorders. Results indicated that those using the *Addiction-Comprehensive Health Enhancement Support System* app, which included both instructional material (e.g., guided relaxation) as well as interactive interventions (e.g., alerts sent to the patient when approaching a high-risk location like a familiar bar), reported fewer risky drinking days and a higher likelihood of consistent abstinence during the follow-up period than did those from the treatment as usual only group.

Mobile health (mHealth)

Although many applications of AA target psychopathological symptoms and syndromes, it is important to recognize that AA can contribute to a variety of constructs relevant to psychological science, more broadly. For example, there is a large push to use AA in the service of health promotion and disease prevention (Heron & Smyth, 2010; Kaplan & Stone, 2013). Specifically, many phenomena, experiences, and behaviors that have previously been only studied in the laboratory or clinic can now be investigated in daily life. There are examples of physiological states, like blood pressure, for which everyday life measurements are much better in predicting mortality than assessments which take place in the clinic or the laboratory (Pickering et al., 1988). Furthermore, retrospective reports of symptom, of engaging in prescribed healthy behaviors, and of complying with medication regimens are known to be unreliable and subject to intentional and unintentional biases (Schwartz, 2012). For these reasons, the field of mobile health (mHealth) has developed to more precisely assess and, ultimately, treat health problems as they unfold in daily life. Although mHealth interventions in daily life hold great promise, results to date regarding the efficacy of these interventions (demonstrated through randomized, controlled trials) has been disappointing (Kaplan & Stone, 2013). One explanation is that, to date, there has been little over-sight of the development of these mHealth interventions from a psychological perspective to ensure that the technological developments are based on the principles of evidenced based interventions known to affect the targeted behavior (Kaplan & Stone, 2013; Trull & Ebner-Priemer, 2013).

Challenges and Future Directions

Although we are excited about the future prospects of using AA methods, it is important to note some pressing issues that must be considered in future applications of this methodology. First, as it becomes more common place to transmit AA data in real-time, researchers will need to be more vigilant about protecting confidentiality and privacy of this information. In addition to getting a person's informed consent before collecting AA data, it is also necessary to ensure that data on the devices are encrypted, that transmission of the data is secure, and that data are encrypted on servers. Second, the amount of data that can be collected using AA method is exponentially larger than what many psychological scientists are used to managing. AA data are often collected over much of the 24 hour day and over many days. Therefore, expert data management and expertise in quantitative methods appropriate for "big data" like these are needed. However, the ability to collect massive amounts of data does not imply that theory should be abandoned completely; existing theories can be tested and modified based on data from AA studies. Third, smartphones have some limitations that can affect the collection and processing of data as well as momentary interventions. These include limitations in memory, battery power, hardware compatibility with software, cost, and constraints on the format of stimuli that are presented (Miller, 2012). Finally, there are currently thousands of apps that have been developed for a range of psychological or health problems (e.g., depression, obesity, asthma, diabetes, lack of physical activity, etc.). However, to date, there has been little over-sight of these largely commercial products as to the scientific evidence base supporting the content and methods of these products. Fortunately, empirically-based, well-constructed apps for health issues are

becoming more available (e.g., PTSDCoach, Depression CBT Self-Help Guide, depressioncheck, T2 Mood Tracker). We encourage psychological scientists to take the lead in addressing these issues and concerns so that the science of human emotions and behavior can be advanced. AA is a very promising methodology both in its ability to produce data that can test many theories of psychological mechanisms and of behavior change as well as in its ability to provide a new dynamic and ecological perspective on psychological and behavioral processes as they unfold in daily life.

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Recommended Readings

Kaplan RM, Stone AA. An excellent overview of the application of AA methods to health and the field of mobile health (mHealth). 2013 (See references list).

Mehl, MR.; Conner, TS. Handbook of research methods for studying daily life. New York: Guilford Press; 2012. Comprehensive guide and resource for AA studies

Shiffman S, Stone AA, Hufford MR. 2008 (see references list). Excellent overview of ecological momentary assessment and its applications, especially in the field of addictions.

Trull TJ, Ebner-Priemer UW. 2013 (See references list). Comprehensive discussion of the field of AA, primarily focusing on applications in clinical psychology.

Wilhelm P, Perrez M, Pawlik K. 2012 (see references list). Excellent historical overview of the development of methods to study daily life.