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Trends in Ambulatory Self-Report: The Role of Momentary Experience in Psychosomatic Medicine

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Abstract

In this article, we review the differences between momentary, retrospective, and trait self-report techniques and discuss the unique role that ambulatory reports of momentary experience play in psychosomatic medicine. Following a brief historical review of self-report techniques, we discuss the latest perspective which links ambulatory self-reports to a qualitatively different conscious self – the 'experiencing self'– which is functionally and neuroanatomically different from the 'remembering' and 'believing' selves measured through retrospective and trait questionnaires. The experiencing self functions to navigate current environments and is relatively more tied to the salience network and corporeal information from the body that regulates autonomic processes. As evidence, we review research showing that experiences measured through ambulatory assessment have stronger associations with cardiovascular reactivity, cortisol response, immune system function, and threat/reward biomarkers compared to memories or beliefs. By contrast, memories and beliefs play important roles in decision making and long-term planning, but they are less tied to bodily processes and more tied to default/long-term memory networks, which minimizes their sensitivity for certain research questions. We conclude with specific recommendations for using self-report questionnaires in psychosomatic medicine and suggest that intensive ambulatory assessment of experiences may provide greater sensitivity for connecting psychological with biological processes.

Keywords

ecological momentary assessment; PANAS; emotion; memory bias; stress; questionnaires

Self-reports are ubiquitous in psychosomatic medicine and related fields like behavioral medicine and health psychology. It is a rare study that does not have participants verbally describe something, whether it be their emotions, physical symptoms, health behaviors, or other patient reported outcomes (PROs). Traditional reporting formats require people to report their experiences from memory through the use of trait or retrospective questionnaires. By contrast, momentary self-report techniques, such as ambulatory assessment, allow people to report experiences that are happening in real-time across multiple moments in their daily lives. In this article, we review the core differences between trait, retrospective, and ambulatory self-report techniques, and highlight the powerful role that ambulatory self-reports of experience play in psychosomatic research.

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We start with a brief review of self-report techniques and then propose that scientific understanding of self-reports has progressed from simply documenting how ambulatory self-reports may be less biased by memory than traditional self-reports to recognizing that self-reports evoke different types of constructed experience – the self in the moment (the experiencing self), the self through time (the remembering self), and the belief-based self (the believing self) (1 - 4). Moreover, each state of subjective construction (experiences, memories, and beliefs) serves a unique function (e.g., for navigating current environments, decision-making and long-term planning) that, in part, is based on its unique pattern of underlying neurobiology. From this perspective, the experiencing self measured through ambulatory assessment plays an important role in connecting psychological processes to bodily processes (cardiovascular, hormonal, immune). We review evidence showing that ambulatory reports of daily experiences often show stronger connections with autonomic, hormonal, and immune system processes than do corresponding retrospective and trait self-report measures. By contrast, the remembering and believing selves measured through traditional self-reports play important roles in health decisions. We end with five practical recommendations for choosing self-report techniques in psychosomatic medicine.

Trait, Retrospective, and Ambulatory Self-report Techniques

Trait and retrospective self-report questionnaires, which we collectively call traditional self-report techniques, rely on a memory-based reporting format in which people are asked to remember and summarize experiences, often over long periods of time (weeks, months, or a lifetime). At the highest level of abstraction are trait questionnaires (also called global questionnaires) in which people are asked to remember and aggregate experiences over the widest time frame—one's lifetime. Trait questionnaires are used to assess personality, temperament, and emotional style (e.g., the NEO PI-R; the Buss-Perry Aggression Questionnaire) (5, 6). For example, the neuroticism scale of the NEO PI-R instructs respondents to rate the extent to which they agree or disagree with general statements like "I often feel tense and jittery" or "I often get angry at the way people treat me" (5). Likewise, in the trait format of a widely used affect measure – the Positive and Negative Affect Schedule (PANAS), individuals rate the extent they *generally feel* 20 high activation emotions like 'enthusiastic', 'nervous' and so on (7). Trait questionnaires are popular and easy to use, and perhaps because of these factors, they have been the primary way of looking for connections between psychological concepts and underlying biology (cf, 8). Other traditional self-report procedures are explicitly retrospective in nature; they ask people to remember their prior experiences over a particular timeframe. For example, the Center for Epidemiologic Studies Depression Scale requires respondents to reflect on their emotions and behaviors *during the past week* (CES-D) (9). Some of the most common health inventories use a one to four week retrospective timeline (SF-36 Health Survey) (10) [for discussion of recall timeframes in PROs, see (11).]

By contrast, momentary self-report procedures have people describe their thoughts, feelings or behaviors as they are happening in real-time (or close to real-time). Momentary self-report procedures can be done in the laboratory (12, 13), but they are more commonly conducted over many time points in naturalistic settings using a class of procedures called experience sampling methods (ESM) (14), ecological momentary assessment (EMA) (15), or, increasingly, ambulatory assessment (AA) (16); www.ambulatory-assessment.org). [For a recent handbook on these methods, see (17).] While early procedures collected data using paper-and-pencil surveys sometimes combined with audible pagers (18, 19) and later, data were collected with palmtop computers and personal digital assistants (PDAs) (20 - 23), today, advances in internet and mobile technology enable efficient data collection through daily internet diaries, mobile phones and smartphones, as well as PDAs (24). Ambulatory self-report procedures have been used in psychosomatic medicine and related health fields to

measure a variety of experiences and behaviors including emotions, pain, fatigue, coping, and daily stress (25 - 29) as well as health behaviors like smoking and alcohol use (30, 31). For more detailed reviews of AA methods in these areas, see (32 - 35).

Evolving Themes in the Science of Self-Report: Relationship among Trait, Retrospective, and Ambulatory Self-Reports

Since ambulatory assessment techniques were introduced, scientific understanding of their differences from traditional memory-based reports has evolved. In this section, we review three conceptual themes that characterize an understanding of their relation. The core differences, assumptions, and recommendations of each theme are shown in Table 1. Although we discuss the three themes separately and in loose chronological order, these groupings are more conceptual than historical as there is overlap in their publication dates.

Ambulatory Self-Reports are Less Biased than Traditional Self-Reports

Soon following their development, ambulatory assessment procedures came to be seen as the more valid measure of experience compared to traditional memory-based procedures. [For a history of AA, see (36)]. Researchers believed that intensive momentary reporting allowed them to obtain an "objective" account of activities and experiences as they unfold for a respondent over time, whereas traditional self-reports gave them a reconstructed and potentially fallible account of prior experiences from memory. In behavioral economics, Kahneman called this momentary record – as applied to hedonic mood states – *experienced utility* (37). With ambulatory assessment, it became possible for researchers to create their own aggregates of experienced utility over time, and compare those to the subjective aggregates provided by respondents (38 - 41) (12, 42 for laboratory-based AA studies).

Early research revealed the extent to which memory based self-reports deviated from more immediate "objective" accounts obtained through ambulatory assessment [for reviews of memory biases, see (43, 44)]. For example, early EMA research on smoking cessation showed that people poorly recalled their quit dates and they overestimated in memory their actual experience of distress when quitting smoking in comparison to what they actually reported in real-time using an electronic diary (30). Women also overestimated in retrospective ratings their premenstrual symptoms relative to what they reported in the moment (45). This general pattern of overestimation in memory has since been replicated for a variety of emotions (46) as well as physical pain (47, 48). Early pain research also showed that retrospective reports of pain were influenced by pain at the time of recall (49, cf. 50), and by the most intense pain during the previous week (51). Importantly, this latter research by Stone et al. extended laboratory evidence demonstrating that people often neglect the duration of their experiences and instead weight aggregate judgments by their most intense and most recent episodes ("peak and end" effects) (51, 52). Taken together, these AA applications corroborated evidence of the fallibility of autobiographical memory (53) and highlighted the advantages of measuring experiences in real-time to remedy bias.

Implicit in this perspective is that different kinds of self-report procedures could be arranged hierarchically from the most biased to the least biased (see Table 1, *Core Difference*). In this hierarchy, ambulatory self-report procedures were considered the most valid, and thus came to be seen as the "gold standard" of self-report, whereas memory-based reports were considered the least valid (e.g., 54, 55). Underlying this hierarchy is that momentary experience was the criterion to be captured, and it could be done with more or less validity depending on the method used. This went hand in hand with the assumption that self-reports at different levels of abstraction *should* map onto each other. That is, a retrospective report about how one felt over the past two weeks should correspond fairly closely to an arithmetic

mean of what actually happened over the past two weeks. Likewise, a trait report of personality should closely correspond to the accumulated lifetime experiences. To the extent that beliefs or memories diverged from actual experience, this pattern of bias called into question the validity of traditional self-reports.

Ambulatory Self-Reports Reflect Different Types of Knowledge

In time, there has been a shift in understanding the relationship between traditional and ambulatory self-reports. This shift was rooted in the research from cognitive psychology which at the time distinguished between semantic and episodic declarative memory as distinct mental processes (56). While semantic and episodic memory are now considered types of memory processing tasks rather than distinctive knowledge systems (57, 58), research from cognitive psychology helped researchers to understand that the distinctions between traditional and momentary self-reports were more than a simple matter of bias – they were reflecting different sources of knowledge that people use when reporting their subjective experiences in these different ways.

Robinson and Clore (59) outlined this perspective best in their accessibility model of emotional self-report, which linked trait, retrospective, and momentary self-reports of emotion to different types of subjective knowledge. As shown in Table 1, trait self-reports were characterized as measuring semantic knowledge—that is, conceptual knowledge extracted from momentary experience (among other sources) that is no longer associated with time and place. By contrast, ambulatory assessment procedures were characterized as measuring episodic knowledge—that is, event-specific knowledge about subjective *experiences situated in a particular time and context* (60). When momentary self-reports are used, respondents can directly introspect on *experiential knowledge* as it is being generated (e.g., current pain levels, emotions, feelings of stress). When short term recall reports are used such as with daily diaries (61) or the Day Reconstruction Method (62), people were thought to use episodic memory to recreate the episodic details of events, which can introduce episodic memory biases (e.g., peak-and-end effects). When longer term retrospective reports are used (e.g., one to four week recall), respondents appear to stop trying to recall and summarize memories for specific experiences, and instead start accessing relevant semantic knowledge to help guide their verbal reports (63). Thus, retrospective reports are often more consistent with semantic beliefs than actual experience (38, 65-71) – they incorporate a greater degree of gender and cultural norms (65 - 68) and intensify personality differences (38, 69).

This shift from simply documenting bias to trying to understand the knowledge contained within the content of verbal reports led to new underlying assumptions about self-report procedures. As shown in Table 1 (*Assumptions*), from this perspective, ambulatory assessment procedures were no longer seen as inherently better than traditional self-reports; *they were different*. They provided different yet complementary information about psychological functioning (64, 72 - 74).

Different Self-Reports Tap Different Functional Selves

A recent research theme builds on the previous perspective by suggesting that self-reports measure *different types of conscious "selves"* (2- 4, 75), namely, the experiencing (momentary), remembering (retrospective), and believing (trait) self. These conscious selves become activated in different circumstances by different task demands, have different inputs with the brain and body, and serve different functions in behavior and decision making.

The concept itself of differing selves with different relative inputs and qualities of consciousness itself is not new (e.g., 3, 60). For example Markus and Wurf (1987) discussed

the concept of multiple selves that are context dependent. In 1993, Singer and Salovey wrote about "The Remembered Self" (3). In 1985, Tulving wrote about different qualities of consciousness – autonoetic and noetic conscious–when people use episodic and semantic memory, respectively (60). However, recent publications, including those by Wilson and by Kahneman, have explicitly mapped different selves onto different types of self-report procedures. For example, Kahneman recently expanded on his concept of experienced utility to distinguish between the 'experiencing' and 'remembering' self that are captured by momentary and traditional self-reports respectively (1, 75). Likewise, research in affective forecasting has distinguished between past, present, and future (predicted) selves, which are tapped by retrospective, online, and prospective self-reports respectively (4). Thus, from this perspective, different self-report procedures cultivate different "selves" that guide how a person responds on that instrument.

We would also like to point out that differing selves (experiencing, remembering, and believing selves) likely reflect different relative inputs of immediate sensory experience (from the world and/or the body) versus experience that is derived from long-term memory (3, 60). The experiencing self is, relatively speaking, more tied to the corporeal information from the body and sensory information from the world. As such, the experiencing self should be closely linked to brain activity within those networks that collectively help to represent and regulate a person's current autonomic state and changes in homeostasis ["core affect network" (76) or "salience network" (77)]. The experiencing self should also be tied to portions of this network that are involved in the conscious representation of somatovisceral cues such as the dorsal anterior cingulate cortex (77) and anterior insula (78) [for an excellent neuroscience review in psychosomatic medicine, see (79)]. By contrast, the remembering and believing selves require greater activation of the default/long-term memory network, relatively speaking.[i] There may be less of a link to the current sensory state of the body, particularly for the believing self. Although sensations from the body are never really 'off' or irrelevant to any mental state, representation of the body in awareness is likely minimized phenomenologically during beliefs as opposed to the immediate present.

Each self, in turn, plays important roles in mental life and behavior. The experiencing self serves to integrate information across different systems- in present time awareness- in order to respond flexibly and in a coordinated way to both novel and known environments (80, 81). The experiencing self is, essentially, the 'front line' self that functions to help individuals maintain homeostasis and navigate physical and social environments *in situ*. By contrast, the remembering self filters and consolidates our experiences so that we can learn, communicate, and make decisions about the future based on our past. The characteristics of the remembering self reflect the three main functions of autobiographical memory– self (e.g., maintaining continuity of the self), social (e.g., facilitating communication), and directive (e.g., guiding planning and decision making) (82, 83). Lastly, the believing self is also a 'story teller' but at a higher level of abstraction that reflects the collection of identities and self concepts that help individuals maintain identity through time (2). The believing self also serves as mental scaffolding for interpreting incoming information, and for anticipating and forecasting the future, among other roles (2, 45).

Practical Implications of Differing Selves for Psychosomatic Medicine

In the previous section, we reviewed three perspectives on the differences between momentary (ambulatory), remembered, and trait self-reports. Of these three perspectives, the

[i]The "default network" (126, 127) or the "long term memory network," appears to be active whenever people engage in inwardly-focused mental activity, such as spontaneous, highly associative mental activity (e.g., daydreaming or mindwandering) (13), constructing an imagining of the future or a memory of the past (128), or constructing object perceptions (129).

theme of differing functional 'selves' with different connections to the bodily and sensory input may have several practical implications in psychosomatic medicine. Understanding the distinctions among experiences, memories, and beliefs can help researchers choose which 'self' they want to cultivate for a given hypothesis, and which corresponding self-report measure to use. In this section, we review several practical implications of this perspective using examples within psychosomatic medicine research. The following sections highlight the role of the experiencing self in psychosomatic medicine; the last section highlights briefly the role of the remembering and believing selves as they affect health related decisions.

The Experiencing Self May Show Stronger Connections to Bodily Processes than the Remembering or Believing Selves

Research suggests a strong link between the psychology of the experiencing self and stress related bodily reactions such as cardiovascular reactivity, hypothalamic-pituitary-adrenal (HPA) axis reactivity, and immune system function. It is the experiencing self whose blood pressure rises in response to stressful situations (84), whose cortisol responds to a stressor (29), and whose immune system reacts to elevated feelings of hostility during spousal fights (85). Although humans can evoke the stress response through memories and anticipated thinking (86), acute autonomic, hormonal, and immune responses are most commonly activated as people act and react to life's momentary stressors through the eyes of the experiencing self. As evidence of this linkage, psychological states measured intensively through ambulatory assessment often show stronger associations with various cardiovascular, HPA, and immune biomarkers compared with traditional self-reported traits. For example, in their cardiovascular research, Kamarck and colleagues proposed that everyday experience – in particular, how people interpret and respond to daily stressors– incorporates (and therefore reflects) sympathetic nervous system (SNS) activity (84). Alterations in SNS activity, in turn, lead to increased risk of cardiovascular conditions like atherosclerosis. Through the Pittsburgh Healthy Heart Project, Kamarck and colleagues (84) used ambulatory assessment to collect momentary self-reports of psychosocial stress along five dimensions (e.g., social conflict, task demand, decisional control, negative affect, and arousal) concurrent with ambulatory blood pressure and heart rate readings in daily life. Analyses showed strong associations between momentary self-reports of psychosocial stress and ambulatory blood pressure and heart rate. Moreover, aggregated momentary reports of daily stress predicted atherosclerosis risk measured by mean carotid artery wall thickness, whereas *comparable trait measures of stress did not*. Similarly, recent research on patients with coronary heart disease showed that momentary affective experience during a 24 hour monitoring period was a stronger predictor of ambulatory heart rate variability than were scores on the Beck Depression Inventory (87). Taken together, this research suggests that momentary measures of psychosocial stress and emotions taken *in situ* outperformed global or retrospective measures in predicting disease risk. In other words, the psychology of the experiencing self mattered more to cardiovascular risk than the psychology of the remembered or believed self. This asymmetry makes sense given that the experiencing self has greater links to components of the salience network and networks involved in the regulation of autonomic activation. Therefore, the experiencing self—and its links to hemodynamic reactivity— may be an important risk factor in the development of disease (84).

The experiencing self is also strongly tied to hormones such as cortisol, a stress-related byproduct of the hypothalamic-pituitary-adrenal (HPA) system. For example, Nicolson (88) showed that ambulatory self-reports of emotional states, daily hassles, and stressors – not just the experience of major life events– can increase salivary cortisol in daily life. Research has also shown links between fluctuating mood states and ambulatory cortisol in a sample of

white collar workers (89) and higher salivary cortisol levels among people currently experiencing or anticipating a stressor (29). Importantly, there appear to be stronger associations between cortisol and affect that is measured using ambulatory assessment than when using questionnaires like the trait version of the PANAS (25). For example, Steptoe and colleagues found that higher momentary positive affect was strongly related to lower waking and total cortisol levels, whereas trait affect was only weakly related to waking cortisol levels, despite momentary and trait affect in this study being moderately correlated r = .46 (25). These findings are consistent with the cardiovascular findings reviewed above (84, 87) which, together, show that repeated momentary measures of affect outperform the corresponding trait measure in predicting these particular biological responses.

The experiencing self also has links to immune system function. For example, laboratory work by Kiecolt-Glaser and colleagues shows that the immune system is especially sensitive to the experience of hostility (85). Hostile interactions among couples slowed wound healing by 60% compared to couples without such hostility. Similarly, research suggests strong associations between the experience of momentary affect and immune responses (90-93). For example, in a laboratory study of upper respiratory viral infection, a measure of baseline state negative affect taken before virus administration significantly predicted a biological marker of immune function (mucus secretion), whereas a trait negative affect measure taken on the same day did not (91). In another study by the same team, lower levels of positive affect aggregated from daily measures were associated with a 2.9 increase (odds ratio) in the likelihood of getting a cold, whereas lower levels of positive affect measured using a traditional trait measure were only associated with a 1.6 increase (odds ratio) in the likelihood of getting a cold (92). While both odds ratios were statistically significant, effect sizes were stronger for the averaged daily measure than for the trait measure. Thus, the averaged daily measure of positive affect provided a more sensitive account of participants' emotional states in the time leading up to virus administration. In light of this evidence, variations in state affect—through connections to the ANS and HPA-activity—are thought to be an important mechanism affecting immune system function (91, 94, 95).

The Experiencing Self May Show Stronger Connections to Reward and Threat Circuitry than the Remembering or Believing Selves

The experiencing self also may have stronger links to the core affect network that modulates reactions to reward and threat. For example, recent evidence shows that fMRI measured patterns of striatal activation to reward stimuli were strongly associated to reports of positive emotion measured using ambulatory assessment (96, 97). Associations with trait positive emotion were not tested; however, we suspect that patterns with trait reports would have been much weaker because trait reports measure the believing self, which is more temporally distant from the experiences that should be affected by striatal differences in reward processing. By measuring feelings of pleasure in real-time in response to real-world rewards, the researchers were able to capture the feelings that were most functionally linked to the underlying neurobiological processes.

Other empirical evidence suggests that the experiencing self has strong ties to amygdala activation as it related to the core affective network. In a prospective imaging experiment, individuals who reported greater experiences of negative affect across 28 days of experience sampling demonstrated significantly greater amygdala activation during the first block of briefly presented, masked fearful faces one year later, when compared to those who reported lower levels of momentary negative affective experience (98). Although other studies have found a link between amygdala response and trait measures of neuroticism that are taken close to the time of scanning (99), trait ratings of neuroticism taken by Barrett et al. at the beginning of the experience sampling study did not predict amygdala response one year later.

Experiences also may show earlier responses to pharmacological interventions, particularly those interventions targeted at the salience network. In a trial of anti-depressant medication by Lenderking and colleagues, changes in depressive symptomology were detected earlier among patients randomly assigned to track their symptoms using daily diary questionnaires compared to patients who reported their symptoms using standard one-week recall measures (100). Interestingly, weekly clinician assessments using the Hamilton Rating Scale for Depression (HAM-D) and the Montgomery-Asberg Depression Rating Scale (MADRS) showed similar changes in depression between the two reporting groups. Cautiously, the authors suggested further research on this finding, but mentioned that "findings are also consistent with the hypothesis that [daily symptom reports may be] a more sensitive measure of response to depression treatment than the HAM-D or MADRS." (p. 875). Other researchers have noted similar concerns about the sensitivity of summary scales as primary endpoints in pharmacological research (101). For example, Pasqua and colleagues (101) noted that "Summary scales [like the HAM-D] are not sufficiently sensitive to differences in pharmacological properties and possibly too crude a measure to translate efforts … into clinically meaningful differences" (p. 150). Although Pasqua and colleagues suggest improving sensitivity by developing better depression sub-scales, the work by Lenderking and colleagues suggests improving sensitivity by tracking real-time symptomology in daily life.

Using Trait Measures as Proxies for the Experiencing Self can Lead to Null or Inconsistent Patterns in the Literature

Researchers need to understand that, as a general rule, trait or global measures tap knowledge that is more deliberate, reflective, and stable in nature (15, 59). As a result, using trait measures as short-cuts to the experiencing self can result in reduced sensitivity of measurement, weaker effect sizes, or even null results. Yet in many areas of research, trait reports are still used as the primary way of linking psychological concepts like emotional style to biology (8). As Kagan wrote:

> A serious problem with the reliance on [trait] questionnaire indexes of personality is that the scientists interested in [their] biological correlates…typically relate a profile of blood flow or a genetic polymorphism… with a questionnaire measure that can be obtained in less than an hour and lacks an equally sound theoretical background. Because the questionnaire data are too crude an index of the psychological correlates of a genetic feature, biochemical profile, or brain state, this strategy is unlikely to reveal strong relations between the biological and psychological measures. (p. 369) (8)

We agree with this observation; however, offer a middle way rather than abandoning self-reports in favor of objective measures (8, 102, 103). We suggest that intensive ambulatory assessment of experiences in real-time can lead to more sensitive measurement of phenomenological endpoints, leading to improved detection when linking subjective factors to biological factors. The reason is that ambulatory assessment provides a window onto subjective experiences that are more temporally and functionally connected to the bodily processes that modulate situated and contextualized behavior. In short, by using more sensitive self-report methods, researchers will maximize their ability to detect linkages between the psychological and biological. As noted by Lane and colleagues, this linkage is often the critical "starting point" for both establishing a phenomenon and then investigating the mechanisms that connect these levels (104).

Consider the genetic underpinnings of emotion. Despite molecular evidence that the serotonin transporter gene (5-HTTLPR) regulates serotonin uptake (105), and that serotonin transporter gene differences are related to fMRI measured amygdala sensitivity (106),

research linking this gene to subjective emotional phenotypes among non-clinical samples has been mixed (107). Yet, the bulk of this research has relied on trait reports of emotion such as neuroticism questionnaires as the principal measure of subjectively experienced emotion. But the serotonin transporter gene is probably more effective at modulating the emotions of the *experiencing self* rather than the believing self. Using a 30-day daily diary technique, research by the first author and colleagues found that young adults with the risky 5-HTTLPR short allele reported elevated feelings of anxiety in daily life, especially on days with greater stressors (108). Importantly, while differences were found in the daily reports of anxiety reactivity, there were *no genotype differences in trait reports of anxiety* using a standard neuroticism questionnaire (NEO-FFI) despite the state and trait anxiety measures being correlated. Thus, we observed reliable genetic differences at the state level, but failed to show genetic differences at the trait level. A similar pattern was shown for a gene variant (rs13212041) that affects regulation of the serotonin 1B receptor, which is involved in aggression (109). Among young men, we found strong associations between this gene variant and aggregated reports of state anger and hostility from daily diaries (effect size Cohen's $d = .57$). We found weaker, although still significant, associations with a measure of trait anger and aggression ($d = .43$) (from unpublished data) (109). Genetic associations have also been found for the Catechol-*O*-Methyl Transferase (*COMT*) Val/Met polymorphism and ambulatory reports of reward experiences in daily life (110). Taken together, this research suggests that ambulatory assessment may be more sensitive for measuring the real-time emotional correlates of genes that modulate neural structures involved in automatic emotion processing. To the extent that other genes are involved in regulating the core affect / salience network or other circuits that regulate subjective phenomenology (e.g., pain), ambulatory assessment will likely provide the most sensitive self-report measure.

Ambulatory assessment may also help clarify inconsistencies in other areas of research linking subjective outcomes to brain processes, such as the emotional effects of mindfulness meditation interventions. Research has found brain changes as a result of mindfulness training such as greater left-sided hemispheric activation (111, 112); however, these changes often do not correspond with changes in self-reported emotion. This is not entirely surprising given the complex relationships between brain activity, bodily processes, and subjective measures at any given point (113, 114). Yet, often with laboratory studies, emotions are usually measured in the standard ways – either with trait measures of affective style (111), or momentary reports made in the lab before and after training (112). These approaches may not be sensitive enough to detect affective changes as a function of meditation training. In a Goldilocks sense, trait measures of emotional style may be "too cold" – too slow and sluggish to change because they capture enduring beliefs about a person – but momentary measures administered only once or twice may be "too hot"— too volatile and overly sensitive to extraneous variables unless they are aggregated over many repeated observations.

For these reasons, ambulatory assessment methods might provide greater resolution to affective changes that unfold over longer periods of time with mindfulness practice. For example, in research by Fredrickson and colleagues, training in loving kindness mediation among a community sample resulted in improvements to their daily mood states over the 9-week period compared to those in a waitlist control condition (115). Moreover, self-reported positive emotions in daily life were "the mechanism of change" (p. 1045) that led to improvements in other traditional endpoints such as global purpose in life, improved social support, and improved health symptoms. Indeed, other ambulatory assessment research has revealed affective differences between high and low mindful individuals and between new and advanced mindfulness meditators in daily life (116 - 118). Taken together, research

suggests that ambulatory assessment of affective experiences in naturalistic settings may be a useful tool for linking mindfulness practice to emotional changes.

Remembering and Believing Selves Show Stronger Connections to Health Decisions

Health decisions like choosing a doctor and returning for routine health check-ups can have strong implications for mental and physical health. For these processes, the psychology of the remembering or believing selves may play more important roles than the experiencing self. Indeed, there is growing awareness that people's recollections, however distorted, play an important role in prospective decision making (1, 42, 82, 83, 119). For example, how people remember painful procedures, more than their actual experience during the procedure, affects important decisions such as whether to undergo the procedure again. In one of the earliest demonstrations of this phenomenon, Kahneman and colleagues showed that people's memories for aversive events (e.g., submersing a hand in cold water) were highly influenced by how the procedure ends, and people were more likely to choose to undergo aversive experiences again if they had experienced "a better ending" (42). Later, this work was extended to a clinical sample of 682 colonoscopy patients, some of whom underwent a modified procedure that added several minutes of not-painful time to the end of their colonoscopies (120). Those who remembered the procedure as less painful were more likely to undergo follow up colonoscopies 5 years later. These findings suggest that memories – and the use of retrospective self-reports – may serve important functions in the context of prospective health decisions and behavior. Thus, doctors (and researchers) should carefully consider the way that their patients remember health information, and health-related experiences including visits to the doctor.

Research in social psychology also highlights the important function of retrospective memories in behavior and decision making (44). For example, a two-week computerized experience sampling study tracked the anticipated, experienced, and remembered emotions of university students' as they went on a spring break vacation (121). Students' anticipated and remembered feelings were much more positive than what they actually reported during their trip. Importantly, when asked whether they would repeat the trip again, their decisions were driven by their recollections. Thus, biased estimates of the past can be good predictors of future choice (1, 44, 122).

Taken together, research demonstrates a growing awareness of the special utility of the remembering self particularly for health-related decisions. The implication of this framework is that retrospective and trait self-reports will be maximally useful in research in which people activate their default/long-term memory networks to use their remembered or summary judgments to guide expectancies, decisions, and behaviors. In these contexts, memory-based self-reports may be the more sensitive measure than momentary self-reports for capturing decisional factors.

Summary and Recommendations

We believe that the science of self-reports has evolved through three themes of understanding. While different self-report procedures were originally ranked and directly compared with each other, later it was assumed that different self-report procedures captured different types of knowledge for experience. Today, there is a growing awareness of different conscious selves (experiencing, remembering, and believing selves), their functions, and relative links to bodily and brain processes. These linkages, in turn, should help inform researchers' decisions about how to use self-report procedures effectively in science. Based on this evidence, we can formulate several specific recommendations:

1. *Use ambulatory self-reports to maximize sensitivity when connecting psychological with stress-related biological processes*. In general, biological pathways (ANS, HPA, immune system, threat/reward circuits) involved in managing stress and maintaining homeostasis appear more strongly connected to the experiencing self than to the remembering or believing selves. Thus, when linking psychological phenomena to these systems, ambulatory assessment may provide a more sensitive psychological measure than traditional memory-based reports.

2. *As a general rule, avoid using retrospective or trait reports as proxies for actual experience*. Using trait measures as proxies for experience may result in weaker or inconsistent results particularly when tested in connection to biological pathways. The evidence reviewed in this article showed many examples of when patterns were not found in trait reports but were found in real-time reports using ambulatory assessment (25, 84, 87, 91, 98, 108). While experience, memories, and traits may all correlate (sometimes highly), they will not necessarily show the same associations with a predictor or criterion of interest.

3. *Think about which 'self' is appropriate for a given research question*. If interventions are being used, consider the hypothesized mechanisms through which an intervention operates. If an intervention is designed to improve the experience of mood, reduce pain, or reduce stress-sensitivity, then ambulatory self-reports should provide greater resolution of treatment processes compared to memory-based reports. In that situation, use of highly stable trait measures may underestimate the effects of interventions designed to change experience. However, if an intervention acts to address beliefs and secondary appraisals of experiences after they occur, then treatment effects may be more apparent in retrospective measures.

4. *If you need to measure experience, there are affordable ways to do it*. While it can be expensive to do computerized ambulatory assessment using smartphones or PDAs [see (24) for current technology options], there are other low cost ways to obtain close to real-time self-reports intensively over time. Lower cost alternatives include internet daily diaries that can be programmed at a fractional cost of traditional computerized experience sampling (61), the Day Reconstruction Method (62), text-messaging or interactive voice recording with participants' own mobile phones (123, 124), and web-enabled surveys with hyperlinks sent to participants' own smartphones (125). Each of these approaches offers a more affordable and accessible way of tracking individuals in their daily lives. [For a beginning guide on getting started with these methods, see (123).]

5. *Do not abandon self-reports, but instead use them wisely*. Self-reports provide insight into the subjective lives of people, which have important implications for their health. Yet standard questionnaire approaches have come under criticism (rightly so) for being the primary way of linking biology to psychological concepts like emotional style (8, 103). We agree that exclusive reliance on traditional self-reports is scientifically limiting. Instead of abandoning subjectivity in favor of objective measures, we propose using intensive momentary self-reporting techniques as a more sensitive way of linking psychological to biological processes. More broadly, we encourage a more considered approach that recognizes the core differences among self-report techniques and the potential power of ambulatory self-report techniques in psychosomatic medicine.

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Abbreviations

AA	ambulatory assessment

ANS	autonomic nervous system
CA/SAL	core affect/salience network
CES-D	Center for Epidemiologic Studies Depression Scale
COMT	Catechol-*O*-Methyl Transferase
D/LTM	default network/long term memory
EMA	ecological momentary assessment
ESM	experience sampling method
fMRI	functional magnetic resonance imaging
HAM-D	Hamilton Rating Scale for Depression
HPA	hypothalamic pituitary adrenal
IM	immune system
MADRS	Montgomery-Asberg Depression Rating Scale
NEO-FFI	Neuroticism, Extraversion, Openness - Five Factor Inventory
NEO PI-R	Neuroticism, Extraversion, Openness Personality Inventory – Revised
PANAS	Positive and Negative Affect Schedule
PDA	personal digital assistant
PROs	patient reported outcomes
SF-36 Health Survey	Short Form- 36 Health Survey
SNS	sympathetic nervous system
STM	short term memory
5-HTTLPR	5-hydroxytryptamine transporter gene-linked polymorphic region

Table 1

Three Conceptual Themes in Self-Reports: Core Differences, Brain and Bodily Systems, Assumptions, and Recommendations from each Theme

Conceptual Theme	Core Difference	Systems	Assumptions	Recommendation
Bias				
Traditional- trait	Most biased	Not specified	• Self-reports should converge. • Divergence indicates bias. • AA is better.	• Use AA whenever possible.
Traditional- retrospective				
Ambulatory- end of day				
Ambulatory- momentary	Least biased			
Knowledge				
Traditional- trait	Semantic knowledge	Semantic memory	• Self-reports may not converge. • Divergence occurs because self-reports tap different subjective knowledge. • AA is different, not necessarily better.	• Use AA to measure episodic or experiential knowledge.
Traditional- retrospective	Semantic/episodic blend	Semantic, episodic memory		
Ambulatory- end of day	Episodic knowledge	Episodic memory		
Ambulatory- momentary	Experiential knowledge	Working memory, STM		
Differing Selves				
Traditional- trait	Believing Self	D/LTM	• Self-reports may not converge. • Divergence occurs because self-reports tap different functional selves with different neurobiology. • AA is different because it captures the experiencing self.	• Use traditional self reports when hypotheses concern believing or remembering selves. • Use AA when hypotheses concern the experiencing self or when linking experience to homeostatic autonomic biological systems.
Traditional- retrospective	Remembering Self†	D/LTM		
Ambulatory- end of day	Remembering Self††	D/LTM, CA/SAL, HPA, IM		
Ambulatory- momentary	Experiencing Self	CA/SAL, ANS, HPA, IM		

Notes. AA = ambulatory assessment; D/LTM = Default /long term memory network; STM = short-term memory CA/SAL = core affect/salience network; ANS = autonomic nervous system including sympathetic and parasympathetic divisions; HPA = hypothalamic-pituitary-adrenal axis; IM = immune system.

† likely a blend of remembering and believing;

†† likely a blend of remembering and experiencing.