CHAPTER 22

Physiological Measures

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Historically, psychophysiological measures have made an invaluable contribution to personality psychology. Questions regarding interindividual differences and intraindividual changes in emotion, cognition, motivation, arousal, and attention are core topics within personality psychology, and these questions are particularly amenable to a psychophysiological approach. In particular, psychophysiological measures can help researchers develop more comprehensive, differentiated conceptualizations of temperament and personality dimensions by elucidating biological processes that might serve as precursors, concomitants, markers, or moderators of such differences (see Cacioppo, Tassinary, & Berntson, 2000, for an excellent discussion of the precise distinction between these concepts). Yet integrating psychophysiological measures into personality research involves both logistical and conceptual complexities and may seem daunting to researchers without biology-oriented backgrounds. Our goal in this chapter is to provide an accessible, user-friendly overview of some of the most widely used psychophysiological indices in social-personality psychology and to provide some basic technical and conceptual guidelines as to their use and interpretation. We focus on the hypothalamic–pituitary–adrenocortical (HPA) axis of the endocrine system (assessed via salivary cortisol), cardiovascular measures of autonomic nervous system (ANS) activity (assessed via heart rate, blood pressure, respiratory sinus arrhythmia, cardiac output, pre-ejection period, and total peripheral resistance), and electrodermal measures of ANS activity (assessed via skin conductance). Space limitations obviously preclude exhaustive treatment of all the relevant biological and technical information, and therefore Table 22.1 provides additional references to which readers can turn for additional information about each measure. This table also includes references for additional psychophysiological parameters

Robins, Richard W.(Editor). Handbook of Research Methods in Personality Psychology. New York, NY, USA: Guilford Publications, Incorporated, 2007. p 370.
http://site.ebrary.com/lib/utah/Doc?id=10201021&ppg=386

TABLE 22.1. Additional References on Physiological Systems

Basic cardiovascular functioning	Blascovich & Kelsey (1990); Brownley et al. (2000)
Impedance cardiography	Sherwood (1993)
Parasympathetic nervous system functioning (RSA, vagal tone)	Porges (1995); Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996)
Ambulatory blood pressure measurement	Mussgay & Rüddel (1996)
Electrodermal activity	Blascovich & Kelsey (1990); Dawson et al. (2000); Tranel (2000)
HPA and SAM axis activity	Baum & Grunberg (1995); Blascovich & Tomaka (1996); Lovallo & Thomas (2000)
Other endocrine measures	Baum & Grunberg (1995); Becker, Breedlove, Crews, & McCarthy (2002)
Surface electromyography (EMG)	Tassinary & Cacioppo (2000)
Human startle eyeblink reflex	Dawson, Schell, & Bohmelt (1999)
Electroencephalography (EEG)	Coan & Allen (2003); Davidson, Jackson, & Larson (2000)
Event-related brain potential (ERP)	Fabiani, Gratton, & Coles (2000); Rugg & Coles (1995)
Positron emission tomography (PET)	Dougherty, Rauch, & Fischman (2004); Reiman, Lane, Van Petten, & Bandettini (2000)
Functional magnetic resonance imaging (fMRI)	Davidson (2003); Reiman et al. (2000)
Immune functioning	Maier & Watkins (1998); Segerstrom & Miller (2004); Uchino, Kiecolt-Glaser, & Glaser (2000)
Sexual response	Geer & Janssen (2000); Janssen (2002)

that may be of interest to personality psychologists, but which we do not cover in detail in this chapter, such as muscular activity in the face and other parts of the body via surface electromyography (EMG), measurement of the human startle eyeblink reflex, measures of brain activity, such as electroencephalography (EEG), event-related brain potential (ERP), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI), immune functioning, and genital sexual response. Although these measures are being used with increasing frequency, they typically involve greater technical sophistication and greater expense than the measures covered in this chapter, and are therefore less widely used and less accessible to the average personality psychologist.

Finally, in considering psychophysiological research, it is useful to bear in mind the distinction between "trait-based" and "state-based" investigative approaches. The former focus on stable, trait-like characteristics of individuals (i.e., do neurotic individuals have specific patterns of electrodermal reactivity to stress?), whereas the latter focus on situation-specific changes in affective, cognitive, or physiological state that generalize across individuals (under what conditions does evaluation apprehension reliably trigger HPA reactivity?). The state-based approach is a fundamentally within-person approach (comparing an individual's baseline responses to the same individual's responses under specific conditions, such as stress), whereas the trait-based approach is a fundamentally between-person approach (comparing different individuals' baseline or reactivity responses).

Of course, there is some overlap between the two; most notably, there is between-person variability in the *degree* of within-person reactivity to most laboratory tasks, and thus some trait-based approaches use mixed models that focus on within-person *and* between-person effects. Yet the basic distinction is helpful to bear in mind, as it has important implications for the selection of psychophysiological measures, their integration into research design, and their interpretation. For example, baseline measures of physiology, typically taken during a long quiet resting period, may be of little intrinsic interest to researchers investigating experimen-

tally induced deviations from baseline. Yet for researchers investigating stable interindividual differences, baseline measures may be of considerable interest. Because interindividual differences are the "bread and butter" of personality psychology, we place primary emphasis on the applications of psychophysiology to individual differences.

Finally, researchers who are beginning a program of psychophysiological research may also seek information about where to purchase the necessary equipment. An excellent Web-based resource listing a broad range of U.S. and international companies selling psychophysiological research systems can be found at *www.psychophys.com/company.html*. Companies vary widely in regard to whether they sell integrated, multicomponent systems or whether they sell equipment component by component. Some companies will customize a system based on the researcher's needs. Costs, too, vary widely. Simple systems measuring one or two parameters may be purchased for less than $1,000, whereas more complex, integrated systems may cost 50 times as much. Researchers purchasing equipment for the first time are advised to speak *directly* to customer support personnel at various companies to determine what type of system meets their specific research needs. Another important consideration is technical support: How easy is it to obtain telephone assistance at odd hours (such as evenings and weekends) for unexpected technical problems? If a piece of equipment needs replacement or repair, what is the average turnaround time? Even 3–4 days of "work stoppage" can be a logistical nightmare for laboratories in which subjects are scheduled back-to-back for days or weeks at a time. Finally, many companies will provide, upon request, names of established researchers using their systems and/or lists of published studies conducted with their equipment. Contact a vendor's current clients and find out what type of research they do, why they chose this particular vendor, and whether they would make a different choice now.

General Laboratory Guidelines

Although different psychophysiological measures are appropriate for different types of research questions, certain general guidelines regarding laboratory practice apply to all of these measures. First, researchers should keep in mind that the entire laboratory environment can play a role in influencing participants' psychophysiological responses from the moment they walk in the door (Christenfeld, Glynn, Kulik, & Gerin, 1998). Does the laboratory resemble a living room, complete with decorative lamps and plants, a comfortable couch, and framed posters on the walls, or does it have a sterile, potentially intimidating feel, with bare walls, rigid chairs, and harsh fluorescent lighting? A good general practice is to tailor the laboratory environment so that it mimics the setting to which one is attempting to generalize the findings. Hence, a clinical setting may be appropriate for assessing individuals' reactivity to work-related or performance-based stressors, whereas a home-like setting may be more appropriate for assessing couples' reactivity during marital squabbles.

If the laboratory visit will involve the administration of a stress task (addressed in more detail below), it is preferable for the person who administers the stress task to be *different* from the person who greets participants, walks them through the informed consent procedure, hooks them up to the equipment, and debriefs them at the end of the assessment. It is ideal to keep constant the sex, general age, and attire of the experimenter, as well as the person who hooks up the participant to the physiological equipment. With child and adolescent participants, it may be advisable to ensure that the research assistant hooking up the physiological equipment is of the *same sex* as the participant.

It is preferable (and critical in the case of cortisol assessments, described in greater detail below) to perform laboratory assessments at approximately the same time of day for all participants. Regardless of time of day, however, participants should be instructed (and reminded) to refrain from smoking, taking over-the-counter medication, eating, and drinking caffeinated beverages for at least 2 hours before coming to the laboratory. Adherence to this request should be confirmed during the informed consent procedure. For lengthy laboratory visits, researchers should consider keeping snacks and beverages on hand to offer to (potentially famished!) participants as soon as they have finished the psychophysiological assessments.

Whether one is interested in basal physiological functioning (i.e., continuous physiological functioning that maintains basic, vital activities

of the organism) or task-related reactivity, an accurate baseline assessment is critical. Given that many individuals find the process of coming to a laboratory and getting fitted with physiological equipment to be mildly arousing in and of itself, it is preferable to allow individuals at least 10 minutes to get used to the equipment and their surroundings before officially beginning the baseline assessment, which should last approximately 5–10 minutes. In addition, instead of having participants simply sit quietly during baseline assessment, it is increasingly common to administer what is called a "vanilla" baseline, in which individuals are engaged in a relaxing, nondemanding task that minimally engages their attention, such as rating their liking of a variety of pleasant landscape photographs. Vanilla baselines show greater stability of physiological responding, both within the baseline assessment and across assessments administered to the same person on different occasions (Jennings, Kamarck, Stewart, & Eddy, 1992).

For researchers measuring respiratory sinus arrhythmia (RSA), an index of parasympathetic nervous system (PNS) activity described in greater detail below, an additional baseline assessment during which participants carefully control their respiratory frequency is also ideal. This is because estimates of RSA are sensitive to respiratory rate, and large changes in respiratory parameters can alter the degree of association between RSA and true PNS activity (Berntson et al., 1997). Some researchers therefore statistically control for respiratory rate when analyzing RSA data, yet this is an extremely conservative correction approach, and other researchers maintain that it is not necessary in studies that focus primarily on within-person changes in RSA across different laboratory tasks (Houtveen, Rietveld, & De Geus, 2002). Yet when *between-person* comparisons are the primary focus, as is typically the case with assessments of baseline vagal activity, respiration can be easily standardized by simply having respondents breathe along with a tape recorder or metronome that paces their inhalations and exhalations (respiratory frequencies of 6–8 seconds are suitable for this purpose) for a period of 3–5 minutes.

Two factors that critically affect the interpretation of baseline and reactivity data are *age* and *gender*. Age and gender differences have been documented for all the physiological systems commonly assessed in personality research, and researchers therefore risk misinterpreting their findings unless they take these dimensions into account, either by including them as covariates or selecting their samples for homogeneity. Cross-sectional studies, for example, have found that both parasympathetic and sympathetic nervous system functioning varies markedly from infancy to late adulthood (Korkushko, Shatilo, Yul, & Shatilo, 1991; Uchino, Kiecolt-Glaser, & Cacioppo, 1992), as does HPA activity (Seeman, Singer, Wilkinson, & McEwen, 2001; Walker, Walder, & Reynolds, 2001). In considering the effects of age on HPA activity, it is appropriate to remember that these effects are more a function of *development* than of simple *chronological age*. For example, the developing and changing sleep–wake cycle of the infant is associated with variability in his or her HPA functioning, making it difficult to interpret associations between cortisol, behavior, and emotion (de Weerth, Zijl, & Buitelaar, 2003). Once children reach toddlerhood, their patterns of HPA reactivity are more consistent, allowing for more robust interpretations of individual differences (Gunnar, Sebanc, Tout, Donzella, & van Dulmen, 2003). Nonetheless, patterns of HPA reactivity continue to change from adolescence all the way into late adulthood; for example, the HPA axis is more reactive among younger than older adults (Kudielka, Buske-Kirschbaum, Hellhammer, & Kirschbaum, 2004).

Gender, too, is strongly associated with a variety of differential patterns of both basal and stress-related autonomic (Kiecolt-Glaser & Newton, 2001; Levenson, Carstensen, & Gottman, 1994) and HPA functioning (Otte et al., 2005; Seeman et al., 2001). Hormonal fluctuations over the menstrual cycle also influence cardiovascular and HPA axis activity (Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Sato, Miyake, Akatsu, & Kumashiro, 1995), and thus a female participant should provide the date of her last menstrual cycle and her average cycle length so that her menstrual phase can be determined and statically controlled.

Choosing Laboratory Stressors

Many psychologists have used psychophysiological measures to assess interindividual differences in physiological reactivity to con-

trolled laboratory manipulations. In some cases, the content of the manipulation is critically important to the research question, as in research on gender differences in responses to imagined scenarios of infidelity (Pietrzak, Laird, Stevens, & Thompson, 2002). In other cases, researchers may simply want to elicit stress and/or anxiety in the most reliable way possible. Although it may seem that "any stressor will do" for such research designs, this is not the case. Rather, operationalizing the construct of stress/anxiety for the purposes of assessing psychophysiological reactivity is a complex task. What type of stress is of interest? Should participants feel challenged and motivated to perform to their highest ability, or should they be led to feel inadequate, evaluated, threatened, or even angry?

Laboratory tasks that elicit different emotional and motivational states are known to have distinctive profiles of reactivity and recovery across different physiological systems (see, e.g., Tomaka, Blascovich, Kelsey, & Leitten, 1993). The most notable effects have been documented for the following characteristics: (1) whether the task requires active effort, watchful attention, or passive participation (Smith, Ruiz, & Uchino, 2000); (2) the incentive or penalty used to elicit task performance (Waldstein, Bachen, & Manuck, 1997); (3) the difficulty, effort requirement, and familiarity of the task (Kelsey et al., 1999); (4) the extent to which individuals can control their own performance and/or the administration of rewards and penalties (Peters et al., 1998); (5) whether participants perceive that they do or do not have the resources to perform the task successfully, denoted as a "challenge" versus a "threat" appraisal (Tomaka, Blascovich, Kibler, & Ernst, 1997).

The distinction between challenging and threatening tasks is particularly tricky, inasmuch as individuals draw upon a variety of explicit and implicit cues—as well as their own stable self-concepts—in making such appraisals. Thus, factors such as self-esteem (Seery, Blascovich, Weisbuch, & Vick, 2004), the presence of an evaluative or nonevaluative audience (Kelsey et al., 2000), person-characteristics of the audience or experimenter (Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001), the type of feedback given on performance (Earle, Linden, & Weinberg, 1999), and emotional cues (Blascovich & Mendes, 2000) can influence respondents' experiences of challenge versus threat. Thus, researchers should ideally assess participants' appraisals of task difficulty, controllability, and performance both before and after the task in order to validate its intended psychological characteristics.

The tailoring of task characteristics, of course, depends on the aim of the study and the context to which one wants to generalize the research findings. Thus, personality researchers interested in trait-like patterns of reactivity to performance motivation should select a "challenge" task that involves controllable, moderate effort in response to incentive, whereas those interested in trait-like patterns of reactivity to anxiety may want to select a "threat" task that maximizes feelings of apprehension and is perceived as uncontrollable. Perhaps most important, however, whenever variability *across individuals* in trait-like patterns of reactivity is of interest (rather than variability *across tasks or testing situations*), it is generally recommended to administer multiple tasks within the experimental session and average the resultant responses within physiological parameter and within task type (Kamarck, Debski, & Manuck, 2000; Pruessner et al., 1997), thereby yielding (for example) an aggregate measure of heart rate to challenge, heart rate to threat, electrodermal response to challenge, electrodermal response to threat, and so forth. This is important because previous studies have found only mild-to-moderate intertask consistency, test–retest reliability, and longitudinal stability in physiological reactivity (see Kamarck & Lovallo, 2003; Manuck, Kamarck, Kasprowicz, & Waldstein, 1993), raising concerns about the categorization of individuals into "high-reactive" and "low-reactive" groups on the basis of a single task. Some studies have found that correlations between physiological reactivity and various personality dimensions are strengthened when aggregated measures are used (Pruessner et al., 1997).

Another consideration to keep in mind is that some classes of tasks may elicit more consistent within-person response profiles than others (Manuck et al., 1993). Perhaps most notably, tasks that provoke extremely high or low reactivity may fail to elicit the range of variability necessary to identify individual profiles—if a stimulus is threatening enough, everyone will show a robust fight-or-flight response, whereas if it is too mild, nobody will. Thus, researchers interested in idiographic analyses of trait-like

response profiles should pilot test and select tasks eliciting moderate reactivity (Kamarck & Lovallo, 2003).

Using Multiple Measures and Analytical Approaches

Individuals who are consistently "high-reactive" in one physiological parameter are not necessarily high-reactive on others, and therefore personality researchers interested in trait-like patterns of reactivity should include not only multiple tasks, but multiple physiological measures to capture different aspects of the overall stress process (such as endocrine vs. cardiovascular reactivity; sympathetic nervous system activation vs. parasympathetic withdrawal; vascular vs. myocardial changes in blood pressure, all of which are addressed in greater detail later below). This will allow the researcher to reliably characterize individuals not only with respect to whether they are consistently high-reactive or low-reactive on one particular physiological parameter, but whether they consistently show certain *combinations* of reactivity patterns, such as high heart rate *in the absence of* correspondingly high HPA reactivity, or parasympathetic withdrawal *plus* myocardial-driven changes in blood pressure. The fact that individuals consistently differ from one another with regard to such response profiles has been termed *individual response stereotypy* (Engel, 1960), and the question of whether certain response patterns are systematically related to psychological traits or health risks is an active topic of current psychophysiological research (Berntson & Cacioppo, 2003).

In addressing such questions, researchers should bear in mind that levels of consistency and reliability vary across different physiological measures. For example, research using different subject populations has consistently found greater test–retest reliability in heart rate than in diastolic blood pressure (Kamarck et al., 1992). Task characteristics also influence reliability: for example, blood pressure readings show greater reliability for nonspeaking than for speaking tasks (Swain & Suls, 1996), and greater reliability when task difficulty is calibrated to each individual subject, typically using computerized task protocols (Kamarck et al., 1992).

Analyses also require careful consideration. Instead of simply comparing individuals' baseline-to-task reactivity, researchers should consider examining other dimensions along which individual differences in reactivity might be manifested: threshold to respond, level of peak response, rise time to peak response, and degree and timing of recovery (Brosschot & Thayer, 1998; Davidson, 1998). Unfortunately, the psychometric characteristics of most of these less widely used parameters are less well established (Davidson, 1998), although there has been increasing research on the appropriate modeling of recovery profiles (Christenfeld, Glynn, & Gerin, 2000). Yet such measures have the potential to significantly refine our capacity to capture meaningful individual and situational differences with potentially important mental and physical health implications (see, e.g., Brosschot & Thayer, 1998).

Finally, in addition to measuring participants' cognitive appraisals of the task, researchers should also include self-report measures of individuals' subjective emotional states, not only immediately before and after the tasks, but also after a fixed recovery period (typically 2–3 minutes). Although it is commonly assumed that psychophysiological measures are, in fact, primarily useful as valid indices of individuals' authentic subjective responses to experimental manipulations, in actuality the relationship between subjective and physiological responses appears to be substantially more complex and inconsistent (Blascovich, Brennan, Tomaka, & Kelsey, 1992). Even setting aside the inevitable ambiguity associated with self-reports of emotion, most individuals are also poor judges of changes in their own physiological states, such as increases in heart rate or body heat (Edelmann & Baker, 2002), as well as sexual arousal (Heiman, 1975). The circumstances under which one does or does not find direct correspondence between self-reports and physiological responses remain to be fully specified and have become an increasing topic of theory and research (see Cacioppo et al., 2000, on the full range of possible relations between psychophysiological measures and psychological constructs). Because discrepancies may be found for some physiological parameters and not others, the measurement of multiple physiological systems can aid researchers in interpreting their meaning; for example, might they stem from dysregulation in one particular physiological system (such as hypocortisolism, reviewed below), or might they reflect a global tendency to

Robins, Richard W.(Editor). Handbook of Research Methods in Personality Psychology.
New York, NY, USA: Guilford Publications, Incorporated, 2007. p 375.
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misreport or misinterpret subjective experience, in which case self-reports should diverge from *multiple* physiological parameters?

Considering all of these complexities, the ideal research design for identifying individual response profiles would involve the administration of *multiple* tasks eliciting moderate reactivity, classed within different task types (i.e., several active coping tasks *and* several passive coping tasks), repeated across *multiple* testing sessions (different days, different times of day), using a wide range of physiological *and* self-report measures. Of course, this ideal scenario is logistically unfeasible, but it provides a useful template to keep in mind when deciding which design elements are most indispensable for certain hypothesis tests and how such decisions affect the interpretation of these tests. With these general guidelines in mind, we now offer a more detailed discussion of the specific physiological systems likely to be of greatest interest to personality psychologists.

The HPA Axis

The neuroendocrine system balances concentrations of hormones in the body with the psychological and physical demands of the environment. Neuroendocrine responses to environmental demands are observed in two major axes: the sympathetic–adrenal medullary (SAM) axis (involving the release of catecholamines such as norepinephrine and epinephrine), and the HPA axis (involving the release of CRH [corticotropin-releasing hormone], ACTH [adrenocorticotropic hormone], and cortisol, as reviewed in Baum & Grunberg, 1995).

Most personality-oriented research documenting associations between neuroendocrine functioning and psychological traits has focused on the HPA axis, and our review mirrors this emphasis. The disproportionate attention to the HPA axis may be due to the fact that HPA activity in response to environmental demands is associated with appraisals of such demands as threatening (i.e., exceeding the individual's capacity to cope) or affectively negative, whereas SAM activation appears to represent an adaptive response to challenge situations in which the individual feels he or she has sufficient coping resources (for reviews, see Blascovich & Tomaka, 1996; Cacioppo, 1994). Given that investigations into the potential biological correlates of psychological states and traits tend to cluster around negative phenomena such as anxiety, neuroticism, inhibition, and aggression, the predominant focus on HPA rather than SAM activation is understandable.

Although HPA activation results in the secretion of a variety of hormones, it is most commonly assessed via *cortisol*, which is secreted by the adrenal gland and serves to regulate both homeostatic functioning and stress reactivity. The pathway to cortisol secretion begins in the hypothalamus, where CRH is released into the anterior pituitary in response to environmental demands. CRH secretion triggers the release of ACTH, which causes the synthesis of cortisol in the adrenal gland. The cessation of cortisol production is accomplished through a negative feedback loop. Specifically, once sufficient plasma levels of cortisol have been reached, CRH synthesis is inhibited, thereby down-regulating the chain of events required for additional cortisol production.

Measurement Issues

Cortisol can be measured in blood, urine, or saliva. All three provide reliable indices of cortisol secretion, but measurement in saliva is by far the most commonly used method, largely because it is the most noninvasive (requiring only that participants saturate a sterile swab and store it in a plastic tube) and the most convenient for subjects to self-administer in their natural environments. The latter reason is particularly important because cortisol secretion shows strong diurnal variation (reviewed below), and hence accurate assessment of total cortisol secretion requires collecting multiple samples over the course of the day, ideally for several days. This can be easily accomplished by instructing research subjects to collect and store a series of saliva samples on their own, following a prearranged schedule, but would be logistically problematic for collecting urinary or plasma samples. Common practice in using salivary cortisol samples is to have participants immediately refrigerate or freeze their samples until mailing them back to the researcher. However, as long as they are shipped within 4 days, refrigeration is not necessary. Beyond that point, mold may begin to grow. Some maintain that mold growth compromises the interpretation of the assay, whereas others argue that it does not. The safest course, of course, is to refrigerate or freeze the samples (for long-term storage, it is preferable to freeze

the samples at –20° C). If samples are sent off-site to be assayed and shipment delays are anticipated, they can be packed with dry ice. If they can be expected to arrive within 3–4 days, no such precautions are necessary. A number of laboratories in the United States and Europe provide assay services, for fees ranging from $2.50 to $15.00 per sample (two of the most widely used are the Kirschbaum laboratory in Germany, *biopsychologie.tu-dresden.de*, and the Penn State Behavioral Endocrinology laboratory, *bbh.hhdev.psu.edu/labs/behavioral%20endo%20lab/bel.html*). Another option is to conduct assays in-house, using assay kits that are available for purchase. This gives the researcher more control over the process, but requires substantial additional investment in laboratory supplies (such as precision pipettes, centrifuges, etc.), staff training, and quality management. To get a sense of the degree of complexity involved in analyzing one's own samples, and the type of equipment required, see the detailed instructions on the Salimetrics website, at *www.salimetrics.com/ercortisolkitinsert.htm*. Salimetrics is only one of many companies that sell assay kits. Additional detail on the "nuts and bolts" of collecting and analyzing salivary cortisol can be found on the Kirschbaum and Penn State websites, mentioned above, and in the 2000 report on salivary cortisol measurement produced by the John D. and Catherine T. MacArthur Research Network on Socioeconomic Status and Health, *www.macses.ucsf.edu/Research/Allostatic/notebook/salivarycort.html*.

Unlike measures of autonomic functioning, in which physiological reactivity is immediately measurable after the onset of a psychological stimulus, it takes approximately 20–30 minutes for HPA responses to show up in cortisol concentrations. Thus, in order to assess HPA responses to specific events, researchers should collect cortisol samples 20–30 minutes *after* the event has occurred. This also obviously affects measurement of baseline cortisol levels in laboratory environments. Rather than collecting a baseline sample as soon as the participant has arrived at the laboratory, it is preferable to take his or her baseline sample 20–30 minutes after the participant has had an opportunity to calmly acclimate to the lab environment. For field studies in which participants provide multiple within-day cortisol samples, it is advisable to collect information on the participant's activity level, food consumption, alcohol and tobacco use, and emotional state *20–30 minutes before* the saliva sample is taken, as these factors are known to influence cortisol levels (Backhaus, Junghanns, & Hohagen, 2004).

Yet by far the most important methodological consideration for cortisol assessment is the time of day. Cortisol secretion shows distinct diurnal variation, typically peaking immediately after waking, significantly dipping before noon, minimally rising again for a period, and then resuming a steady decline into the mid-to-late evening hours (reviewed in Lovallo & Thomas, 2000). The specific shape of this diurnal curve varies from individual to individual (see, e.g., Smyth et al., 1997), and has been of considerable interest for its associations with a variety of psychological states, traits, and conditions (reviewed below). Yet this diurnal profile must also be taken into account for accurately measuring HPA reactivity to both naturally occurring and laboratory stressors. Generally, cortisol reactivity to stress appears greatest when basal cortisol concentrations are low (Dallman et al., 2004), and it is therefore ideal to conduct laboratory stress protocols in the late afternoon or early evening. With respect to naturally occurring stressors, which may occur at any time, researchers should control for the expected cortisol level for the particular time of day before interpreting a certain cortisol level as indicating a low or high stress response.

Basal HPA Functioning

Assessment of individual differences in basal HPA functioning typically focuses on three different outcomes: the overall shape of the diurnal profile, the morning "peak" or "challenge," or the total cortisol concentration over the entire day (sometimes called AUC, or "area under the curve"). Individual differences are observed in each of these domains, and therefore each may be of interest to personality psychologists. As noted earlier, a normal diurnal profile involves a strong morning peak that declines subsequently, with a minimal increase in the early evening. To accurately capture this profile, it is generally recommended that sampling begin with the moment of waking (while the respondent remains in bed), then 30 minutes later, followed by 3 hours after waking, 8 hours after waking, 12 hours after waking, and finally at bedtime (Stewart & Seeman, 2000). This measurement profile provides the most accurate portrait of diurnal fluctuation in cortisol as well as the most accurate assessment of over-

all cortisol levels throughout the day (AUC). As these dimensions fluctuate to some degree from day-to-day, however, collection of data on at least 2 consecutive days is preferable (Stewart & Seeman, 2000). Increasing the number of within-day measurements as well as the number of days sampled will improve reliability.

Most research on individual differences in cortisol profiles has concerned "flattened" patterns of cortisol release, characterized by a blunted morning peak and/or a minimal decline into the evening and overnight. Because this pattern tends to be produce low measures of total daily cortisol concentration over the day, it has been called "hypocortisolism" (Gunnar & Vazquez, 2001; Heim, Ehlert, & Hellhammer, 2000). Some research suggests that flattened cortisol profiles are associated with adverse early life conditions that produce dysregulation in the HPA axis or dysregulation in cognitive appraisals of stressors (reviewed in Gunnar & Vazquez, 2001). One study, for example, found flattened profiles to be associated with insecure childhood attachment relationships, as assessed retrospectively with the Adult Attachment Interview (Adam & Gunnar, 2001). A blunted morning response has also been associated with lower socioeconomic status (SES) (Brandtstaedter, Baltes-Goetz, Kirschbaum, & Hellhammer, 1991), job burnout (Pruessner, Hellhammer, & Kirschbaum, 1999), and self-reported job stress (Caplan, Cobb, & French, 1979). The previous night's sleep quality is also associated with morning cortisol peaks and should be assessed in investigations of this parameter (Backhaus et al., 2004). Although studies have not found consistent links between personality traits and diurnal profiles (Smyth et al., 1997), this remains an active area for research, specifically with respect to the potential importance of early adverse experiences in permanently altering individuals' psychological and physiological capacities for stress and emotion regulation (Gunnar & Vazquez, 2001; Hart, Gunnar, & Cicchetti, 1996).

Research on flattened diurnal cycles has also proved informative in helping to explain the fact that associations between AUC cortisol concentrations and measures of stress or maladaptation have varied notably across studies and even within samples, such that cortisol levels sometimes appeared elevated in individuals with high stress or negative affectivity (Polk, Cohen, Doyle, Skoner, & Kirschbaum, 2005; Portella, Harmer, Flint, Cowen, & Goodwin, 2005) and sometimes appeared dampened (Anisman, Griffiths, Matheson, Ravindran, & Merali, 2001). Dampened levels have also been associated with aggression and conduct problems in youth (Shoal, Giancola, & Kirillova, 2003). Future research is necessary to pinpoint the specific correlates, antecedents, and implications of atypically high versus atypically low cortisol secretion (Gunnar & Vazquez, 2001; Heim et al., 2000), and this is likely to remain an active topic of interest among personality psychologists. Perhaps the most important consideration for personality researchers is to conduct sufficient descriptive and exploratory analyses to permit identification of different—and sometimes seemingly contradictory—subtypes of HPA response. For example, one study of socially phobic individuals found that a subset of these participants showed significantly *elevated* cortisol stress responses, whereas another subset showed significant *declines* (Furlan, DeMartinis, Schweizer, Rickels, & Lucki, 2001). Computing aggregated correlations between social phobia and cortisol levels would obviously have obscured such a finding.

HPA Reactivity Assessments

There are notable individual differences in HPA stress reactivity that have been the subject of considerable research for their associations with psychological states and traits, as well as with psychiatric conditions such as depression, anxiety, and social phobia (see, e.g., Habra, Linden, Anderson, & Weinberg, 2003; Kirschbaum, Bartussek, & Strasburger, 1992). A comprehensive review of HPA reactivity protocols by Dickerson and Kemeny (2004) found that researchers generally observe the most robust and consistent responses when utilizing stressors that last 15 minutes or longer and which are perceived as uncontrollable and involving social evaluation. A classic example is the Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993), a widely used and well-validated task requiring participants to deliver a speech and perform mental arithmetic in front of an evaluative audience. Recovery profiles have also been of interest with respect to HPA stress responses (Roy, Kirschbaum, & Steptoe, 2001), and can be assessed by collecting an additional cortisol sample approximately 41–60 minutes after the initiation of the stressor (Dickerson & Kemeny, 2004). As in the case of laboratory stressors, discussed ear-

lier, it is important to collect data on participants' appraisals of effort, control, anxiety, and emotional state in order to accurately interpret their levels of reactivity (Dickerson & Kemeny, 2004; Polk et al., 2005).

As with diurnal cycles and overall cortisol concentrations, it is important to note that one cannot uniformly interpret high cortisol stress reactivity as indicative of highly negative states or traits. Although studies typically find that heightened cortisol reactivity and attenuated recovery are associated with traits such as negative affectivity and social inhibition (Habra et al., 2003; Kagan, Resnick, & Snidman, 1987) and are typically interpreted as indicative of poor emotion regulation (Scarpa & Raine, 1997), other studies have found that *blunted* patterns of reactivity are also maladaptive (Buske-Kirschbaum et al., 1997) and appear to be linked to early experiences with adversity that might produce dysregulation in the HPA system (Hart, Gunnar, & Cicchetti, 1995). Thus, as with AUC measures, researchers should inspect their data for the possible existence of multiple response profiles rather than averaging together cortisol increases with cortisol decreases.

Overall, studies investigating global associations between HPA reactivity and *personality* dimensions have found inconsistent patterns (Berger et al., 1987; Brandtstaedter et al., 1991; Goodyer, Park, Netherton, & Herbert, 2001), but some have suggested that interpretable associations are more likely to emerge in studies of *habituation* to repeated stressors than in single assessments of stress reactivity (Kirschbaum, Wust, Faig, & Hellhammer, 1992). Repeated exposure to stress generally produces rapid habituation (Kirschbaum et al., 1995), yet some individuals fail to show this effect, instead maintaining sustained levels of high HPA response that can have adverse health consequences (Krantz & Manuck, 1984; Munck, Guyre, & Holbrook, 1984). One study found that individuals whose cortisol responses failed to show habituation to repeated stress were lower in self-esteem and extraversion and higher in neuroticism and physical complaints (Kirschbaum et al., 1995), and another found that such individuals tended to be depressive and harm avoidant (Gerra et al., 2001). Thus, personality researchers interested in cortisol stress reactivity should consider assessing *progressive habituation* to repeated stressors rather than either singular or aggregated stress responses.

ANS Measures

Assessments of ANS functioning are, without question, among the most widely used psychophysiological measures in psychological research. The most common measures are heart rate, blood pressure, electrodermal activity, and respiratory sinus arrhythmia (sometimes referred to as *heart rate variability* or *vagal tone*), but in recent years assessments of pre-ejection period, cardiac output, and peripheral resistance have become more common. In selecting among these measures, researchers should keep two basic distinctions in mind: that between sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) functioning, and that between cardiac and vascular reactivity. Each has relevance to the types of research questions typically asked by personality psychologists.

SNS versus PNS Functioning

The parasympathetic and sympathetic branches of the ANS have antagonistic effects on the physiological processes involved in stress reactivity. The SNS is responsible for redistributing metabolic output in times of external threat, and therefore heightened activation of this system produces the physiological changes most commonly associated with "fight-or-flight" responses: increases in heart rate, blood pressure, sweating, cardiac output, vasoconstriction, and blood flow to the skeletal muscles, myocardium, brain, kidneys, gastrointestinal tract, and skin. In contrast, the parasympathetic system is responsible for maintaining normal growth and restoration of internal organs, processes that are suspended in times of intense stress. Thus, heightened engagement of this system produces the types of physiological changes typically associated with relaxation rather than arousal, such as deceleration in heart rate and blood pressure. These changes function to distribute metabolic energy toward normal maintenance of internal organs and to maintain a state of homeostasis. During periods of stress, however, the PNS typically "withdraws" to shift metabolic and attentional resources to the stressor without requiring overactivation of the SNS (Calkins, 1997). Recovery from stress is typically associated with reinstatement of PNS activity, which functions to reestablish homeostasis.

Thus, all changes in ANS activity are driven by the *coordinated* up-regulation and down-

regulation of the PNS and the SNS, rendering meaningless any notion of "generalized autonomic arousal." Stress-related increases in heart rate, for example, may result from heightened SNS activation, PNS withdrawal, or some graded combination of the two. Similarly, poststressor declines in heart rate may result from decreased SNS activity *or* increases in PNS activity. The specific balance of SNS and PNS functioning (sometimes called "autonomic balance") has been shown to vary not only across tasks, but also across individuals (Berntson, Cacioppo, Quigley, & Fabro, 1994), and is thought to be a trait-like individual difference dimension that emerges early in development (Friedman & Thayer, 1998) and that has implications for cardiovascular health risk and psychological functioning.

Specifically, patterns of cardiovascular stress reactivity that are driven by the SNS rather than the PNS are associated with hypertension and other long-term cardiovascular health risks (Kristal-Boneh, Raifel, Froom, & Rivak, 1998), as well as immune deficits (Croiset, Heijnen, Van der Wal, De Boer, & De Wied, 1990; del Rey, Besedovsky, Sorkin, da Prada, & Arrenbrecht, 1981). They have also been associated with a stress-prone, "Type A" personality (Kamada, Miyake, Kumashiro, Monou, & Inoue, 1992). High sympathetic tone has also been found to be associated with inhibition, excitability, emotional liability, a tendency to deny emotions, and susceptibility to psychosomatic complaints (Schweiger, Wittling, Genzel, & Block, 1998).

In contrast, ANS stress responses that involve a greater degree of PNS withdrawal than SNS activation appear to be more rapid, more flexible, and easier to disengage than SNS-dominated responses (Berger, Saul, & Cohen, 1989; Saul, 1990), and thus individuals with more PNS-driven patterns of cardiovascular reactivity are conceptualized as having nervous systems that more flexibly react to and recover from environmental stressors than those with sympathetically mediated patterns (Calkins, 1997; DeGangi, DiPietro, Greenspan, & Porges, 1991; Porges, Doussard-Roosevelt, & Maiti, 1994).

Consistent with this perspective, infants and children with high parasympathetic tone have been characterized as more attentive and reactive to changes in their environment (Healy, 1989; Stifter, Fox, & Porges, 1987), less inhibited (Reznick, Kagan, & Snidman, 1986), and less prone to misconduct (Kibler, Prosser, & Ma, 2004). High parasympathetic tone has therefore been viewed as a key substrate for the development of effective emotion regulation (Porges, 1991; Porges et al., 1994). Studies on adults provide further support for this perspective, finding associations between high parasympathetic tone and more effective emotional and behavioral responses to stress (Fabes & Eisenberg, 1997). In contrast, low parasympathetic tone has been associated with inhibition, aggression, depression, anger, mental stress, generalized anxiety, and panic anxiety (reviewed in Brosschot & Thayer, 1998; Friedman & Thayer, 1998). Personality psychologists interested in integrating autonomic measures into their research should take care to include independent assessments of PNS and SNS activity so that they can capture such differences.

Measuring PNS Functioning: Respiratory Sinus Arrhythmia

Researchers investigating PNS functioning often speak of measuring *vagal tone* (see Porges, 1991; Porges et al., 1994), which refers to the functioning of the vagus nerve (the 10th cranial nerve, a critical component of the PNS) in maintaining chronotropic control of the heart to regulate metabolic output. Vagal tone is typically indexed by measuring the degree of heart rate variability that occurs in response to respiration, known as *respiratory sinus arrhythmia* (RSA). To explain briefly: Heart rate accelerates slightly with each inhalation and decelerates slightly with each exhalation. This regular oscillation reflects the repeated withdrawal and subsequent reinstatement of vagal influence. The greater the vagal regulation of metabolic activity, the more that heart rate will accelerate and decelerate in response to inhalation and exhalation, producing an RSA waveform with a larger amplitude. It is this amplitude that is used as an index of overall vagal control of heart rate (note, however, that there are considerable variations in terminology—studies assessing PNS functioning may refer to *RSA*, *vagal tone*, *heart rate variability* [HRV], or *high-frequency heart rate variability*).

The different methods of measuring HRV, their technical requirements, and their appropriateness for different research aims are comprehensively reviewed in a task force report on these topics (Task Force of the European Society of Cardiology and the North American So-

ciety of Pacing and Electrophysiology, 1996). Presently, most social psychophysiologists use spectral analysis (Porges, 1986) to extract periodicity in the heart period pattern that occurs at the typical respiratory frequency (0.12–40.0 Hz, corresponding to approximately 7.5–24.0 breaths per minute). The variance of the heart period pattern in this bandwidth is calculated as the estimate of RSA. Another technique, called the "peak-to-valley" method (Grossman & Svebak, 1987), uses time series data on heart rate and actual respiratory rate to isolate respiration-induced variability in heart rate on a breath-by-breath basis. There is very high correspondence between measurements obtained using these methods (Grossman, van Beek, & Wientjes, 1990).

Finally, although studies of PNS activity have historically emphasized *basal* parasympathetic tone (measured during a resting baseline), researchers have increasingly investigated stress-related *declines* in PNS activity (often denoted as "suppression") as measures of the capacity to efficiently shift metabolic resources in response to challenge, providing an ancillary index of autonomic and emotional regulation (Cohen et al., 2000; Stifter & Corey, 2001). Supporting this interpretation, individuals with high levels of baseline vagal tone tend to show greater stress-related vagal suppression (DeGangi et al., 1991; El-Sheikh, 2005). Yet these two indices of PNS functioning do not appear to be redundant; studies of children have tended to find that stress-related vagal suppression is a more reliable predictor of adaptive functioning than basal vagal tone (Calkins & Dedmon, 2000).

Furthermore, the degree and direction of task-related change in PNS activity varies according to task characteristics. Whereas stress and negative affect provoke the classic PNS suppression effect, tasks involving nonstressful cognitive attention or social interaction often induce *increases* in PNS activity (Suess & Bornstein, 2000). In addition, some researchers have called attention to poststressor recovery or "rebound" in PNS activity as yet another index of effective regulation (Rottenberg, Wilhelm, Gross, & Gotlib, 2003). Thus, researchers interested in parasympathetic functioning should assess baseline levels as well as stress-induced reactivity and recovery in order to obtain the most complete picture of parasympathetic functioning.

Measuring SNS Functioning: Electrodermal Activity

The most widely used and noninvasive technique for specifically assessing *sympathetic* nervous system activity involves measurement of electrodermal response (EDR), also known as skin conductance (comprehensively reviewed in Dawson, Schell, & Filion, 2000). SNS activation produces greater conductivity in the skin, partly as a result of increased sweat secretion. By passing an electrical current across the skin, one can measure these increases in conductance (also commonly conceptualized as *decreases* in skin resistance). Increases in skin conductance are commonly observed during stress- or anxiety-induced SNS activation, but are also observed as a function of orienting and attention, muscular activity, deep breaths, and thermoregulatory sweating. Hence, in order to reliably interpret skin conductance data, laboratory and stimulus conditions should be carefully controlled.

One of the advantages of assessing skin conductance is that the measure is noninvasive and relatively unobtrusive, and it has shown robust associations with a variety of psychological states and traits in prior research, including repressive coping (Brosschot & Janssen, 1998), anxiety, nervousness, and panic (Carrillo et al., 2001), attachment avoidance (Diamond, Hicks, & Otter-Henderson, 2006; Roisman, Tsai, & Chiang, 2004), harm avoidance (Yoshino, Kimura, Yoshida, Takahashi, & Nomura, 2005), and behavioral inhibition (Fowles, 1988; Raine, Venables, & Williams, 1995). Methodologically, assessment of skin conductance is fairly simple, involving the placement of several electrodes on the individual's nondominant hand, and the primary methodological cautions concern selection of the specific electrode sites, ensuring that respondents wash their hands with a neutral, nonabrasive soap before beginning assessment, and instructing participants to avoid large body movements, which can cause artifacts (for details, see Dawson et al., 2000). The most common electrode sites are the *medial or distal phalanges* of the first and second index fingers. If you turn your hand palm side up and look down at your index finger, the uppermost padded area is the distal phalange. The area just below the crease of the fingertip is the medial phalange. Readings from distal phalanges tend to be higher, and so it is important to report the

specific electrode site so that this can be taken into account when comparing the results of different studies.

Assessments of skin conductance yield two parameters: basal skin conductance level (SCL) and phasic skin conductance response (SCR). SCL represents the overall level of conductance during a particular moment in time, or averaged within a specific epoch. SCL typically declines during long assessments as individuals habituate to their surroundings, but this tendency is typically reversed if individuals are exposed to laboratory stressors. SCR, in contrast, represents discrete "spikes" in SCL that can be counted within different epochs and analyzed with respect to their amplitude and latency. SCRs are of particular interest to researchers investigating autonomic responses to specific stimuli, as they are typically observed immediately after stimulus presentation (representing either an orienting or an emotional response—or both—depending on the stimulus). Such responses are called "specific" SCRs. However, SCRs can also be "nonspecific," meaning that they are observed in the absence of any discernible triggering stimulus. Nonspecific SCRs are typically reported as rates (number per minute), and the rate is typically 1–3. Generally, researchers use a 0.05 microsiemen change in skin conductance level as the criterion for detecting an SCR. This value is somewhat arbitrary but has been conventionally adopted, therefore allowing for valid comparisons across different studies. To score SCRs, researchers typically visually inspect the data and verify that each "spike" in SCL meets the selected criterion to be considered a response. Yet in recent years, several computerized scoring programs have been developed that increase the speed and reliability of this process (see Dawson et al., 2000, for details).

Although they are not perfectly correlated, emotional stress tends to be associated with increases in SCL *and* increases in nonspecific SCRs, and thus either parameter may be used as an index of stress reactivity. There are no firm guidelines as to the use of one index versus the other, but assessment of specific SCRs is particularly appropriate for studies assessing responses to time-delimited stimulus presentation (such as images or words). Such research designs should also consider measuring the magnitude of the SCR, the poststimulus latency to respond, and the recovery time. In general, greater response intensity is manifested not only in more frequent SCRs, but in larger responses that reach their peak more quickly (reviewed in Dawson et al., 2000).

Blood Pressure and Impedance Cardiography

Blood pressure is another widely used cardiovascular measure of ANS activity. Systolic and diastolic blood pressure measure the force of blood against arterial walls. Maximum arterial pressure is reached during ventricular contraction, when the heart beats (denoted as systolic blood pressure, or SBP), and minimum arterial pressure is reached during ventricular relaxation, the period between beats (denoted as diastolic blood pressure, or DBP). Numerous studies have detected that stable psychological traits are associated with heightened blood pressure reactivity, sometimes detected in SBP and sometimes in DBP (Carels, Blumenthal, & Sherwood, 2000; Habra et al., 2003).

An important complication in blood pressure assessments is that they can be decomposed into their *vascular* versus *cardiac* (or *myocardial)* components. In short, an increase in blood pressure can result from greater cardiac output (i.e., greater blood being pumped through the heart and therefore pressing against the arterial walls) or increased resistance in the vasculature (i.e., "tightening" of the arteries, such that blood is being pumped through a smaller space, resulting in increased pressure). Blood pressure changes across different situations and different individuals may be of similar magnitude, yet show notably different patterns of cardiac and vascular change (Manuck et al., 1993; Sherwood, Allen, Obrist, & Langer, 1986), often called the "hemodynamic profile." Generally, vascular responses are more closely associated with hypertension than with cardiac responses. Moreover, stress tasks that involve active coping more typically evoke myocardial responses, whereas passive tasks tend to evoke vascular responses (reviewed in Gregg, James, Matyas, & Thorsteinsson, 1999). Researchers are increasingly investigating whether intraindividual variability in *overall* blood pressure reactivity is differentially driven by myocardial versus vascular factors among different individuals (Chen, Matthews, Salomon, & Ewart, 2002; Hawkley, Burleson, Berntson, & Cacioppo, 2003), and this question is likely to be of interest to personality psychologists.

The standard oscillometric methods for assessing blood pressure (involving the familiar inflatable blood pressure cuff) can provide separate assessments of systolic and diastolic pressure, but cannot provide independent assessments of myocardial versus vascular changes. However, *impedance cardiography* is a well-validated technique for doing so that is used with increasing frequency among health psychologists. This technique also allows for the specific measurement of cardiovascular correlates of SNS activity (just as RSA provides for PNS activity).

Impedance cardiography uses external current and voltage electrodes to pass a high-frequency, low-amplitude, alternating current through the thorax and measure changes in electrical resistance. Because blood is a conductor, these changes index the changes in aortic blood volume and flow velocity associated with systole and diastole. The technical specifics of impedance cardiography are beyond the scope of this chapter (for more thorough discussion, see Brownley, Hurwitz, & Schneiderman, 2000; Sherwood, 1993). The key advantage of this technique is that it yields measures of (1) pre-ejection period (PEP), technically defined as the systolic time interval, or the time between the onset of left ventricular depolarization to the moment just before blood is ejected from the left ventricle, (2) stroke volume, which can be multiplied by heart rate to yield a measure of *cardiac output*, the total amount of blood being ejected from the left ventricle, in liters per minute, and (3) total peripheral resistance (TPR), or the resistance to blood flow in the peripheral arteries, calculated as mean arterial blood pressure divided by cardiac output. PEP is of interest because it serves as a measure of sympathetic nervous system activity, as increased sympathetic activation leads to greater contractility of the left ventricle and hence shorter systolic time intervals (i.e., *smaller* PEP readings). Cardiac output and TPR are of interest because each of these dimensions represents, respectively, the myocardial and vascular contributors to blood pressure, as reviewed above. Impedance cardiography is quickly becoming standard practice in behavioral medicine research, but is less commonly used by the average psychologist. Nonetheless, personality psychologists whose research questions require specific isolation of SNS activity or identification of hemodynamic profiles will find it indispensable.

Conclusions

The integration of psychophysiological measures into personality research can make an important contribution to overall multimethod approaches in personality psychology that seek to understand how and why psychological traits are associated with diverse domains of human functioning, from cognition to emotion to behavior to physiology. The increasing availability of noninvasive, well-validated measures of multiple physiological systems makes it relatively easy for personality psychologists interested in psychophysiology—even those with little background in human physiology—to integrate these measures into their research programs, given careful attention to some of the biological and methodological basics we have outlined above. The end result may be a more comprehensive understanding of the complex and diverse patterns of interindividual variability in human functioning across different domains.

Recommended Reading

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Note. Also refer to Table 22.1.

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