

Assessment in daily life.
A Review of Computer-assisted Methodologies and Applications
in Psychology and Psychophysiology, years 2000 – 2005

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1 Introduction

Ambulatory monitoring and assessment is an innovative methodology, the use of which has now progressed into many areas of medicine and psychology. This approach places the focus on everyday life (“naturalistic” observation) and emphasizes ecological validity of research findings.

The arrival of pocket-sized (hand-held, palm-top) computers and digital recording systems for physiological data has simplified the acquisition of data considerably. Computer-assisted methodologies facilitate investigations in real-life situations in which relevant behavior can be studied much more effectively than in the artificial laboratory-based research environment. Field studies are essential, for example, in research on stress-strain or on mechanisms that elicit psychological and psychophysiological symptoms.

The roots of ambulatory monitoring and assessment can be found in a number of research orientations that were initially more or less independent of one another, each with its own specific objectives. *Clinical (bedside) monitoring* was introduced as means to continual observation of patients’ vital functions by registering, for example, respiratory and cardiovascular parameters under anaesthesia or during intensive care. *Ambulatory monitoring* refers to continuous observation of free-moving subjects (patients) in everyday life, in contrast to stationary (“wired”) monitoring. Ambulatory monitoring can be conducted either by biotelemetry, that is, transmitter-receiver systems, or – now very common – by a portable recording system. This methodology is well suited to patient cases in which important pathological symptoms cannot, for a number of reasons, be detected in the physician’s office or hospital as reliably as they can under prolonged observation in everyday life. Such cases include hypertension, ventricular arrhythmia, ischaemic episodes, sleep apnea, and epileptic seizures. Here, ambulatory monitoring provides the basis for valid diagnoses and adjustment of medication.

Field research comprises observation in natural settings in contrast to the laboratory. Field research is an essential methodology in social research, cultural anthropology and ethology. Likewise, some research issues in social and clinical psychology require field studies in order to obtain valid data. The practical application and evaluation of behavior therapy places particular demands on naturalistic observation. *Behavioral assessment* methods include a variety of in-vivo (in situ) tests, simulated and quasi-naturalistic settings, such as behavioral approach/avoidance tests (BATs) that were designed to assess behavior disorders and clinical symptoms.

Ambulatory assessment draws on those research orientations that share a common basic ecological perspective. Ambulatory assessment involves the acquisition of psychological data and/or physiological measures in everyday life according to an explicit assessment strategy that specifically relates data, theoretical constructs, and empirical criteria to the given research issue. Such field studies are not solely concerned with the ambulatory monitoring of patients, but include also a broad spectrum of objectives and applications. Common features are: recordings in everyday life, computer-assisted methodology, efforts to minimise method-dependent reactivity, maintenance of ecological validity and, therefore, outstanding practical benefit for various objectives. Most of the previous reviews dealt either with psychological or physiological research: Ager & Bendall, 1991; Barrett & Barrett, 2001; Baumann, Thiele & Laireiter, 2003; Bolger, Davis & Rafaeli, 2003; de Vries, 1992; Hufford, Shiffman, Paty & Stone, 2001; Littler, 1980; Miles & Broughton, 1990; Patry, 1982; Pawlik and Buse, 1996; Perrez, 1994; Shiffman, 2000; Suls and Martin, 1993; Turpin, 1985, 1990; Wilhelm & Perrez, 2001). Both psychological and psychophysiological approaches to ambulatory assessment were covered by Fahrenberg, Leonhart and Foerster (2002), Fahrenberg and Myrtek (2001b) and in two edited volumes (Fahrenberg & Myrtek, 1996, 2001a).

Initially (in the seventies and eighties), ambulatory assessment-based research was chiefly concerned with methodological issues and with conducting pilot studies to explore the potential for and limitations of microcomputer applications in various domains. Since then, an increasing number of applications and a substantial body of research findings has emerged; some of the findings cast doubt on the theoretical positions that were originally based on laboratory observation.

The extent to which ambulatory assessment methodology has developed is evident in the growing number of journal articles and in two edited volumes comprising contributions by numerous international authors from European countries and the US (Fahrenberg & Myrtek, 1996, 2001a). The present review will focus on recent publications from the years 2000 to 2005, without providing a complete account of publications over this period.

The first Section deals with *Assessment Strategies and Issues in Methodology* such as reliability, acceptance of monitoring methods, reactivity aspects, and ethical issues. Subsequently, recent research and applications, and new methods are reviewed under two headings: *Psychological Assessment* and *Physiological Monitoring and Psychophysiology*. According to the number of references, the chief areas of interest were emotion and stress, pain and symptom reports, blood pressure research, and the recording of physical activity and movement patterns. The advances in *Computer-assisted Self-Monitoring and Self-Management* are addressed in another Section. Finally, the impact of the innovative methodology and some perspectives are discussed.

2 Assessment Strategies and Issues in Methodology

2.1 Assessment Strategies

In its early days, ambulatory monitoring was mainly used as a means to collecting data under conditions of daily life, unconstrained by the design requirements of laboratory-based experimental research. Such unconstrained recordings may well be regarded as constituting the antithesis to laboratory experimentation, because single case studies of this kind do not permit making generalized conclusions. New assessment strategies have therefore emerged, and it is interesting to see that these reflect an increasing trend toward greater application of principles of standardized psychological testing and of experimental design in ambulatory assessment without forfeiting the claim of ecological validity.

Computer-assisted methodology is used to assess self-reports, behaviors or physiological measures while the person participates in normal daily activities. The assessment strategies include:

- *Continuous monitoring*: Recordings are made continuously and without specific instructions or restrictions, except for technical reasons which do not permit data acquisition in certain settings. Examples for continuous recordings are ECG-monitoring ("Holter Monitoring") and the accelerometry/actigraphy of physical activity.
- *Monitoring with sampling methods*: The data acquisition is guided by strategies of time or event sampling (or mixed designs), for example, the intermittent measurement of blood pressure with intervals of 20 minutes, or diary entries for the occurrence of symptoms or behaviors.
- *Controlled (structured) assessment*: The data collection is enhanced to include segments of standardized or semi-standardized measurement which serve as a reference for inter- and intra-individual comparison. As part of the standard protocol in 24-hour monitoring, the subjects perform specific tasks, for example, climbing a stairway, performing a mental test, and participating in a short interview. Setting-dependent assessment would restrict the data collection to certain conditions, for example, the workplace or to leisure-time activities.
- *Interactive assessment*: Real-time analysis of physiological recordings is employed to automatically detect, for example, relevant ECG-changes (ST-depression, transient myocardial ischemia, arrhythmia, etc.) or increases in "additional heart rate", that is, in non-metabolic heart rate; additional heart rate is indicative of emotional states. Contingent to changes of such parameters, a patient can be prompted by a beeper signal to record specific events, activities, or subjective symptoms.
- *Bi-directional wireless interactive assessment*: Communication between participants and investigators as well as patients and therapists is possible, and with the provision of computer facilities, communication can be enhanced to support real-time monitoring, data transfer, feedback, or assistance at high-risk workplaces or for the chronically ill (telemedicine).
- *Symptom monitoring and self-management*: A hand-held PC may be useful in the diagnostic assessment of a variety of behavior disorders, for example, in drinking, smoking, or in eating disorders. Such strategies enable symptom-context (contingency) analysis and facilitate self-management in chronic illnesses like hypertension, obesity, hypoglycemia in insulin-dependent diabetes, in asthma patients, etc. Such computer-programs can be further used as a component of behavior therapy.
- *In-field psychological testing*: Standardized psychological tests are performed in specific (naturalistic) settings. Field psychometrics apply various kinds of computerized psychological tests, for example, tests of attention and mental performance, or personality questionnaires. Research questions comprise the stability and variability of psychometric measures, their setting dependency and circadian changes. This methodology permits innovative methods of psychological diagnosis.

- *Field experimentation*: The controlled assessment can be further developed to incorporate basic principles of experimental design, that is, the standardization, selection, construction or manipulation of settings, and randomized assignment of participants to certain conditions.

One of the most noticeable developments is the use of electronic diaries and, in psychophysiology, the synchronous assessment of self-report data and physiological reactions concerning, for example, emotions and blood pressure changes, respectively. Outstanding innovative approaches are reflected in the interactive methods of monitoring and in self-management applications as, for example, in real-time assessment and feedback by reporting physiological changes to the subject.

The Medline Databases defined Ambulatory Monitoring as follows: "The use of electronic equipment to observe or record physiologic processes while the patient undergoes normal daily activities" (year of entry 1995). The previous entry was "Monitoring, Physiologic" (1966-1994). Databases in psychology lack an adequate heading so that a number of keywords have to be searched for, such as computer-assisted methods in research & applied settings; electronic diaries; everyday life situations & current computer-assisted methodology & ecological validity & ambulatory monitoring.

Ambulatory recording in the field of medicine assists primarily in patient diagnosis and therapy evaluation and in monitoring patients at risk. There is, in contrast, a much wider field of application of *computer-assisted ambulatory methods* in psychology and psychophysiology. The following comprehensive definition is suggested:

Ambulatory Assessment: The use of computer-assisted methodology to assess self-reports, behaviors or physiological measures, while the participant is engaged in normal daily activities.

Ambulatory assessment – the term coined in 1996 – brings together those research orientations that correspond to each other in their basic ecological perspective. Ambulatory assessment involves the acquisition of psychological data and/or physiological measures in everyday life according to an explicit assessment strategy which relates data, theoretical constructs, and empirical criteria specific to the given research issue. Although assessment is often understood as data collection ("capturing life as it is") the methodology is by no means restricted to descriptive or data exploration, strategies, it also comprises data acquisition for testing general explanatory hypotheses.

Field studies of this kind are not solely concerned with the ambulatory *monitoring of patients*, but include also a *wide spectrum of objectives and applications*. Features common to these studies are: recordings in everyday life; computer-assisted methodology; the endeavor to minimize method-dependent reactivity; maintaining ecological validity and, in so doing, ensuring outstanding practical utility for various objectives – such as monitoring and self-monitoring; screening; classification and selection; clinical diagnosis; and evaluation – in many areas of psychology and psychophysiology (Fahrenberg, 1994, 1996a; see also, Fahrenberg & Myrtek, 2001b; Patry 1982; Pawlik, 1988; Perrez, 1994; Suls & Martin, 1993; Turpin, 1990). Thus, a methodology exists which is suited to the precisely timed acquisition of self-ratings of mood changes, symptoms, coping strategies, or of behavioral measures, performance data, physiological measures, etc.

Strategies and Designs

Ambulatory assessment, like laboratory research, requires selection of variables, design of time and event sampling, segmentation of records, and appropriate data reduction in order to obtain indices suited to statistical inferences. None of these methodological aspects appear to be characteristic of ambulatory assessment-based field studies; however, time and event sampling and, accordingly, strategies in data reduction may play a more prominent role here. There are many conceivable strategies of data acquisition; these range from a 24-hour continuous observation in ambulatory monitoring of the ECG to a complex design in which time and event sampling of subjective state are combined, and which may even include global retrospective ratings and the participant's evaluation of the monitoring process itself, that is, aspects of reactivity and compliance.

Four types of recording have been proposed: interval-contingent, signal-contingent (randomly triggered), event-contingent sampling, and continuous recordings (e.g., Pawlik, 1988; Reis, 2000). Suls and Martin (1993) suggested a classification system for in situ methods. Sources of reports are self-report, surveillance-report by a trained observer, and automated report. Heger (1990a) distinguished active, passive, and reactive participation of subjects in ambulatory monitoring.

A variety of specific sampling schedules and designs have also been suggested that are common to experimental psychology and behavior observation techniques. The choice of sampling technique depends, of course, on the content domain under study, the research question, cost-efficiency, and a number of aspects more specific to ambulatory assessment. These aspects embrace the time course of target variables and the intended resolution in time, the frequency of events or symptoms, duration of monitoring, reactivity-phenomena, and confounding variables. Additionally, computer-assisted monitoring allows for unique designs as it is the case with interactive monitoring.

A classification of basic assessment models based on certain theoretical assumptions was proposed by Stemmler (1992, 1996). These models specify the type of construct, the mode of operation, and the range of generalizations. This general assessment model was tentatively specified for BP assessment in the laboratory and in ambulatory psychophysiological 24-hour monitoring (Fahrenberg, 1996b).

Various designs for computer-assisted ambulatory assessment have already been employed in psychological research; some of these assessments lasted for many days or weeks. In psychophysiology and in medicine, the restriction to a single 24-hour recording appears to be the preferred format because of the costly equipment.

Multiple Effects

A common feature of ambulatory assessments is that the derived data usually represent not a single and obvious stimulus-response process but may contain multiple effects of everyday life. Investigators may therefore wish to control for unwanted (confounded) variance. Physical activity, for example, is an important source of variance, especially in cardiovascular measures, while arbitrary changes in ambient parameters, such as temperature or noise, may elicit physiological and behavioral adaptation responses. Multi-channel data recorders allow for concurrent recordings of physical activity and ambient parameters, thus providing a means to segmentation of recordings according to high or low activity, etc. The general design of the investigation may also embrace standardized or semi-standardized measurement periods which serve as a reference for inter- and intra-individual comparison. Furthermore, statistical methods may be employed to separate, that is, partial-out, unwanted variance, for example, by analysis of covariance or multi-level analysis. What is more, in physiological data analysis specific algorithms were developed to detect changes in posture and movement behaviors or to adjust measures of heart rate and blood pressure (real-time) for changes in on-going physical activity and energy expenditure (see Section 4.4).

Field Study and Laboratory Experiment

Field and laboratory have often been regarded as alternative strategies in psychological research. The laboratory provides an artificial, though standardized setting that is designed to elicit distinct behavioral responses, thus allowing for controlled observation and experimental testing of explanatory hypotheses. "Field" designates the multitude of real-life settings where behavior occurs naturally, that is, neither initiated nor shaped by an investigator. Textbooks on research methodology usually point out certain features, referred to as advantages or disadvantages, in evaluating laboratory experiments and field studies. Many of these points can be subsumed under the perspective of internal vs. external validity. However, the laboratory-field issue is in need of more differentiation.

A common position is that a two-stage process is fundamental to science. Explanatory hypotheses are derived from and tested in highly controlled experiments in the laboratory. These theories are subsequently transformed into models for applied science by adding specifications and boundary variables. From this follows the notion of internal versus external validity. However, doubt may be cast on the postulated two-stage process because the specification of essential context parameters already belongs to the initial formulation of hypotheses and operational definitions (Gadenne, 1976).

If context-specificity of empirical findings is acknowledged as a general principle in science, the fundamental distinction between laboratory experimentation and ambulatory assessment needs to be qualified. The abstract distinction between laboratory and field should be replaced by specifications in the context of which a theoretical statement is considered valid – in terms of significant contexts and generalizability. Accordingly, research should focus more on the specification and empirical examination of the contexts and of boundary variables that constrain the generalizability of a specific study. The investigator then has the choice of whether to opt for a laboratory setting or real-life settings, as preferred in the given research instance.

The discussion of the laboratory-field issue has a long and often controversial history. This is reflected in the use of essential keywords like internal and external validity, ecological validity, naturalistic observation, behavior settings, socio-ecological units, representative design, generalizability theory, and so forth. Among the noteworthy conceptual developments were contributions from environmental psychology that pertain to the theory of settings and boundary variables in delineation of the supposed realm of validity (for an account of this controversy with particular reference to ambulatory assessment, Fahrenberg & Myrtek, 2001b; Fahrenberg et al., 2002; Patry, 1982; Pawlik, 1988; see also, Bechtel & Churchman, 2002).

Setting and Situation, Context and Boundary Variables

Ambulatory assessment relates to a specific setting or a sequence of settings in real-life as compared to a standard laboratory environment. The psychology of settings and situations is therefore a fundamental issue here. However, generally accepted definitions for “setting” and “situation” cannot be found in the literature and it is likely that such definitions cannot be expected because of the controversial theoretical and methodological issues involved. The following distinction is suggested here:

– *Setting* refers to external environmental conditions, for example, an objective description of location, time, persons and objects present, and other characteristic features of a distinct part of the field. For a given setting, certain behaviors are more probable while other behaviors are rarely or never observed. Many settings thus contain rather specific tasks and incentives, constituting the demand characteristics that elicit typical behavior programs.

– *Situation* refers to an internal representation of a setting, that is, a subjective description relating to experience and evaluation which constitutes the frame of reference for the individual’s emotions, actions and social interactions. A situation can usually be characterized by a focal action or action tendency. Taxonomies for settings and situations have been suggested, but would appear to have found little general acceptance. Such taxonomies may refer to (1) the objective features of a setting, (2) behavior that is typically elicited in a certain setting, and (3) the evaluation of situational aspects which indicate the relative similarity of certain situations.

Both settings and situations constitute the context for the protocol that contains observations, self-reports, and physiological measurements. Accordingly, there is a multitude of context variables that can be specified which may possibly affect the findings. Thus, the concept of a *boundary variable* was introduced to signify a context variable that obviously (1) influences the relationship between variables, (2) may affect the reliability/objectivity of measurement, and (3) may disturb the transfer of results from a focal setting to a criterion setting.

There is a universe of settings and a universe of situations, but the notion that a random sample of natural settings can be obtained seems inadequate because a distinct population of settings/situations cannot be conceived of. In this respect, sampling techniques have to be replaced by the appropriate selection of settings or aggregates of settings. Buse and Pawlik (1994), for instance, derived aggregates for classes of settings and classes of situations in order to investigate inter-setting consistency and inter-situation consistency in individual differences of behavior. The rationale for selecting appropriate settings/situations is therefore an essential step in designing ambulatory assessment strategies. The validity of research findings and the practical utility depend on a sound theoretical and empirical justification of such decisions.

Diaries employed in ambulatory blood pressure monitoring often contain rather crude categorizations of settings, namely, workplace, home, and sleep. A psychological approach that provides essential distinctions is called for. Which setting is rather frequent or important in the individual's time budget? Which setting is especially significant from a psychological-biographical point of view? Which setting is familiar enough to all subjects in the sample with which to render between-subjects comparison possible? Which setting could be designed as a standardized condition for behavioral assessments (in-vivo testing)? In evaluating a 24-hour monitoring it may additionally be essential to know whether the subject spent much time in unfamiliar settings or whether the daily course of events can be assumed to be representative, that is, rather typical of this subject.

An alternative strategy is conceivable, and is actually widely used, especially in clinical studies. Such an assessment would disregard psychological differentiation and classification of settings and be content with an overall finding in ambulatory monitoring, either by recording a "representative" day or by prolonged recordings for days and weeks to capture the essential, less frequent events.

Sampling, Segmentation, Episodes

Frequently raised issues regard the time sampling and the appropriate duration of assessment. A rational approach would point out that an adequate sampling necessitates knowing the time course of the underlying process, that is, response latency, frequency of occurrence and duration. Without such pertinent information, only rules of the thumb can be given at best. Sampling theory is of little help in this respect. The Nyquist-Rule that sampling must be done at twice the frequency of the change one wants to track (1) relates to periodic signals (e.g., sinus-function) and, (2) presupposes that there is only one process of known periodicity. An exploratory approach would start with a rather high resolution and then perform a stepwise aggregation to observe the effect on certain parameters.

Investigators who employ electronic diaries obviously differ in how they weigh the trade-off in measurement frequency and duration. Yet the time-schedule of data collection and the number of items per occasion is often the result of a compromise between cost and utility aspects and the subject's compliance to the repeated measurement.

For the ambulatory monitoring of the ECG, a cost-benefit analysis has been suggested since the rate of detection of certain abnormalities in cardiac functions will depend on the duration of screening. In blood pressure monitoring the guidelines indicate that measurement intervals of 15 or 20 minutes during the day and 30 minutes at night may suffice for a valid assessment of blood pressure level and variability (Pickering, 1991).

Segmentation denotes the distinction of data periods which, according to theoretical or empirical criteria, constitute relatively homogeneous units of functioning within an extended course of observation. Segmentation is an often problematic but essential step, that is, to separate pre-task and task, rest and activity, symptomatic and asymptomatic intervals, and awake and asleep. The segmentation of prolonged recordings is necessary in order to attain the essential data periods that allow for interindividual comparison, or symptom-context-analysis. In physiological recordings, steady state or response criteria can be used for segmentation. If available, concurrent recordings of physical activity provide cues with which to eliminate data periods containing artifacts. Such aspects of sampling and segmentation were discussed in more detail elsewhere (Fahrenberg et al., 2002; Nelson & Hayes, 1986; Pawlik & Buse, 1996; Suen & Ary, 1989).

Episodes are distinct experiences, changes, events or somatic changes that stand out against the background of a more or less stationary process. Such episodes within a continuous recording may be of significance to the subject. An obvious increase in reported momentary emotion or stress is indicative of this. Such psychological episodes are also assessed in a post-monitoring interview. A distinction can be made here between spontaneously reported episodes and episodes that are explored by an interviewer. Episodes that stand out from a stationary process can be defined according to both psychological (self-reported emotion) and physiological criteria (BP changes). Psychological and physiological episodes may coincide; however, many investigators have reported essential discrepancies, that is, "quiet" physiological reactions or subjective symptoms without apparent somatic changes (see Section 4.5).

Ecological Validity

Ecological validity is the key albeit vague concept in ambulatory assessment. Obviously, this concept of validity does not easily lend itself to operational definition. Numerical coefficients of ecological validity are hard to conceive of. Neither correlation/regression analyses comprising laboratory findings and everyday measures (criterion variables) nor generalizability theory can provide comprehensive indices of "ecological validity".

Ecological validity is, like the concept of internal validity, a multi-referential concept. Both concepts embrace a set of perspectives, problems and strategies for control. Basically, both of these concepts entail a system of reference and evaluation of methodology pertaining to a particular research aim. At the core of this discussion is the pertinent question, whether an equivalent type of behavior occurs in these settings („gleicher Geschehenstyp“ Lewin, 1927, 1951). This perspective exists regardless of whether an individual difference (assessment) approach is taken or an explanatory hypotheses is pursued.

Applied Environments

The assumption of ecological validity may be especially evident in the case of *applied environments*, that is, settings in which behavior (including in a very broad sense physiological measures and self-report data) is assessed in order to answer practical questions in contrast to basic research in the laboratory. Work-place settings are by nature non-laboratory. The behavior under consideration is already part of the individual's repertoire and occurs in a familiar environment. However, behavior assessment at the workplace is not entirely naturalistic because the participants usually know that recordings are being made. They may also be aware of the specific hypothesis under investigation or assume certain motives and goals. Such attitudes and attribution processes may affect the compliance and reactivity or may even lead to reactance, that is, defensive and non-cooperative behavior. On the other hand, participants may be especially interested in or even take particular delight in co-operating in such recordings. Even more than with voluntary participants in laboratory research, confidentiality and other ethical issues are involved.

Assessment of individual differences (or average response profiles for certain tasks) in applied environments generally seeks an empirically-based answer to practical questions. Such objectives include monitoring and self-monitoring of performance, evaluation of mental and physical load and overload, selection and classification of personnel, and detection of health risks and evaluation of risk behavior. Within- and between-subject variance or interaction terms may be relevant for such issues and predictor-criterion relationships. Maintaining ecological validity and, therefore, superior practical utility of such objectives requires explicitly stating the goals and strategies of such data acquisition. Especially when costly psychophysiological methods are involved, the empirical validity and, more importantly, the incremental validity (as compared to data already available) have to be discussed on theoretical grounds and within the framework of cost-benefit analyses.

Laboratory-field Comparisons

Investigations were designed to examine the validity of laboratory-based predictions of performance in real-life. Such empirical validation studies played also an important role in the development of psychological tests.

Generally, larger response magnitudes and more realistic effect sizes may be expected in natural settings. Field studies are more suited to prolonged observation that may extend over days and weeks. Accordingly, there is more chance for the detection of rare events and symptoms that occur at low frequencies or only in certain settings. Prolonged observation periods make the averaging/aggregation of measurements possible so that reliability of measures may increase substantially. But field studies can be seriously threatened by the confounding of multiple effects which tend to produce "noise" and, eventually, require relatively large subject samples in order to obtain valid estimates for main effects.

It has been questioned whether certain diagnostic techniques and measurements, for example, blood pressure measurement, in the physician's office or in the psychophysiological laboratory reliably predict individual differences in real-life. Indeed, laboratory-field comparisons revealed significant discrepancies. Office hypertension is a good example of how certain features of the setting and their

meaning to the subject may play an important role in assessing individual differences: Blood pressure readings are elevated when measurement is performed by the physician, while in everyday life normal readings are obtained (see Section 4.2).

Laboratory Field Complementarity

Considering the multitude of research strategies and quasi-experimental designs, it may be misleading to refer to "laboratory" or "field" studies without indicating the features of the specific study under discussion. It would also be oversimplified to state methodological advantages of the laboratory experiment as obstacles in field studies and vice versa, that is, to retain the notion of basically different research strategies instead of a wider perspective that includes laboratory and field as complementary approaches. Basically, such complementary approach would lead to new types of design that should bridge the gap between laboratory and real-life settings, for example, by including standardized settings in the ambulatory monitoring of blood pressure changes in order to obtain baselines and response magnitudes for reliable between-subjects and within-subject comparisons. This approach also necessitates the search for distinctive boundary variables that may affect the relationship between independent and dependent variables or the reliability/objectivity of measurement.

The obvious advantages of ecological validity are usually accompanied by shortcomings in internal validity due to the complexity of effects, problematic control of independent and dependent variables, covariates, and extraneous variables (artifacts, confounds). The observation of distinct stimulus-response relationships will generally be more difficult in ambulatory recordings than in the laboratory. Obvious changes in behavior and physiology may occur that are attributable to either an external event or the subject's actions. In some areas, there is a noticeable trend to supplement field studies and quasi-experimental designs with field experiments that attain higher levels of control so that functional (causal) relationships may be detected more precisely.

2.2 Issues in Methodology: Acceptance, Compliance, and Reactivity

When a new methodology is introduced there is a particular awareness not only of its new potential but also of its possible disadvantages. Ambulatory assessment faces such concerns with regard to acceptance, compliance, and reactivity, and these issues have been discussed by several authors; empirical findings will be reviewed in Section 3. A short comment may suffice at this point that includes some indication as to the operational definitions of these effects. Basically, investigators can try to establish specific attitudes beforehand, they can include control items in the diary program, analyze the documented computer entries, or have the study participants complete a questionnaire assessing their subjective experiences of whether the monitoring caused altered attitudes, mood, or behaviors.

Acceptance

From the beginning, there have been concerns raised about the acceptance of hand-held PC, and the validity of monitoring in daily life. Ambulatory assessment with a pocket PC or recorder depends on the favorable attitude of the participating subjects. It is essential that the equipment is readily accepted and that good compliance to instructions is established and sustained. If the ambulatory monitoring is part of a diagnostic process or a treatment program, the patient's compliance may be higher than in research projects. The ambulatory assessment should, of course, not cause major problems in interacting with the social environment. Acceptability was examined also with respect to preference for electronic diary or paper-and-pencil diaries.

Compliance

Adherence to instructions, to follow agreed procedures for a certain period of time, is a basic requirement. Especially with prolonged recordings in everyday life the compliance may diminish. For example, the frequent assessment of self-reports over time may result in an increasing number of missing data. Commitment, or compliance, depends on the question under study and the participant's general study motivation. The disposition for self-observation and disclosure, general test taking attitudes and certain personality traits may also be considered in this context.

The evaluation of electronic diary compliance has to consider several aspects:

- (1) signal compliance, referring to whether an entry is documented within a certain time interval, that is, frequency of valid data, frequency of delayed entries;
- (2) response latency, that is, average latency and its variability, indicative for interrupts in reporting;
- (3) protocol compliance, that is, the percentage of actual entries made for a particular protocol, compared to the required entries, resp. the number of missing data;
- (4) over-all compliance, that is, the percentage of protocols, valid in every respect, within the study, resp. the percentage of drop-outs.

Because of artifacts, battery problems, etc., further reasons for missing data may be present. Post-monitoring interviews may eventually disclose whether in a particular subject the acoustic signal (beeper) was overheard due, for example, to the device being stored in a bag or in another room, or to it being intentionally disregarded.

Compliance is primarily a concern in acquisition of psychological data. Ambulatory monitoring of physiological functions, for example, cardiovascular measures, and recordings of physical activity, that is posture, movements, and energy expenditure, is based on a continuous or automatically triggered recording. Compliance becomes an important issue when the patient is required to fill salivettes for measurement of cortisol or to enter actually measured data, for example, blood glucose measurement (see Section 4.5).

Reactivity

The method of observation and measurement itself may cause unwanted variance, that is awareness, sensitization, adaptation, and coping tendencies. The monitoring and assessment of activities, emotions and symptoms could influence the phenomena under study. Self-monitoring refers to a two-stage process in which participants first identify that a target behavior or subjective state occurred and then record a response. Self-monitoring has the potential to affect the monitored process, as it makes participants aware of their experience and behavior at a time when they have opportunities to change it. The Heisenberg-Principle has often been cited to indicate a fundamental observation bias. Since method reactivity is common to nearly all methods in psychology and physiology the discussion should focus on aspects that are more specific to ambulatory assessment and on possible effect sizes. – The unspecific method effects include the subject and experimenter expectancy effects, response tendencies like acquiescence, and training or habituation effects.

Three aspects of reactivity appear to be specific to ambulatory assessment. Subjects may: (1) tend to steer clear of certain settings during the recording in order to avoid being monitored there; (2) tend to unintentionally or deliberately manipulate the recording systems, shift settings of the PC, and may even try to get access to the program; and, (3) try to test their capacities or the equipment by unusual patterns of behavior, exercise or vigorous movements, in the case of physiological recordings. In rare instances, manifest reactance is observed, that is, a complete loss of compliance, extending in some instances to counter-directed actions. Reactance is caused by perceived social pressure (commitment) imposed by the schedules agreed beforehand.

Despite its many advantages, computer-assisted self-reporting poses important challenges to researchers. The potential distortion of findings by reactivity is one of the issues often referred to in the discussion and has initiated a number of method studies (see below). Monitoring appears to have more potential because of the prolonged time of self-observation or measurement and due to the invasion of privacy, at least, invasion of daily life (cf. Bornstein, Hamilton & Bornstein, 1986; Haynes & Horn, 1983; Korotitsch & Nelson-Gray, 1999; Stern, 1986).

Conceptually, three kinds of reactivity can be discerned: (1) motivational reactivity, that is, the change in the participants' readiness to comply, (2) behavioral reactivity, that is, the extent to which behavior changes simply as a function of real-time monitoring (cf. Hufford et al., 2002), and (3) procedural reactivity, that is, the development of time-saving strategies and short cuts in response to the imposed demands of the investigation. Reactive measures (measures that change the phenomenon assessed) cause problems in interpreting any changes observed. At the very least a comprehensive post-monitoring interview is recommended in order to obtain information on these essential aspects (Fahrenberg et al., 2002).

Table 2.1: Methodological Issues

	Definition	Indicators/Measures
Acceptability	Readiness of participants to use an electronic diary for self-reporting or to wear equipment such as BP-monitor or activity recorder and electrodes fastened to the body.	Interview/Questionnaire to assess attitudes and experiences (beforehand and post-hoc). Example of a critical item: "Would you volunteer for another study of this kind".
Compliance	Adherence to instructions, to follow agreed procedures for a certain period of time.	Percentage of valid data regarding signal-compliance, protocol-compliance, and study (overall) compliance
Reactivity	Subjective, behavioral and physiological reactions to the method itself and to the experience of being observed or tested.	Item included in self-report: "momentarily disturbed/upset by being signaled". Obvious trends (first/second half of study). Post-monitoring interview/questionnaire, reported increase in self-awareness, boredom and fatigue in self-monitoring, avoidance of or unusual preference for certain settings. Cues from time-budget or behavior observation/ measurement on other days.
Reactance	Negative motivational set caused by the experience of social commitment and perceived pressure.	Prompts intentionally ignored. Unreasonable data entries, attempts at breaking the program code, intentionally damaging the equipment. Participation discontinued.

2.3 Retrospection Effect, Recall-Bias

The retrospection or re-call effect is another important issue in methodology. However, in contrast to the aforementioned matters, the ambulatory assessment methodology is especially suited to largely controlling this effect. Recall bias refers to a complex phenomenon associated with responding to questions on past experiences. A retrospection effect may exist when subsequent events and experiences systematically influence and even distort the subjective evaluation and weighting of previous states. A number of components of bias can be emphasized on theoretical grounds. Some of the hypothetical effects can be tested in laboratory experiments on hindsight and on recall, while some may be examined using standard questionnaires and by varying the test instructions or perceived purpose of the assessment. As compared to laboratory research, the over-all bias in retrospective self-reports may be much more prominent in genuine psychological assessment and in conditions of real-life. For several reasons, it proved difficult to examine retrospection effects in paper-and-pencil diary studies. However, computer-assisted methods facilitated these investigations.

A number of studies have shown discrepancies between actual and retrospective self-ratings done from memory. Findings that pointed to a general recall-bias were reported from investigations in differential and clinical psychology, however, mostly based on questionnaires or paper-and-pencil diaries (Clark & Teasdale, 1982; De Beurs, Lange & Van Dyck, 1991; Hedges, Jandorf & Stone, 1985; Margraf & Jacobi, 1997; Margraf, Taylor, Ehlers, Roth & Agras, 1987; Shiffman et al., 1997; Smith & Safer, 1993; Stone, Kennedy-Moore & Neale, 1995; Stone et al., 1998; Suh, Diener & Fujita, 1996; Thomas & Diener, 1990). Recent reviews on fallacies and biases in thinking, judgment and memory (Pohl, 2004), or more pertinently, on recall biases and cognitive errors in retrospective self-reports (Fahrenberg et al. 2002; Gorin & Stone, 2001) provide convergent empirical evidence as to how bias- and error-prone such psychological data are.

Computer-assisted methods are especially suited to investigating the retrospection bias. In particular, mood and symptom reports obtained in the evening may not represent the prevailing state during daytime. In a first study, self reports on activities and mood were assessed in 42 student subjects employing a high density time sampling (30 min intervals with a random component) which resulted on average in 30 protocols for one day. The MONITOR software was used in this case and 14 items applied (Käppler, 1994; Käppler, Brügger & Fahrenberg, 2001). The averages of these self-ratings were compared to the global retrospective ratings obtained in the evening for the same day. The retrospective ratings generally indicated more negative mood and unease than was to be expected from the actual ratings averaged across the day, that is, a *negative* retrospection bias. The daily course was rated as being more strenuous and the mood as more nervous, depressed and weary, etc., than would have been expected from the averages of repeated self-ratings during the day.

These findings substantiated research by De Longis et al. (1988, 1992) and Hedges et al. (1985), and emphasized more clearly the uniformly *negative* tendency of this retrospection bias. Meanwhile, a number of investigations were conducted based on data from electronic diaries (see Section 3).

2.4 Ethical Issues

Ambulatory assessment is subject to the guidelines of medical and ethical committees on human research to guarantee informed consent and data protection. Examples include the Guidelines published by the American Psychological Association and the Deutsche Gesellschaft für Psychologie. Ethical issues that are specific to ambulatory monitoring studies have rarely been discussed in the literature. Monitoring could be regarded as a case of “big brother is watching you”, that is, an exceptional invasion of privacy.

Guidelines require that the procedure and the expected duration of a study are explained to the participant as a precondition of obtaining informed consent. It may however be more difficult to explain the essential aims of the investigation, variables, and methods of analysis in ambulatory studies than in the laboratory. Especially when psychological data and recordings of behavioral activities are obtained, the participants should be informed about the kind of findings and conclusions that can be derived from such protocols. Obtaining the subject’s informed consent before the recording starts is essential, but it may not go far enough since the exact course of daily activities and events cannot be anticipated. A post-monitoring interview is therefore well suited to recalling specific events and discussing problematic aspects.

Ambulatory assessment may violate privacy more easily than alternative methods, and the matters of appropriate confidentiality and maintenance of data protection is an issue that remains to be satisfactorily addressed (Schuler, 1982; Bersoff & Bersoff, 2000). The participant should expect and be given privacy for any measure, procedure and intervention, with special attention being paid in research to the needs of children and vulnerable populations. Participants must consent specifically to having therapy sessions recorded (e.g., Rae & Sullivan, 2003). Furthermore, persons not being assessed, for example, significant others and bystanders, may become involved when the observation and the evaluation of settings are required. Consent is not required for recording in public places if the recording will not be used in a way that would identify participants or inflict negative consequences (e.g., cause them harm).

At present, the instrumentation hardly allows for recording social interaction in everyday life. New technologies in portable audio and video recordings will however lead to innovative assessment methods. Obviously there is a spectrum of settings and activities in daily life in which other persons than the study participants could be identified.

Electronic instrumentation and computer methods do enable however control of the study participants’ compliance in participating in certain measures (blood glucose, tidal volume), complying in filling salivettes at a predetermined time or in responding to all of the diary items. The principle of informed consent would additionally require that study participants and patients be informed if such control is performed.

There are rather specific requirements of practical importance in certain fields. The Food and Drug Administration in the US mandates that data entries in clinical trials should not be anonymous. Therefore, such data must be linked to the participant and acknowledged by the participant’s signature. This requirement became an important consideration in the selection of a suitable hand-held computer

capable of recording signatures. The guidelines also require that participants should be able to "to make a parenthical comment".

The question is whether the informed consent has to be specified and supplemented by pointing out specifically which output categories are obtained in conducting a certain assessment in daily life. It is suggested here that the post-monitoring interview should be a regular part of any ambulatory assessment. This would allow exploring whether unexpected events or social interactions occurred that deserve deletion of recorded data segments or necessitate extending the informed consent to include such problematic parts.

2.5 Reliability, Consistency, and Sensitivity to Change

The concept of reliability has several notions and there are accordingly alternative approaches available for the estimation of true variance and error variance. Conventional test theory is traditionally concerned with trait measurement and test construction and is predominantly based on inter-individual differences. In ambulatory assessment the state variance is the parameter of main interest and the research question defines which components of observed variance are actually essential and which components are unwanted (and error in this sense).

The traditional notions of parallel-test, split-half, and re-test reliability (reproducibility, stability) are of less interest in ambulatory assessment. Research in this area is primarily concerned with state variance and the empirical studies from this research have contributed to the differentiation of psychometric concepts such as the distinction between intra-setting and inter-setting consistency. The assessment of performance data and mood data under naturalistic conditions allowed for such psychometric studies (Buse & Pawlik, 1994, 1996, 2001; see also, Perrez, Wilhelm, Schoebi & Horner, 2001). Consistency coefficients between certain settings or successive days are especially interesting. Large differences exist between various performance measures and between mood items. Intra-individual variability is not simply error or noise but contains important information.

Internal consistency refers to the degree to which items or components of a test measure the same psychological aspect. To attain a high degree of consistency each item has to correlate highly with the total score computed from all remaining items. It is noteworthy that the preference for high internal consistency favors the selection of items that are very similar, or even redundant in their content. In this case, a single aspect of a theoretical construct is measured more precisely but related aspects of the same construct are not adequately represented, thus resulting in a decrease in the predictive validity of the measure in predicting the full meaning of the construct. The so-called partial incompatibility of reliability and validity is an essential issue in the assessment of subjective state – whether a selection of items or whether scores derived from mood scales (aggregates of items) such as Positive and Negative Affect Scales (Watson, Clark & Tellegen, 1988) are to be preferred.

Two levels of consistency have been delineated (Buse & Pawlik, 1996): *Local reliability* is the consistency of measures or items within the same setting (occasion), whereby the coefficient of agreement is derived by odd-even method or alpha-consistency. Subsequently, coefficients can be averaged across settings/situations or days, the equivalence of such conditions assumed. *Aggregate reliability* is the consistency of aggregates (averages) across certain settings/situations or time intervals, the equivalence of such conditions assumed.

The concept of *sensitivity to change* refers to the discriminative power of a certain measure to yield different values for the same subject in different situational contexts. Generally, discriminative power is required to assess differences between subjects (trait variance), between days (trends), between time of day (general course of day, circadian rhythm), between settings/situations (patterns of experience and behavior). The interaction effect Subject x Setting signifies the individuality of how habitual characteristics interact with settings. Since both design factors are not orthogonal, settings have to be repeatedly realized to enable tentative interpretation of findings. The interaction effect Subject x Day x Time of Day signifies the individuality in the course of the day.

A psychological parameter is sensitive to state change if substantial intra-individual variance exists which is not error variance in a strict sense. From a psychometric perspective, an ideal parameter would be equally

apt to differentiate between subjects, settings, and states. Psychometric evaluation of items and test measures indicate considerable variation between measures in this respect. Such features depend of the psychological content. Furthermore, lack of sensitivity may result from abnormal distribution of measures: scatter, shape or kurtosis, restriction of range, bottom or ceiling effects. Individuals differ remarkably in intra-individual scatter. The rational selection of items often necessitates a compromise. For example, the item "angry, irritated", using a seven-step response format, shows an obvious bottom effect, however, the rare occurrence of a self-rating above scale-midpoint has special significance (for an overview, see Fahrenberg et al., 2002; Suen & Ary, 1989).

In physiological measurement the reliability in a technical sense is higher in most variables than for psychological assessments. A distinction can be made between *accuracy*, that is, agreement with a method used as a reference (average deviation from a "gold standard") and *precision*, that is, the standard deviation of differences between two methods (see, Bland & Altman, 1986). A low sensitivity to change, of course, may be due to low resolution in amplitude and time. Findings from method studies in psychophysiology indicated that, among the familiar measures of activation, heart rate comes up best to meet criteria of reliability, between-subject variance, and, also, sensitivity to change.

2.6 Data Management and Statistical Methods

Ambulatory monitoring studies and their data handling present a challenge in many respects. There is the sheer amount of data to be stored and processed, the dimensionality of data sets, which may comprise subjects, days, settings, number of protocols within a day or setting, items (measures) within a protocol, altogether in a hierarchical or nested order. As soon as multi-method designs are employed, for example, self-reports and concurrent blood pressure measurement, the two recordings have to be synchronized and many other aspects have to be taken into consideration. Accordingly, missing data statistics, outlier and artifact detection, and the aggregation (averaging) over certain time-windows or dimensions necessitate procedures that are less frequently encountered in laboratory experimentation or questionnaire studies.

Ambulatory assessment studies result in a sequence of observations in time. This sequence is called time series if observations are made at (roughly) equidistant intervals. Time series of psychological or physiological data represent on-going psycho-biological processes. This basic relatedness in time constitutes a serial dependency of observations, that is, the assumption of independent sampling, which is basic to many statistical concepts, is not valid here. A number of conditions can be specified why serial dependencies may exist in repeated measurement, for example, training and learning curves, circadian rhythm, weekly and seasonal trends, furthermore, various kinds of method variance, response tendencies, biases, reactivity, and other shared error.

Serial Dependency and Auto-Correlation

There are attempts to estimate serial dependencies in typical ambulatory assessment data. The coefficient of the autocorrelation function and the median of beta-coefficients in regression are useful statistics in this respect. Such coefficients were reported for mood variables, performance data, blood pressure and heart rate assessed at intervals of 15 or 30 minutes (Fahrenberg et al., 2002; Ott & Scholz, 2001; Tuomisto, Johnston & Schmidt, 1996). Noteworthy are findings by Pawlik & Buse (1999; Buse & Pawlik, 2001) regarding a set of performance tests: Coefficients of autocorrelation with lag 1 were in the order of 0.30, decreased clearly with lag 2, and were negligible with lag 3 in most instances. As soon as the general linear trend in performance data, which primarily reflects training effect, was eliminated, lag 2 coefficients were much smaller. However such coefficients varied considerably between subjects. Huitema (1988) concluded that the autocorrelation in time series of typical behavior observations and case studies generally tends to be negligible and could be disregarded. This statement was refuted by Matyas and Greenwood (1991) who concluded from studies on simulated data sets that the distribution of the coefficients plays an important role in evaluation of rather short time series with less than 20 data points.

MANOVA, Multi-level Analysis, Modeling and Non-Parametric Alternatives

The statistical analysis of time series, as compared to a conventional repeated measurement design with one or two replications, involves a number of issues that deserve thorough consideration. For short time series conventional MANOVA with orthogonal factors Subjects and Settings, and repeated measurement on Factor Time (Days) are preferred for testing effects. The estimation of trends is also possible. More recently Multi-Level-Analysis was used in a number of investigations. This concept can be seen as an extension of multiple correlation/regression analysis. Multi-Level-Analysis is appropriate for observations that are hierarchically structured: repeated measurements within days and within subjects belonging to different groups. Hierarchical linear models, mixed-effects regression models or random-effects models are of the same kind. One of the advantages is that, beyond fixed and random factors (alike MANOVA), serial dependencies can be accounted for differently for subjects.

Multi-level-Analysis, thus, is especially suited to hierarchically ordered data sets that contain repeated observations on variables, nested within days of observation, and organized within subjects. These procedures allow treating both subjects and daily observations as independent sampling units and as random effects. The analysis may focus successively on relationships between variables, with and between days, and the effects of individual differences or group differences on within subject variance. Random coefficient multilevel approaches model the influence of within-subject and between-subject factors simultaneously on a variable of interest, including time as a relevant predictor variable (modeling behavior over time). Thus, the degree of interaction between elements of the immediate situation and characteristics of the person to influence momentary state are assessed. This data analytic approach can accommodate an unequal number of data points per subject. On the other hand, there are statistical issues under discussion, for example, accounting for non-perfect reliability of measurement and correlated error. The complexities of Multi-Level-Analysis necessitate that the assumptions guiding the procedure are clearly specified beforehand (see, Affleck, Zautra, Tennen & Armeli, 1999; Cnaan, Laird & Slasor, 1997; Goldstein, 1995; Jaccard & Wan, 1993; Raudenbush & Bryk, 2002; suggested guidelines Schwartz and Stone, 1998; Verbeke & Molenberghs, 1997). (www.ioe.ac.uk/MLwiN). A number of exemplary studies exist (Affleck, Zautra, Tennen & Armeli, 1999; Albert, 1999; Cnaan, Laird & Slasor, 1997; Cook & Lawless, 2002; Edwards, 2000; Kamarck, Schwartz, Janicki, Shiffman & Raynor, 2003; Schwartz & Stone, 1998; Wilhelm, 2001).

Structural modeling and modeling of linear and monotonic growth functions have also been applied to time series data (e.g., Collins & Sayer, 2001). Interestingly, latent class state-trait models that separate stable from variable individuals in longitudinal studies were developed for the case of categorical data (Eid & Langeheine, 2003; Langeheine & Eid, 2003). Models of latent state-trait theory do not assume that persons and situations are independent of one another; this implies that a separation of the Person-Situation interaction term and situational influences is not possible. However, such models separate sources of variance (person, situation, error) and allow tests of the role of situations in explaining stability versus variability of mood. Study designs in which different settings (situations) are each repeatedly realized are desirable to employ such latent class methods. However, the large number of subjects required to test such models may be prohibitive

Many authors show little concern about the scaling with respect to interval measurement, although psychological data are often assessed on categorical or ordinal instead of interval scales. In some statistical approaches there is an apparent contradiction between the sophisticated modeling and the poor scaling quality of the data used. Non-parametric methods are available for many objectives and often provide a reasonable alternative to parametric methods. Bortz, Lienert and Boehnke (2000) presented a wealth of such methods, for example, non-parametric time series analysis, testing of auto-correlation and cross-correlation, estimation of monotonic and non-monotonic trends, and testing effects (see also, Albert, 1999).

Simple scatter plots and other graphic representation can be extremely useful for outlier detection and visualization of trends and serial dependencies (based on successive differences), and moreover, for "fingerprinting" individual time series (Totterdell et al., 1994; Totterdell, Briner, Parkinson & Reynolds, 1996).

Data Screening

The adequate use of statistical models in testing hypothesis, whether by Non-Parametric Methods, MANOVA, Multi-Level-Analysis, or Structural Modeling, requires insight into the structure and specific features of the data set. The conditions to be revealed by stepwise inspection, include the distributions of measures and the relative portion of variance resulting from important sources, differences in intra-individual scatter, the aggregation of data, description of trends and essential trend components, evaluation of trends and trend-related spurious covariation, elimination of trend or trend components if conceptually justified, and, of course, issues in reliability, stability, and consistency.

Such issues in exploratory data analysis, the requirements for use of certain statistical models, and moreover, issues in sampling, segmentation and related aspects, including practical matters, were discussed in a number of reviews (Affleck et al., 1999; Fahrenberg et al., 2002; Larson & Delespaul, 1992; Nelson & Hayes, 1986; Reis, 2002; Suen & Ary, 1989; West & Hepworth, 1991).

2.7 Procedural Issues – toward the Delineation of Guidelines

In the initial stage, the computer-assisted data collection was primarily employed as a descriptive and exploratory method. Time and event sampling and innovative assessment strategies were then introduced. Basic principles of psychological test theory were adopted and further developed to fit the specific needs of this domain. The common notion of reliability and consistency, for example, was extended with respect to local reliability, consistency within-settings and between-settings (see below).

Based on empirical studies, matters of importance such as preference for computer diary or paper-and-pencil, reactivity, and compliance became better understood. Consequently, a number of important aspects to be covered in reporting ambulatory assessment using psychological, physiological and clinical data became obvious (Buse & Pawlik, 1996; Fahrenberg, 1996a; Fahrenberg et al., 2002; Huford & Shiffman, 2002; Stone & Shiffman, 2002; Wilhelm & Perrez, 2001).

A refined methodology of ambulatory psychological assessment has emerged. In the years to come some effort shall be needed to develop common Guidelines that establish principles of sound methodology and essential aspects of ethics specific to ambulatory assessment. In view of the diversity of ambulatory assessment designs and applications there is good reason to attempt at least some standardization and common rules of procedure to enable comparison between research groups and to make quality control possible. Such recommendations and guidelines were developed in other domains, for example, for psychological tests, and physiological and psychophysiological methods. Further examples are the Consensus Conferences in ambulatory monitoring of blood pressure, and the guideline for use of ambulatory recordings of the ECG or the home polysomnography.

A proposal for reporting guidelines in the context of employing electronic diaries was made by Stone and Shiffman (2002). They assume that guidelines will enable researchers to make informed decisions about their momentary study designs and will result in more complete and useful published reports (Table 2.2).

Some pertinent perspectives and principles could be added to this list, for example, with respect to both behavioral and physiological data. Multi-method assessment strategies will require further specification. Furthermore, ethical considerations, which may be specific to this domain, have to be attended to. Nevertheless, this proposal appears to be an appropriate starting point toward the establishment of *Ambulatory Assessment Guidelines*.

Table 2.2: A Proposal for Reporting Guidelines (Stone & Shiffman, 2002, p. 238)

Design Issue	Reporting Guidelines
Sampling	<ul style="list-style-type: none"> a. Rationale for sampling design b. Sampling density and schedule c. Implications for bias and validity
Momentary procedures	<ul style="list-style-type: none"> a. Descriptions of prompting and recording methods b. Description and definition of participant-initiated event entries c. Description of how non-responses are handled d. Whether response-delaying procedures were available e. Definition of an immediate and timely response
Data acquisition interface	<ul style="list-style-type: none"> a. Description of physical characteristics of diary or palmtop computer b. Description of mode of item presentation c. Discussion of important algorithm features d. Text of items and response options and how they were derived or modified
Compliance	<ul style="list-style-type: none"> a. Rationale for compliance decisions b. Presentation of systematic compliance rates (% of required assessment episodes completed) c. Demonstration that compliance was accurately and objectively assessed
Participant training and monitoring	<ul style="list-style-type: none"> a. Description of training procedures b. Use of run-in or training periods c. Procedures to enhance compliance
Data management procedures	<ul style="list-style-type: none"> a. Discuss data management decisions that affect data analysis b. Define missing data criteria and actions
Data analysis	<ul style="list-style-type: none"> a. Rationale for aggregated or disaggregated approach b. Clearly specified model used in analyses c. Details of procedures, such as autocorrelation approach, random effect levels

2.8 Origins and Developments of Computer-assisted Ambulatory Assessment

Before the advancement of "electronic diaries" other methods of registering psychological data in everyday life were well tried and tested. These methods include event recorders for timed registration of stimuli and responses, "beeper" studies using a programmable wristwatch to prompt the subject to respond to a questionnaire, self-ratings on diary cards, and electronic data logger.

In psychology, the first comprehensive investigation to employ microcomputers was reported by Pawlik and Buse (1982). This methodology developed rapidly and parallel to the paper-based Experience-Sampling Method which came out at that time (Larson & Csikszentmihalyi, 1983; Csikszentmihalyi & Larson, 1987; see also, Barrett & Barrett, 2001). It appears, that the first controlled field experiment to employ an electronic diary was published from the Swiss Federal Institute of Technology Zürich (Höfer & Bättig, 1994) on cardiovascular, behavioral, and subjective effects of caffeine versus decaffeinated coffee in everyday life.

Pawlik (1988, 2001) was primarily interested in differential psychology when he introduced the novel, computer-based methodology. The Behavioral Data Recorder, later known as the AMBU, was developed to overcome the problems associated with questionnaire-based research that used only retrospective person-situation data. Computer-assisted field psychometrics allowed for the study of consistency of psychological measures under everyday-life conditions and situational variation. Evidence

of reliability and of consistency across occasions and settings was presented. Larson and Csikszentmihalyi (1983) likewise stated that the Experience Sampling Method ESM obtained information about the private as well as the public aspects of individuals' lives, secured data about behavioral and intrapsychic aspects of daily activity, and obtained reports about people's experiences as they occur, thereby minimizing the effects of reliance on memory and reconstruction.

Recordings of movement behavior in daily life were made as early as 1895, and there were ECG recordings in 1961, and blood pressure recordings in 1967. In psychophysiology, self-reported mood states and heart rate changes were registered by means of a portable ECG-recorder, however, still without support of computers (Roth, Tinklenberg, Doyle, Horvath & Kopell, 1976) or long-term recordings of heart rate and physical activity in outpatients were made (Taylor et al., 1982). The medical instrumentation progressed from the analog (cassette) recorder for physiological measures to digital systems. The advances in microprocessor technology and storage capacity not only soon paved the way for multi-channel recordings, they enabled the signal input to be pre-processed and, in another innovative step, led to the real-time analysis of medically important changes such as the immediate detection of heart rate changes or ST-depression in the ECG. The Proceedings of the International Symposium on Ambulatory Monitoring, initiated in 1975 by Stott et al. (Stott, 1976, 1982), show a gradual transition from analogue to digital technology and the development of computer-assisted methodologies. Origins and developments of ambulatory monitoring and assessment were discussed in a number of reviews (Fahrenberg, 2001; Barrett & Barrett, 2001; and referring to electronic diaries in clinical trials, Koop & Mösges, 2002).

The advantages of computer-assisted self-reports have already been outlined while the innovative methodology developed (Pawlik & Buse, 1982; Perez & Reicherts, 1989; Heger, 1990b; Taylor, Fried & Kernard, 1990; Fahrenberg, Heger, Foerster & Müller, 1991; Stone & Shiffman, 1994; Ebner-Priemer, 2006).

Journals devoted to this subject: *Biotelemetry and Patient Monitoring* (1972–1982, then, *Acute Care* 1983–1989; *Journal of Ambulatory Monitoring* 1988–1995), *Biotelemetry* (1974–1977), *Blood Pressure Monitoring* (1996–), *IEEE Transactions on Biomedical Engineering* (1953–), *Journal of Medical Engineering & Technology* (1976–), *Medical & Biological Engineering & Computing* (1962–), and *Physiological Measurement* (1980–). Except for *Behavior Research Methods, Instruments & Computers* (1968–), there is still no journal dedicated to this methodology in psychology. Journal with titles indicating "Assessment" very rarely contain articles on ambulatory monitoring and assessment.

Publication Rate in Medicine and Psychology

The ambulatory monitoring of BP and the ECG are now indispensable routine methods in medicine. The ever more widespread application of the new methodologies can be attributed to their practical usefulness as evidenced by the increased validity of diagnosis and in the external validity of therapy outcome evaluation. The increase in number of publications reflects the acceptance of computer-assisted methods in medicine.

Table 2.3: Ambulatory Monitoring Entries in MEDLINE Databases

Terms	Databases Total	Years 2000 –2004
Electronic Diary (Key word, Key concept)	48	32
Monitoring, Ambulatory (1995 –...)	1.382	
Monitoring, Physiologic	2.727	
Total	4.452	2.318
Ambulatory Monitoring (BP or ECG)	3.715	1.866
Actometer and	347	197
Accelerometry	20	15

In contrast, computer-assisted monitoring and assessment still appear to have had little impact in psychophysiology and psychology. Although electronic diaries may clearly be considered the method of choice for a large number of research questions, apparently, the majority of diary studies and clinical trials still preferred paper-and-pencil methods. PsycINFO and German PSYNDEX still have a comparatively small number of entries relating to computer-assisted ambulatory assessment, diaries, and monitoring, estimated at less than 100 references for the years 2000-2004 (Figure 2.1). Both Databases lack an adequate heading so that a number of keywords have to be searched for, thus hampering access to and retrieval of literature.

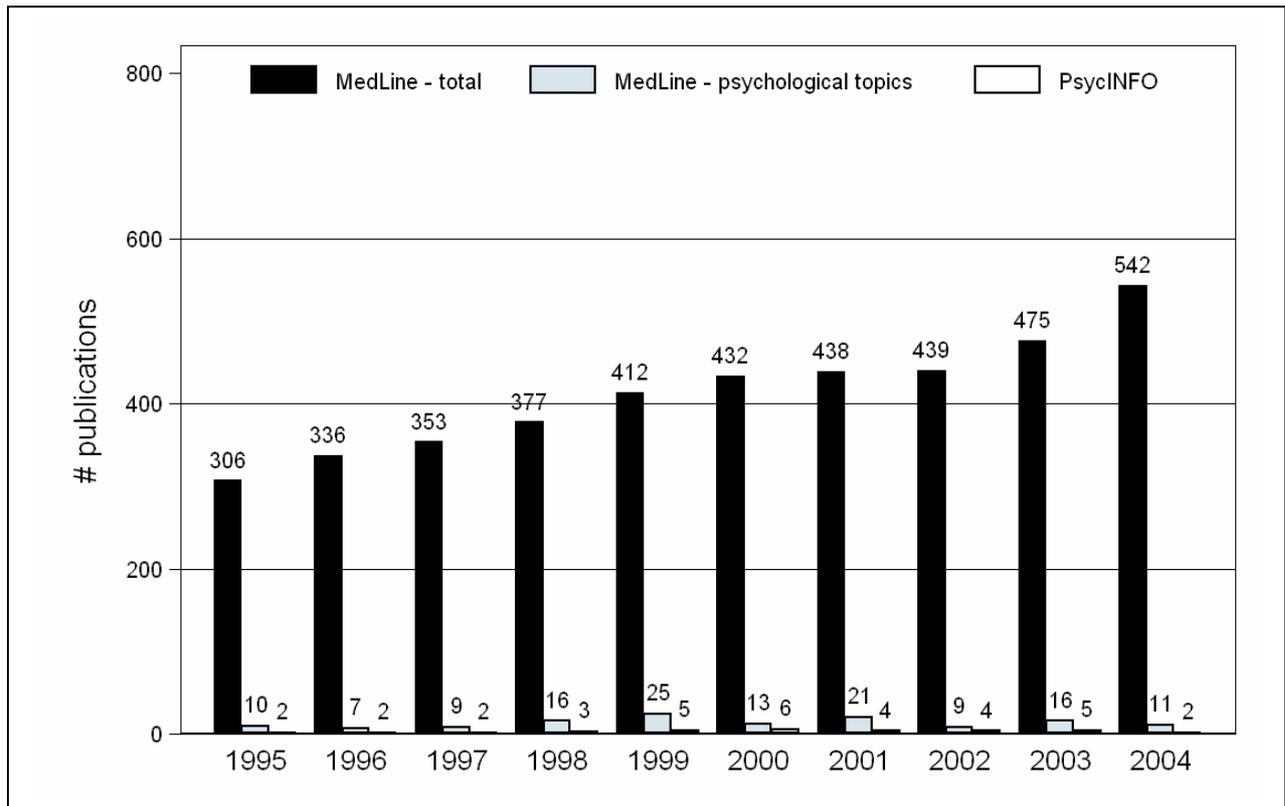


Figure 2.1: Ambulatory Monitoring Entries in Medline and PsycINFO Databases (adapted from Kufeld & Kubiak, personal note, 2005). Note: The search was made for "ambulatory monitoring" as a keyword: (1) Medline total number of references, (2) Medline psychological topics, and (3) PsycINFO, restricted to journal articles.

The progress in ambulatory monitoring and assessment in psychology and psychophysiology has been documented in the proceedings of two conferences which were supported by the Deutsche Forschungsgemeinschaft. The two volumes containing altogether 59 chapters (24 and 35 chapters, respectively) contributed by international authors achieved a fairly good coverage of research in ambulatory assessment, basic and applied, both in connection with the workplace and with patients (ed. by Fahrenberg & Myrtek, 1996, 2001). A textbook (in German language) provided a general introduction to ambulatory assessment in psychology and psychophysiology, and an overview on research and application. It includes a discussion of essential issues in methodology, as well as examples easily adaptable for teaching purposes in university classes (Fahrenberg, Leonhart & Foerster, 2002). An updated review for the years 2000 to 2005 would now appear to be necessary. A balanced representation is intended, regarding essential contributions from Europe and the US.

At the same time, a Bibliography in Ambulatory Assessment including more than 1.800 references is available from this Site.

3 Psychological Assessment

3.1 Acquisition of Psychological Data by Hand-held PC

Computer-assisted self-report methods were introduced in psychology about 25 years ago. In many studies, hand-held (palm-top) PC replaced the conventional paper-and-pencil methods. To date, the new methods have been predominantly applied as an "electronic diary" (pain diary, job stress diary) for recording self-reports on mood and other aspects of subjective state, including physical complaints and symptoms.

The availability of portable microcomputers in the seventies paved the way for the first attempts to implement such devices for data acquisition in psychology. The first large scale study/studies using programmable microcomputers have been conducted since 1976 by Pawlik and Buse (1982) at the Psychology Department in Hamburg. They investigated the variability of mood and activities between subjects, settings, and days, in order to establish a valid basis for the discussion of the trait-situationism-interactionism issue in personality research. Later-on, this group included computerized tests of cognitive performance and certain physiological parameters (see below).

From the very beginning, Pawlik (1988) and Larson & Csikszentmihalyi, (1983) pointed out that the new methodologies provide a means with which to obtain reports about people's experiences as they occur. In the following, a number of developments were made (Myrtek et al., 1988; Perrez & Reicherts, 1989; Hedges, Krantz, Contrada & Rozanski, 1990; Heger, 1990b; Taylor, Fried & Kernardy, 1990; Fahrenberg, Heger, Foerster & Müller, 1991; Stone & Shiffman, 1994).

A number of previous reviews have given a picture of the development of this methodology, usually in the context of diary methods or methods of clinical trials (Baumann, Thiele & Laireiter, 2003; Fahrenberg & Myrtek, 2001a; Fahrenberg et al., 2002; Perrez, 1994; Wilhelm & Perrez, 2001). For no apparent reason, some reviews have limited themselves to research in the US (for example, Barrett & Barrett, 2001; Bolger, Davis & Rafaeli, 2003; Shiffman, 1999; Hufford et al., 2001; Raymond & Ross, 2000), while others have provided a more representative account of research.

The electronic diary study technology has been able to adopt the essential principles and suggestions from the conventional paper-and-pencil methods. These principles and suggestions are also applicable to computer-assisted methodology and include general issues in measuring change, psychometric aspects and statistical concepts or basic psychological requirements such as commitment and willingness to disclose personal data. Issues like method reactivity, and compliance are features common to both approaches. In addition, recent reviews of diary methods listed a typology of research questions, schedules of data collection (sampling) and data analysis (Baumann, Thiele & Laireiter, 2003; Bolger, Davis & Rafaeli, 2003; Fahrenberg et al., 2002; Shiffman, 2000; Stone & Shiffman, 1994; Thiele, Laireiter & Baumann, 2002; see also, Wilz & Brähler, 1997).

A typical Monitoring Protocol

A rather typical protocol may contain five to seven prompts per day. Each protocol includes about 5 to 20 items regarding, for example, context (setting, activity, social context) and items or adjective scales to assess momentary mood, symptoms, experiences, and finally, control items. The morning and the evening protocol may include additional and retrospective questions. Each protocol requires about one to two minutes to complete. The prompts are either activated at random or scheduled according to event sampling or time sampling procedures. Fixed schedules may have random components and, possibly, the start and end time are set for each subject to meet the individual's course of the day. A typical study covers at least one day, often a couple of days or a week, and rarely longer periods of time, and depending on the study incorporates free periods within a design. One report per day may be sufficient in such cases, instead of multiple reports.

Advantages

The application of a programmable pocket PC in ambulatory assessment has many advantages:

- alarm functions for prompting the subject at predefined intervals and a built-in reminder signal;
- programming allows to put the system to sleep ("snoozing") for variable length of time;
- both the start and end times can be set for each participant at the beginning of the diary period;

- accurate timing of input, delay of input (response latency), and duration of input;
- flexible layout of questions and response categories, customized graphical and intuitive data-entry screens, visual analog scales, anatomical body diagrams to mark localization of symptoms, even handwritten signatures and comments; open-ended questions requiring the answer to be typed on the keyboard or an input to the audio channel;
- branching of questions and tailor-made sequential or hierarchical strategies;
- concealment of previously recorded responses from the subject, or allowing the subject to review and change their answers;
- event-contingent and time-contingent responses, or mixed schedules, within the same study;
- algorithms for computer-assisted adaptive and learning processes;
- tracking compliance objectively;
- convenience and ease of edit checks, reliable transfer of data to a stationary PC, and directly importing into conventional packages for statistical analysis;
- taking advantage of software developments to conduct interactive monitoring, for example, prompting the participant to answer certain questions, contingent to automatically detected changes in physiological measures.

Modern electronic diaries, available with wireless functionality, will encourage (promote) new assessment strategies (see Section 2):

- wireless real-time electronic data capture;
- wireless two-way communication that enables messaging to the patient via mobile phone and immediate access to data as it is collected;
- giving feedback regarding compliance;
- enabling interventions in clinical settings and applied environments;
- web-based utilities, including access to expertise, data retrieval, audiovisual communication.

The hand-held computer is connected to a mobile phone so that all diary data, patient compliance data, and technical performance (e.g., battery function) can be monitored through a secured Web site (Nyholm, Kowalski, & Aquilonius, 2004). New devices support two-way messages and allow the subjects to sign each report and handwrite short on-screen comments. The investigator or study coordinator can respond to the incoming data, start transmission of diary data to the network computer or send outgoing message to be read on the subject's screen. More features and IT-developments encourage new applications.

Validity Issues

There is convergent evidence from experimental studies on recall and hindsight bias, from autobiographical research, and from computer-assisted diary methods, to suggest that the validity of retrospective reporting is highly questionable, that it may be distorted and inaccurate. It is also well known that basic discrepancies exist between objectively measured behavior and subjective behavior reports.

The evidence is that retrospective self-reports only partially reflect the actual experience and behavior process and that they represent cognitive re-constructions, which are shaped by recall-bias, negative retrospection effect, response tendencies, cognitive heuristics, attributions and social stereotypes, and naïve concepts from folk psychology. Of course, reporting in the first-person perspective is not verifiable from a third-person perspective, with the exception of reports on manifest behavior. In responding to a questionnaire each subject is usually required to form an aggregate impression across situations and periods of time. The process of how such experiences are weighted and aggregated from memory remains unknown.

In contrast, electronic diaries permit certain sources of variance to be detected, controlled or taken into account by the use of computer-assisted (momentary) assessment. Momentary reports provide a way of:

- representing the actual process of experience and behavior;
- incorporating in each protocol an address, that is, particulars of the actual setting within the day-to-day environments;
- allowing a much higher density of sampling due to the ease and technical efficiency in electronic data collection on multiple occasions in time and in behavior settings;
- ensuring all entries are time stamped;
- attaining a much higher compliance, and reducing the recall bias.

Accordingly, self-reports are anchored to behavior settings within the natural environment and in real-time. It is therefore reasonable to make the claim that momentary self-reports have a higher validity and reliability as compared to context-free and retrospective questionnaire data.

In summary, ecological validity and a higher technical reliability of computer-assisted recordings can be generally assumed compared to paper-and-pencil questionnaires and diaries. Essentially, Ambulatory Assessment provides context-related, multi-occasion, time-stamped, direct monitoring and close assessment of daily activities, subjective state, pain and physical symptoms, adherence to drugs (medication), or of certain behavior problems.

Limitations

The versatility and wide acceptance of computer-assisted data acquisition is unmistakable although there are limitations and obvious restrictions. All participants of such studies will need sufficient practical training in order to avoid, at least, malfunctions and missing data. In spite of the obvious increase in computer-literacy within the general population, there are sub-populations that are less familiar with these devices or may experience problems. Although compliance may be generally expected to be higher in studies employing computer-diaries than in those using paper-diaries, the initial enthusiasm associated with the participant's use of a novel method may not last throughout the study. The frequent beeping of the electronic companion and, on occasion, the inconvenient timing of the beeper may contribute to this after a couple of hours or days. A careful balancing of frequency and duration of self-reports is necessary.

Practical problems may arise with batteries running out. The PC needs to be actively on-line for the whole period of monitoring, although mostly at a reduced level, with intermittent phases of alarm and data input. Indeed, an essential consideration in the development of schedules of data-acquisition was the conservation of battery power. Battery life varies greatly and is hard to predict. Present-day hand-held devices and PDAs have lower power-consumption so that recording time is less restricted than previously.

There are further reasons for data loss that are specifically associated with the computer-assisted methods. Participants may use the hand-held PC for their own purposes rather than adhering to its intended use, or may attempt to break the code and intentionally alter program features. Computer-assisted methods generally improve the subject's compliance. Nevertheless, missing data may occur frequently when the beeper signal is inadvertently or intentionally overheard. Compliance, acceptance, and aspects of reactivity and related issues as well as design features were examined in a number of method studies (see Section 2).

Computer-assisted methods of data-collection appear to be efficient, but the costs need to be considered too: costs and resources required to train participants, cost of the hand-held PC, essential replacement of damaged devices, as well as costs for the introduction of a new generation of hand-held PC (PDA) every couple of years. Costs arise also for software, that is, for development or acquisition of suitable software and acquisition of licenses although some open-source (freeware) has been made available. The major obstacle remains that the software and certain features of the operating system are fairly specific to a certain device and may not be compatible with the subsequent model. In this case the program has to be transported and adapted, a process that may involve considerable resource investment in programming.

Computer-assisted Data Collection: Descriptors and the Databases

Although computer-assisted methods in data collection (psychological assessment, self-monitoring) are now quite common, the databases contain a diversity of terms (key words) with which to refer to such methods. A standard terminology – rather like "Ambulatory Monitoring" for physiological recordings in daily life – has not yet evolved.

The diversity of terms is striking: Computer-assisted diary methods, electronic diary (e-diary), electronic data capture, computer-assisted self-report, pocket (hand-held, palm-top) computer, personal digital assistant (PDA), experience sampling method (ESM), ecological momentary assessment (EMA), computerized diary, electronic data capture (EDC), electronic patient diaries (EPD), electronic patient reporting, electronic patient reported outcome (e-Pro), portable mood mapping, mobile computer-assisted data collection, etc. This multiplicity of terms reflects to some extent the authors' personal interest in highlighting his or her own contribution or can be seen as the result of commercial affiliations or claims. Patent infringement lawsuits were recently filed in the US against competitors. The objective hereby is easy to deduce from the Internet-homepages of companies like PHT, CRF Inc., invivodata Inc. and etrials Worldwide. The invalidity of such claims or patents is quite obvious, particularly for those who are familiar with the origins and developments of these technologies and the fact that the basic program features remain much alike. Interestingly, the pioneer studies in this domain and essential contributions from European authors were not referred to in this context.

Hardware and Software

Initially, some researchers developed their own hardware solutions, tailor-made for certain tasks. This is an exception nowadays. The market now offers comparatively cheap devices and the majority of investigators seem to favor the generally available hand-held PC although some features may considerably restrict the range of application.

Computer-assisted self-reports require a hand-held PC with certain features: a large display, easy handling of basic controls, clock, beeper with volume control, sufficient capacity of storage, low power consumption, and a low weight. For many applications it may suffice to use certain buttons and to record only numbers and "yes" or "no" responses. In this case, a smaller hand-held PC, for example, the Palm™ series, may be preferable, although small keys or a stylus may present a problem for some subjects or patients. The choice of input device, touchscreen or keyboard, will depend from the study aims. For specific applications, a comparatively large alphanumeric keyboard (complete QWERTY) is also preferable in order to obtain verbal responses. The latter may involve, for example, recording comments about specific events, or reporting more precisely the occurrence of physical and psychological symptoms, which in either case hardly fit pre-defined categories. Eventually, such recordings may be replaced by audio recordings, provided that the device has sufficient storage capacity.

Following the progress made in pocket-sized computers, software to facilitate the use of hand-held PCs in field studies has been developed in many institutions, more or less geared to the needs of certain projects. More flexible software systems suited to the requirements of a variety of applications are still an exception. The computing platforms in current use, especially the PalmOS with the Palm Pilot Series and the Windows CE operating system have different capabilities which may pose specific limitations. Platform-independent software is desirable, yet difficult to establish.

There has been a rapid succession of new developments that are incompatible in essential functions. Bearing in mind that this will most likely continue to be the case, researchers will have to take the arrival of new devices into account, meaning that they may have to start afresh several times in their on-going research; wireless message pads and new IT-applications in particular will continue to present new challenges.

Recording Systems

A detailed review of devices and software is not the intention here. However, a few systems have to be mentioned because they were more widely used in the past. Some of the software solutions were multi-purpose software and may therefore be of greater general interest than the specialized pain or symptom diaries.

AMBU

The computer-assisted Testing-System for Ambulatory Monitoring (AMBU) began development in 1976 and originally used tailor-made microcomputers (e.g., BIDATA, Zak GmbH). The freely programmable behavior recorder employed check-lists of many items for the description of settings and situations, location, social context, momentary activities, mood, etc. A time-sampling study of 135 students during leisure time indicated that the results had ecological validity and high psychometric reliability (on an item basis). The system was further developed to include two physiological measures

and 11 short tests for in-field performance testing. The Test Battery Measuring Mental Activation contains, for example, Alertness Test, Continuous Performance, Go/NoGo-Paradigm, Mental Rotation, Grammatical Reasoning, Tracking Task (Buse and Pawlik, 1982, 1996, 2001; Pawlik und Buse, 1999, 2002). Interestingly, the pioneering work by Pawlik and co-workers in Hamburg was not generally noted by American reviewers, with the notable exception of Csikszentmihalyi himself (Hektner & Csikszentmihalyi, 2002).

ESM and ESP

The Experience Sampling Method (ESM) was proposed as a means to capture information about private and public aspects of individuals' lives, intrapsychic, and behavioral aspects of daily activity. ESM is a research procedure that involves asking individuals to provide systematic self-reports at random occasions during a normal week. It was originally a paper-and-pencil method which was used in conjunction with a clock, with pager or with a pre-programmed wrist watch to allow for time sampling (Larson & Csikszentmihalyi, 1983; Csikszentmihalyi & Larson, 1987; Hektner & Csikszentmihalyi, 2002; de Vries, 1992; Brandstätter, 2001). A computer-based version is available: computerized ESM or palmtop Experience Sampling Program (ESP) (Barrett, & Barrett, 2001). The ESM and its modified versions were used in many studies.

COMES/COMRES and FASEM-C

The Computer Assisted Recording System was introduced in 1987 to assess self-reported coping behavior with stress in daily life (HP 360 LX). This approach was subsequently expanded to assess social regulation of stress and emotions. The method allows for simultaneous assessment of causal attribution, social coping, and empathy with the partner in daily family life (Perkonigg, Baumann, Reicherts & Perrez, 1993; Perrez & Reicherts, 1989; Perrez, Schoebi, & Wilhelm, 2000; Perrez, Wilhelm, Schoebi & Horner, 2001; Wilhelm, 2004).

MONITOR

This highly flexible software system for ambulatory assessment has been in development since 1987 and assesses self-reports on settings, location, activities, social contact, posture and movement (self-ratings), mood and strain, physical symptoms, comments on certain events, and two performance tests, a Go/NoGo-paradigm and a working memory test. The Casio PB 1000 and Psion Series 3 supported item-response mode and free text input via keyboard. A special version of MONITOR for blood pressure research served to guide patients through a sequence of recordings and controls to secure reliable data collection and also included the recording of individual evaluations or comments on a walkman audio recorder (Heger, 1990b; Fahrenberg et al., 1991; Brüchner, 1998; Fahrenberg, Hüttner & Leonhart, 2001; Hüttner, 2002).

EMA

Ecological Momentary Assessment is a computerized refinement of EMS in which randomly timed assessments are combined with event-contingent assessments, and it can be adapted for various research efforts (cf. Hufford et al., 2001; Shiffman, 2000; Stone & Shiffman, 1994). This electronic diary software for Palm was primarily used to assess patient experience, especially as a pain diary and as means to obtaining reliable data on drug adherence in everyday life. A number of feasibility studies and method studies were also published regarding this software system.

SONET-CT-96

A computer-assisted interaction diary which assesses social network and social strain to facilitate socio-diagnosis has been in development since 1991 for the Atari Portfolio and HP 1000 palmtop (Baumann, Thiele, Laireiter & Krebs, 1996; Baumann, Feichtinger & Thiele, 2001).

DABS

The Diary of Ambulatory States DABS was another method to recording self-reports relating to psychosocial influences on ambulatory cardiovascular activity (Kamarck et al., 1998).

DIALOG PAD

A miniaturized dialog pad including an easy to apply instruction language for item lists, complex questionnaires, and performance tests was developed for Varioport (or stand-alone). Because of its low power consumption it can run for up to four weeks (Mutz & Becker, 2006; Stephan, Mutz, Feist & Weiss, 2001b).

Medi-Pad, ClinDiary et al.

An increasing number of application software and of specific hardware/software packages exists, tailor-made to meet the requirements for application in medicine both for doctor and patient (cf. Koop & Mösges, 2002; Torchio, Molino, Sestero, Seidenari & Molino, 2003). Patient reported outcome and pain diaries are increasingly employed in patient monitoring and clinical trials (Shiffman, Hufford & Paty, 2001).

OBSERVER

A software system for collection and analysis of observational data was introduced 1991 to simplify the recording of behavior observations in field studies in animal and human ethology (Noldus, 1991; Behavior Observation System, Noldus Information Technology, AG Wageningen, NL). A selection of platforms is used and Noldus Information Technology provides advanced video analysis systems, videotaped training courses, program updates. Conferences on Measuring Behavior assist in application of the OBSERVER

Open-source Freeware

Internet addresses indicate that in a few instances freely distributed software (freeware) is available under PalmOS or Windows CE (EMA/EMS, Barrett, & Barrett, 2001; Entryware System 3.0., Gravlee, 2002).

Behavior Rating and Measurement

The hand-held PC has so far been predominantly used in psychology for recording self-reports on mood and other aspects of subjective state, including physical complaints and symptoms. Today's pocket-PCs also allow for programming of performance tests, whereby reaction time tasks, memory tests, etc., are displayed on the screen. There are other kinds of data obtainable in field studies: objective features of a behavior setting, ratings of environmental aspects, behavior observations, and behavior and performance measures. The contents of a computer-assisted protocol may potentially include, for example, self-measurements of various kinds (for example, tidal air flow in asthma patients, glucose level in diabetes).

Comparatively little effort in direct measurement of behavior is evident as compared to physiological measurement. The exception is accelerometry (actigraphy) of posture and motion (Section 4.4). The instrumentation of ambulatory assessment may further include voice recording by means of micro-cassette dictating systems or a voice recording via throat microphone to obtain data for the analysis of speech pattern in everyday social situations (Krüger & Vollrath, 1996).

The Test Battery Measuring Mental Activation (AMBU) may signal the beginning of the standardization in this domain, possibly based on a core set of normative data. Reference data of this kind could be invaluable for many studies. A set of psychometrically proven tests and a selection of items (adjectives) and item formats to assess activity level, basic mood dimensions, and workload (job stress) are highly desirable.

3.2 Methodology

Designing User Interfaces

The design for the application of an electronic diary for collecting data from elderly patients with Parkinson's disease is likely to be different from that for children (Palmlblad & Tiplady, 2004). Patients must be capable after a short period of training of using the system and be comfortable with it. Designing user interfaces is an essential issue in improving acceptance and reliability of computer-assisted methods. Such aspects include screen layout and controls, screen displays, text displays, symbols and font size, color and visual contrast,

scroll bars and buttons. Navigation choices include numeric entries, keypads, visual analogue scales, multiple selections, and if, for example, unreasonable values were to be entered, these choices often include logic checks and feedback. On the other hand, battery power of the devices does not always suffice for an enriched screen layout in longer studies.

The reliability of a new visual analog scale (VAS) display method for a 19-item VAS-based mood questionnaire, the VMQ, administered via hand-held computer (HHC) was examined. The effect of the smaller screen size on accuracy and precision of VAS completion was investigated in 28 subjects using 4- and 10-cm paper-based VASs, and the influence of digital vs. paper medium was also tested in 39 subjects, who completed the same task, using 10-cm paper and 4-cm HHC-based VASs. Findings indicated that reducing VAS size produced no significant loss of response precision or accuracy in subject response. HHC-based items demonstrated high 10-minute test-retest reliability (Kreindler, Levitt, Woolridge & Lumsden, 2003). User comfort level and preferences of handheld computer-assisted methods over paper-and-pencil were examined in obstetric patients. Previous computer experience and lower education level predicted greater hand-held computer preference (Bernhardt et al., 2001).

Hand-held PC vs. Paper-and-Pencil Methods

The acceptance of electronic versus paper diary methods and the individual preferences for each method were examined in a number of studies in healthy subjects and patients (Bernhardt et al., 2001; Hank & Schwenkmezger, 1996; Hank, Schwenkmezger & Schumann, 2001; Hinkel & Scholz, 2001; Jamison, 2002; Peters et al., 2000; Rose et al, 2002; Stone, Shiffman, Schwartz, Broderick & Hufford, 2002, 2003; Van Den Kerkhof, Goldstein, Blaine & Rimmer, 2005). Ratings of acceptability were obtained in a post-monitoring questionnaire or interview. Electronic diaries for monitoring chronic pain were applied in 36 patients with low back pain patients who preferred them to paper diaries and showed much higher rates of compliance and satisfaction over a 1-year trial (Jamison et al., 2001). In conclusion: Several articles reported findings that suggest a preference for electronic diaries or that they were accepted as much as paper diaries. There was no evidence that electronic diaries were *less* acceptable, as might have been expected by some psychologists. Generally, a high agreement (concordance) of electronic and paper diaries was found. However, such comparisons imply a number of issues. The findings may be confounded by method-dependent differences in compliance, frequency of missing data, reliability of data checks and data transfer (cf. Hank & Schwenkmezger, 1996).

Compliance

Compliance is an important issue in the methodology of ambulatory assessment since a higher compliance is claimed for electronic diaries as compared to conventional paper-and-pencil methods. Many investigators reported that their study participants or patients were remarkably compliant, although it is evident that a perfect compliance may be an exception because the signal can be overheard or is particularly inconvenient at a certain time so that response was not possible. The participants were aware of the fact that the punctuality of their entries was being recorded (and therefore open to inspection by the investigator) and this obviously had a motivation effect.

Compliance with electronic diaries and paper diaries as well as compliance enhancing features were examined in various fields. Method studies evaluated the average compliance in electronic and paper-diaries and used designs with randomized groups or cross over designs. In a recent study participants were chronic pain patients. They were assigned to use either an electronic diary or a paper-and-pencil diary which was instrumented to track diary use by recording each time the paper diary binder opened. Three pain entries per day for a period of 21 consecutive days were scheduled. Electronic actual compliance was 94 %. With diary cards, overall compliance was 90%. However actual compliance was only 11 %, indicating a high level of faked compliance (Stone et al., 2002). *Signaling does not adequately improve diary compliance (Broderick, Schwartz, Shiffman, Hufford & Stone, 2003).*

A randomized trial of electronic versus paper diaries in children was used to examine the impact on compliance, accuracy, and acceptability ratings in sixty children. Findings showed that the e-diary could be feasibly used with children with recurrent pain and suggested significantly greater compliance and accuracy in diary recording compared to traditional paper diaries (Palermo, Valenzuela & Stork, 2004). A comparison of electronic diary reports and questionnaire method directed at drinking and associated coping behaviors was

also reported (Todd et al., 2005), and in connection with blood glucose measurement (Leopold & Schandry, 1996).

The measurement of momentary cortisol levels in saliva requires the participants to fill the salivette at a predetermined time of day. The participant's compliance is an essential aspect of this method. The first method study was probably conducted in 44 patients and 29 controls employing the MEMS-Track-Cap (Apex Ltd.) to assess compliance. The discrepancy between reported time for early morning filling of salivettes and recorded time was on average 27.6 minutes. Only 38 % of the subjects reported time lie within a 5-min range of the recorded time, and 59 % deviated by at least 15 minutes. Thus, true compliance was lower than generally expected. Apparently, the reported wake-up time was unreliable. It is concluded that early morning cortisol studies should use MEMS technique in conjunction with an actometer to claim reliable results (Averbuch, Weintraub, & Pollock, 1988; Wilmers, Schwerdtfeger, Wark, Berger & Bohus, 1995).

Effects of non-compliance on cortisol results were examined in a recent study. Twenty female twin pairs and nineteen of their sisters were instructed to take saliva samples when signaled at ten unpredictable moments on each of five consecutive days. Subjects recorded collection times, unaware that compliance with the sampling protocol was being investigated by means of electronic monitoring devices. Only samples taken up to 15 min after the signal according to self-report were defined as adherent to the protocol. Samples taken up to 10 min after the self-reported collection time according to the monitor were defined as accurate. Self-reported adherence to the sampling protocol was 96.4%, verified compliance was lower, with 81% of all saliva samples accurately timed. Contrary to previous reports, inclusion of non-compliant samples in the analysis did not distort the cortisol diurnal profile. *Electronic monitoring of salivary cortisol sampling compliance in daily life* (Jacobs et al., 2005).

Another study examined how accurately subjects adhered to the instructions to collect six saliva samples throughout 1 day. Objective compliance was measured using an electronic monitoring device given to 23 subjects with and 24 subjects without knowledge of the nature of the device. Thirty-one subjects (74%) were found to comply with the sampling instructions, and 11 (26%) failed at least once to obtain the saliva sample at the correct time of day. This finding can be regarded as partially invalidating the cortisol results and as masking potential differences between subject groups of interest. In view of this, the use of electronic monitoring devices is therefore recommended. *Compliance with saliva sampling protocols: Electronic monitoring reveals invalid cortisol daytime profiles in noncompliant subjects* (Kudielka, Broderick & Kirschbaum, 2003). Inconsistent findings regarding the cortisol awakening response in depression may be due to such differences in method compliance, and, also, to psychosocial factors. *Blunted Cortisol response to awakening in mild to moderate depression: Regulatory influences of sleep patterns and social contacts* (Stetler & Miller, 2005).

A recent meta-analysis addressed the concordance of self-report measures of medication with non-self-report measures. In only 17 percent of comparisons self-measures were highly concordant with objective electronic monitors (Garber, Nau, Erickson, Aikens & Lawrence, 2004).

Reactivity

Reactive measures (measurements that change the phenomenon assessed) cause problems in interpreting any changes observed. Reactivity to ambulatory monitoring and assessment is a matter of continuing debate. Method studies in real life, however, impose particular problems. Independent and valid measures of the variable under study should be available and adequately controlled designs are required.

Motivational reactivity, which is one aspect of method reactivity (see Section 2.2), can be studied based on measures of compliance or by evaluation of the participant's comments on the monitoring. Does the frequency of missing data show a significant trend over the duration of the study? Does the post-monitoring interview or questionnaire reveal an increase in self-awareness, boredom and fatigue in self-recording, avoidance of or unusual preference for certain settings, etc.? Such exploratory analyses were reported already, for example, by K ppler (1994).

The reasons for missing data in patient's reports were investigated by comparing self-report and electronic diary method (Aaron, Mancl, Turner, Sawchuk & Klein, 2004). Sixty-two pain patients rated pain intensity, pain-related activity interference, and perceived stress three times a day for 8 weeks on palmtop computers.

The average electronic diary completion rate was 91%. The correspondence between self-report and electronic data was high for the overall number of missed entries. The most common self-reported reasons for missing interviews were failure to hear the computer alarm (49 %) and inconvenient time (21 %). Method reactivity may depend on sampling density. This hypotheses was examined in 91 patients with chronic pain randomized into four groups with differing levels of momentary monitoring over 2 weeks. Little support was found for reactivity defined as temporal shifts in pain over the study or as changes in recalled weekly pain due to momentary monitoring. Compliance with the electronic diary protocol was 94% or better, and was not related to sampling density (Stone et al., 2003).

Behavioral reactivity is another aspect of method reactivity. The detection of changes in behavior patterns actually requires independent observations. Obvious differences, for example, between findings from first and second half of an investigation, may be due to other factors. Likewise, the relative stability of measures may not demonstrate that behavioral reactivity was not present.

Peters et al. (2000) investigated reactivity and compliance in pain patient's reporting. Pain, disability and psychological adaptation were assessed four times a day for 4 weeks by electronic diary in 80 patients reporting various duration of unexplained pain. The over-all pain report was stable across the 4-week period, and the authors concluded that there was no evidence of instrument reactivity. Pre- and post-monitoring measures of drinking in undergraduate problem drinkers showed that a 2-week monitoring protocol had no effect on reported drinking or readiness to change drinking habits (Hufford, Shields, Shiffman, Paty & Balabanis, 2002). Another study examined the relationships between the patient's post-monitoring commentaries and actual self-reporting in 71 patients with chronic temporomandibular disorder pain. Electronic diaries were completed 3 times daily for approximately 2 weeks and showed statistically significant changes. In retrospection, 73 % of patients reported that the assessment affected their experience of pain, whereas 51%, 45%, and 39% thought that it affected their daily activities, mood, and beliefs, respectively. Subjective reactivity was generally not significantly related to changes in actual diary data (Aaron, Turner, Mancl, Brister & Sawchuk, 2005).

A noteworthy example for behavioral reactivity to being monitored was reported by Costa, Copley, Griffith and Steptoe (1999; see Section 4.2). The level of physical activity was measured at the day of the BP monitoring and alone for a separate day and evening. Physical activity was significantly reduced during the monitoring day.

Of course, there are important differences with respect to obtaining psychological or physiological data. Electronic diaries require repeated attention and accurate responding. On the other hand, 24-hr recordings of the ECG or of physical activity is a passive condition in which there is probably little awareness of such physiological recordings except for having the device attached to the body.

The conclusion is that the effects of motivational and behavioral reactivity in ambulatory assessment (self-monitoring) should not be over-estimated. However, the variables which eventually influence the magnitude and direction of this reactive behavior change are not easily examined in real life. Further research is required, relating, for example, reactivity aspects, degrees self-reported awareness, and frequency of missing data with the participants' psychological characteristics.

3.3 Applications

Computerized everyday assessments of subjective state and behavior are rare in differential psychology and personality research. Besides the research program by Pawlik and Buse (see, Section 3.1) there are to date only a few investigations based on ambulatory assessment strategies. The applications in psychology mostly deal with the management of pain (pain diaries), with job stress, mood and quality of life. However, computer-assisted data collection appears to be the method of choice in many areas of research and applied assessment.

Mood, Daily Life, Quality of Life, Work Stress, and Coping

Anxiety, affect, and activity in teenagers were monitored in daily life with electronic diaries. The everyday experiences of a community sample of 159 adolescents differing in anxiety level (according to standard trait questionnaires) were assessed every 30 minutes for two 4-day intervals. High-anxiety teenagers expressed higher momentary levels not only of anxiety and stress but also of anger, sadness, and fatigue, along with lower levels of happiness and well-being. They reported stronger eating and smoking urges and more tobacco use, fewer telephone and other conversations and less recreational activities relative to achievement-oriented pursuits. Despite a tendency to spend less time with peers, high-anxiety teenagers were more likely to show reduced anxiety when in the company of friends. The reported differences in affective, behavioral, and contextual domains were even more pronounced when definition of the subgroups was based on diary reports rather than on questionnaires. On the whole, there were few gender differences (Henker, Whalen, Jamner & Delfino, 2002). As part of a health enrichment study in 8 to 10 year old girls, besides questionnaires on optimism, pessimism, self-concept, and sedentary preferences, the physical activity was monitored for three days with an actometer. *Psychometric properties of optimism and pessimism: Results from the Girl's Health Enrichment Multisite Studies (Taylor et al., 2004).*

A longitudinal study of stress and health offered the opportunity to investigate how adolescents who lived at a distance from the disaster site reacted to the events of September 11, 2001. Electronic diary ratings of moods before and after the attacks of September 11 were compared and, in addition, a questionnaire was given 2 - 5 months after the events in 171 adolescents. When adolescents were asked directly about the event (focused impact) many of them reported changes in everyday activities and signs of distress and negative affect, but no significant changes were detected in their ongoing, momentary mood reports before and after September 11 (ambient impact). It was concluded that refined assessments are needed to evaluate the degree to which self-reported traumatic symptoms reflect significant clinical distress versus an attentional focus generated by the question-asking project. *Adolescents react to the events of September 11, 2001: Focused versus ambient impact (Whalen, Henker, King, Jamner & Levine, 2004).*

The electronic diary methodology can be used to obtain self-reports and concurrent self-report from partners or other family members. How is my partner feeling in different daily-life settings? The accuracy of spouses' judgments about their partners' feelings at work and at home was specifically investigated (Wilhelm, 2004; Wilhelm & Perrez, 2004). Another aspect is the frequency of emotions and emotional states in everyday life as reported by a normal population (Myrtek, 2004; Wilhelm, Schoebi & Perrez, 2004).

A noteworthy pioneering study investigated coping behavior in daily life (Perrez & Reicherts, 1989). Similar studies were reported more recently. *Do we know how we cope? Relating coping reports to global and time-limited retrospective assessments (Todd, Tennen, Carney, Armeli, & Affleck, 2004).* *A comparison of coping assessed by ecological momentary assessment and retrospective recall (Stone et al., 1998).* Both studies observed discrepancies in retrospective accounts that indicate that there are weak relationships between global and daily reports and this would suggest the use of time-limited self-reports instead of global accounts. Previous investigations based on paper-diaries already had pointed out the bias in creating retrospective reporting of stress-strain and coping processes. The development of computer-assisted diaries thus provided for reliable timing and recording of data (see below, for empirical findings on the negative retrospection effect).

Coping with stress was investigated in 108 women with varying socioeconomic status (SES) who monitored positive and negative psychosocial experiences and emotions across 2 days. Measures of intrapsychic and social resources were aggregated to represent the reserve capacity available to manage stress. Lower SES was associated with less perceived control and positive affect, more social strain and fewer resources relative to those with higher SES. *Socioeconomic status, resources, psychological experiences, and emotional responses: a test of the reserve capacity model (Gallo, Bogart, Vranceanu & Matthews, 2005).*

Pleasant affects and unpleasant affects obtained by experience-sampling studies show high discriminant validity with respect to subjective well-being (hedonic balance). Extraversion was more highly related to aspects of pleasant affects than unpleasant affects, and neuroticism was more highly related to unpleasant affects. The specific item happiness was superior in prediction of life-satisfaction as compared to the average of all pleasant affects *Affect measurement in Experience Sampling research (Schimmack, 2003).* Present theories of emotion are often based on dynamic concepts of appraisal although methodological concerns

about the research, including biased recall, heuristic responding, ethical issues, and weak and unrealistic induction of emotions in laboratories exist. The authors used ecological momentary assessment to provide a more ecologically valid test of appraisal theories. The emotions and appraisals of Singaporean police officers were measured over the course of an ordinary workday whereby "happiness" was the main focus. The findings indicated that happiness was reported primarily in association with a specific combination of 3 relevant appraisals: high pleasantness, high perceived control, and low moral violation. *The use of ecological momentary assessment to test appraisal theories of emotion (Tong et al., 2005).*

As part of the continuing process in empirical validation of the Freiburg Personality Inventory (FPI-R), an ambulatory assessment was conducted which comprised 59 employees, male and female participants, age 19-58, mostly with higher education. MONITOR software was used to obtain reports, 5 times on a typical day, on momentary setting, activity, social contact and mood (14 adjective items) in daily life. A number of substantial correlation coefficients were observed, especially with four FPI-dimensions (Life Satisfaction, Strain, Health Complaints, and Emotionality), however there were no relationships with Extraversion (with the exception of "self-confident, self-conscious"), Social Orientation, or Aggression. It was concluded that the personality trait descriptions were not equally well represented in the item content domain used for the electronic diary. A close correspondence of psychological descriptive terms on both sides would serve to increase questionnaire-diary correlations (Fahrenberg, Hampel & Selg, 2001). Interestingly, hardly any relationships were observed in 33 female students who responded to MONITOR six times per day for one week between personality trait scores and type and frequency information regarding reported daily activities, momentary setting, and social situation (Fahrenberg et al., 2002).

The ambulatory assessment of perceived and objective work-demand and strain appear to be an essential task in industrial psychology. Possibilities and boundaries of computer-assisted data acquisition at the work place were discussed and recommendations with respect to design of items (self-report, description of the settings) and sampling were given (Rau & Triemer, 1999). In a field study mood curves at normal working days were assessed (Triemer & Rau, 2001). This study examined the associations between Positive Affectivity (PA), Negative Affectivity (NA) and cardiovascular activation in 145 female and male white collar workers assessed during 24 hours by means of a hand-held computer and ambulatory monitoring of blood pressure, heart rate, and motor activity. There was a significant decrease in PA and NA over the day until the evening. The psychophysiological results (see Section 4.5) imply that computer-assisted methods and the dichotomy of PA/NA are useful instruments for analysis of strain and mood during the working day.

Job stress diaries are suitable to research whether specific features of job design were related to personal development and health (Rau, 2004a, 2004b; Triemer, 2002). Objectively evaluated task requirements were used to classify jobs causing high strain, low strain, and jobs conducive to personal development. Self-reports about job characteristics did not differ between low- and high-strain jobs, however, employees working in jobs conducive to personal development perceived the highest job demands and decision latitude. Another field study examined the relationship between job characteristics and positive experiences under flow conditions (Rau & Riedel, 2004). For each work place an objective analysis of job design features based on observation was conducted. Standard questionnaires for assessment of perceived job characteristics and demand/control latitude were also used. Self-reports on subjective state and activities were recorded hourly during one day. Flow condition during work was defined by three variables: high perceived control, mental tension/effort above average, and positive subjective state above average. From 114 male employees 15 employees met these criteria. The findings suggest that adequate job design is associated with positive subjective state at the work place, and that it possibly helps to promote personal development and health.

The associations between work stress and mental health were compared in employees and self-employed workers, and with the numbers of general practitioner (GP) services used by these two employment groups, the study recruiting altogether 2275 men and women. A hand-held PC was used but responses were entered under the supervision of an interviewer. Self-employed men and women reported more decision authority than the employees. Overall, self-employment was found to be associated with relatively few mental health benefits. Women who were self-employed reported worse physical health than their counterpart employees. Perceived work stress factors were associated with the use of GP services by self-employed men, the association in woman was however stronger in employees (Parslow et al., 2004).

A study reported the validation of the Work and Health Interview (WHI), a questionnaire that provides a measure of lost productive time from work absence and reduced performance at work. Absence time, time

away from call station and electronic continuous performance, and repeated electronic diary data (n = 48 participants) were obtained approximately eight times a day over a 2-week period to estimate time not working. At a population level, the WHI provided an accurate estimate of missed time from work and total productive time when compared with workplace and diary estimates. At an individual level, the WHI measure of total missed time, but not reduced performance time, was moderately accurate (Stewart, Ricci, Leotta & Chee, 2004).

A number of ambulatory studies employed the Freiburger Monitoring System (FMS) to interactively assess emotions concomitant with detected episodes of additional heart rate. These investigations also reported data on settings, activities, social context, job demands and further psychological variables in many groups of subjects at the work place and during leisure time activities (Myrtek, 2004; see, Section 4.5).

Clinical Studies

Pain diaries are among the most frequent applications of electronic diary methods. In general, patient reported outcome constitutes an essential data source in evaluation of clinical interventions. Feasibility studies in many fields suggest that electronic diaries are an acceptable method of obtaining better information on the extent and duration of symptoms, difficulties in the postoperative process, or management of chronic disease.

Examples for the potentialities of electronic pain diaries were: *Electronic Diary Assessment of Pain-Related Variables: Is Reactivity a Problem?* (Aaron, Turner, Mancl, Brister & Sawchuk, 2005); *Reasons for missing interviews in the daily electronic assessment of pain, mood, and stress* (Aaron, Mancl, Turner, Sawchuk & Klein, 2004); *Ambulatory monitoring of physical activity and symptoms in fibromyalgia and chronic fatigue syndrome* (Kop et al., 2005); *analysis of the relationship between activity and pain in chronic and acute low back pain* (Liszka-Hackzell & Martin 2004); *Electronic pain diary: a randomized crossover study* (Gaertner, Elsner, Pollmann-Dahmen, Radbruch & Sabatowski 2004); *Associations among pain intensity, sensory characteristics, affective quality, and activity limitations in patients with chronic pain* (Litcher-Kelly, Stone, Broderick & Schwartz, 2004); *Assessment of pain related fear, attention to pain, and pain intensity in chronic low back pain patients* (Roelofs, Peters, Patijn, et al. (2004); *Psychosocial factors in a fibromyalgia syndrome (FMS) patient. Assessment by means of electronic pain diaries – casuistics and multivariate time series analysis* (Muller, Bieber, Muller, Blumenstiel & Eich, 2004); *Pain assessment in patients with fibromyalgia syndrome* (Williams et al., 2004); *Clinical pain in chronic widespread pain – selected methodological issues* (Gendreau, Hufford, & Stone, 2003); *Activities of daily living were assessed in a comparative study in patients with chronic low back pain and nonsymptomatic controls* (Spengelink, Hutten, Hermens & Greitemann, 2002); *Outcome measures for complex regional pain syndrome* (Schasfoort, Bussmann & Stam, 2000); *Electronic diaries for monitoring chronic pain: 1-year validation study* (Jamison et al., 2001); *Development and user's acceptance of the General Electronic Psychotherapy Diary* (Hinkel & Scholz, 2001); *Intensive momentary reporting of pain with an electronic diary: reactivity, compliance, and patient satisfaction* (Stone et al., 2003).

Pain, disability and psychological adaptation were assessed four times a day for 4 weeks by computerized diary in 80 patients reporting various duration of unexplained pain. The over-all pain report was stable across the 4-week period, that is, no evidence of instrument reactivity was found. However, pain report appeared to be highly variable both between and within days. About half the patients showed a clearly increasing trend in pain during the day. Patients with less than 6 months of pain reported significantly less pain intensity, disability and fatigue than patients whose pain persisted for more than 6 months. Longer pain duration was associated with increased catastrophizing and solicitous responses from the spouse. Comparison of scores obtained with diary versus questionnaire assessment indicated moderate correlations for most variables. Retrospective (questionnaire) assessment of pain intensity yielded significantly higher pain scores than diary assessment. *Electronic diary assessment of pain, disability and psychological adaptation in patients differing in duration of pain* (Peters et al., 2000). In 125 patients with fibromyalgia, who were enrolled in a randomized, placebo-controlled trial of milnacipran, pain intensity levels and variability (SD) were assessed. There were large between-subject differences in real-time pain reports. Pain variability was relatively constant over time within individuals. Patients with larger pain fluctuations were more likely to respond to placebo. *Characterization and consequences of pain variability in individuals with fibromyalgia* (Harris et al., 2005).

Non-headache symptoms in migraine were assessed before, during, and after migraine in a mixed event- and time-sampling design. Out of 120 patients who originally volunteered 97 patients had usable data. Patients correctly predicted migraine headaches from 72 % of diary entries with 22 premonitory, cognitive and physical symptoms. Some of these symptoms had specific warning features. *Premonitory symptoms in migraine: An electronic diary study* (Giffin et al., 2003). The potential for symptom-context-analyses in migraine were also evident in other investigations. *Towards an objective quantitative assessment of daily functioning in migraine: a feasibility study* (Tulen, Stronks, Busmann, Peppinkhuizen & Passchier, 2000); *Ambulatory monitoring of diurnal changes in pain disorder, migraine and rheumatoid arthritis* (Godaert, Sorbi, Peters, Dekkers & Geenen, 2001).

Patients with borderline personality disorder (BPD) experience more frequent, stronger, and longer-lasting states of aversive tension. This hypothesis was tested in a sample of 63 female subjects with BPD and 40 mentally healthy controls who participated in ambulatory assessment employing the MONITOR software. On two consecutive days, participants were prompted at hourly intervals to record their current state of aversive tension and antecedent events. Compared with controls, states of aversive tension occurred significantly more frequently in BPD patients. The average levels of aversive tension were significantly higher, and the rate of increase in tension was much sharper. Furthermore, states of aversive tension persisted for a longer period. Among BPD subjects three events (rejection, being alone, and failure) accounted for 39% of all events preceding states of tension. *Aversive tension in patients with borderline personality disorder: A computer-based controlled field study* (Stiglmayr et al., 2005); *Spannung und Dissoziation bei der Borderline-Persönlichkeitsstörung* (Stiglmayr, 2003); *States of aversive tension in patients with borderline personality disorder: A controlled field study* (Stiglmayr, Grathwol & Bohus, 2001).

Palmtop computers were used to gather self-report data on obsessive-compulsive disorder symptoms and other environmental and mood variables from 13 outpatients (aged 19-49 yrs) for a period of 3 days. The computers beeped hourly between 9 a.m. and 9 p.m., prompting participants to complete a questionnaire which included a modified version of the Yale-Brown Obsessive Compulsive Scale. Data collected via computer-administered questionnaires showed only moderate agreement with data from clinician-administered interviews. *In vivo measurement of obsessive-compulsive disorder symptoms using palmtop computers* (Herman & Koran, 1998).

Noteworthy are studies in fields other than pain monitoring. In one study, an individualized asthma education program was based on daily assessment of symptom perception. *Giving feedback to asthma patients. Ambulatory monitoring in patient education* (Leopold & Schandry, 2001). In another study, electronic diaries were used in an international clinical trial of asthma in 118 patients. The eight week study involved morning and evening assessment using a few items on symptom intensity and the best of three peak flow readings on a scale, and involved the use of the relief inhaler. A high compliance (86 %) was obtained and, on the whole, it was concluded that this methodology was very satisfactory. *Use of pen-based diaries in an international clinical trial of asthma* (Tiplady, Jamieson & Crompton, 2000).

Assessment of postsurgical recovery after discharge was investigated in 32 females. After a hospital stay of 1 - 6 days the patients were asked to record symptoms and other data over one month concerning quality and duration of sleep, incidence of pain and interference with daily activities. Most patients found the electronic diary easy to use, and none found it difficult. Electronic diaries appear to be an acceptable method for obtaining better information on the extent and duration of symptoms and other difficulties in postsurgical recovery (Begg, Drummond & Tiplady, 2003).

Diary data were employed for analyzing a multi-modal therapy concept for fibromyalgia patients. Patients kept an electronic diary for 13 weeks. Pain intensity, depression, sleep quality, anxiety and self-efficacy were assessed by means of visual analogue scales. The resulting multivariate time series were aggregated over individuals, and partial spectral coherences between each pair of the variables were calculated. From the partial coherences, interaction graphs were plotted to assess the common underlying dependency structure of a number of patients. Findings were in favor of the main hypothesis that self-efficacy plays a central role in the therapy process (Feiler, Muller, Muller, Dahlhaus & Eich, 2005).

Ambulatory assessment, clearly, is the method of choice in research on multiple chemical sensitivity (MCS) in actual life. Multiple symptoms are provoked in multiple organs by exposure to, and ameliorated by avoidance of, multiple chemicals at low levels. Fourteen patients with MCS, diagnosed according to the 1999 consensus criteria, and 12 healthy controls underwent 1-week measurement of physical and psychologic symptoms and of the levels of exposure to various chemicals. This pilot study revealed that some causative chemicals were detected in 11 of 14 MCS patients. Eleven of the 17 physical symptoms and all four mood subscales examined were significantly aggravated in the interview based on "patient-initiated symptom prompts." However, there were no differences in physical symptoms or mood subscales between MCS patients and control subjects in the interview based on random prompts. It is concluded that these patients do not have either somatic or psychologic symptoms under chemical-free conditions, and symptoms may be provoked only when exposed to chemicals. *Symptom profile of multiple chemical sensitivity in actual life* (Saito et al., 2005).

Behavior Problems, Psychiatric Disorders

The everyday life of 153 adolescents with low, middle, or high levels of attention-deficit/hyperactivity disorder were assessed either by parent or teenager him or herself twice each hour, across two 4-hour recording intervals. High ADHD symptom-level was associated with more negative moods, lower alertness, more entertaining activities, more time with friends, and more tobacco and alcohol consumption. Parent-defined reports revealed a similar over-all pattern, but fewer associations. The results suggested that ADHD symptoms, even at subclinical levels, were correlated with behavior patterns that may be important for therapy. *The ADHD spectrum and everyday life: Experience sampling of adolescent moods, activities, smoking, and drinking* (Whalen, Jamner, Henker, Delfino & Lozano, 2002).

Smoking, excessive eating and alcohol consumption are behaviors that would clearly benefit from assessment by ambulatory monitoring since situations and moods obviously play an important role in eliciting such behaviors. Assessment of such contextual variables in daily life were examined in a number of studies (for example, Mucha, Mutz, Stephan & Pauli, 1996; Shapiro, Jamner, Davydov & James, 2002; Shiffman et al., 2002; Whalen, Jamner, Henker & Delfino, 2001). *An evaluation of the relationship between mood and binge eating in the natural environment using ecological momentary assessment* (Wegner et al., 2002).

Ecological momentary assessment was used in a number of studies of smoking, alcohol or drug abstinence and relapse. Daily recordings of decreases in abstinence self-efficacy (ASE) and increases in positive smoking outcome expectancies (POEs) predicted the occurrence of a 1st lapse on the following day *Dynamic self-efficacy and outcome expectancies: prediction of smoking lapse and relapse* (Gwaltney, Shiffman, Balabanis & Paty, 2005). The situations that are associated with changes in self-efficacy during an attempt to quit smoking were assessed in 214 smokers. Higher urge to smoke and negative affect were associated with reduced self-efficacy. Although alcohol and coffee consumption are associated with heightened lapse risk, they were unrelated to abstinence self-efficacy. The findings indicate that self-efficacy may be reactive to affect-motivational states during a quit attempt. *Situational correlates of abstinence self-efficacy* (Gwaltney, Shiffman & Sayette, 2005). Day-to-day changes in mood and stress did not predict lapse risk, but more proximal changes in affect were associated with lapses: Many lapses were marked by intense negative affect NA and by NA increases in the preceding hours. Individual differences in baseline self-efficacy SE predicted lapse risk, but daily SE was relatively stable during abstinence and did not influence lapse risk. Further data emphasize the importance of person by situation interactions and, generally, the importance of dynamic changes in background conditions and in immediate states as important influences on lapses and relapse. *Dynamic influences on smoking relapse process* (Shiffman, 2005).

The individuals' capacity to exert self-control of drinking was examined in daily life. On days that participants experienced more self-control demands than average, they were more likely to violate their self-imposed drinking limit after controlling for mood and urge to drink. There was no relationship between self-control demands and urge or intention to drink, nor were self-control demands related to plans to limit drinking. *Daily fluctuations in self-control demands and alcohol intake* (Murraven, Collins, Shiffman & Paty, 2005). Craving for alcohol, reaction time, sadness and anxiety were

recorded 8 to 12 times a day, over three weeks of detoxification in 14 alcoholics on an electronic diary issuing random prompts. Craving episodes were more frequent and intense than previously reported. Age, gender, sadness, anxiety and the number of previous detoxifications were predictive factors of craving during detoxification. Antidepressants, anticraving medications but not benzodiazepines were negatively associated to craving. Reaction time (representing a measure of cognitive interference) was significantly increased in univariate analysis when a craving episode occurred but this difference did not persist after multivariate analysis. *An in vivo study of the relationship between craving and reaction time during alcohol detoxification using the Ecological Momentary Assessment* (Lukasiewicz, Benyamina, Reynaud & Falissard, 2005). Urges for alcohol and conditions of relapse were studied in 48 alcohol-dependent subjects. A cluster analysis based on mean and standard deviation of urges was conducted and four distinct urge patterns during abstinence were identified. Clusters differed in negative affect and anger but not in abstinence rates. *Patterns of urges during early abstinence in alcohol-dependent subjects* (Krahn, Bohn, Henk, Grossman & Gosnell, 2005).

The use of an electronic diary for patients with Parkinson's disease was examined in 12 patients. The diary recorded the motor status every 30 minutes while awake for 7 consecutive days. Although some of the patients reported minor difficulties, especially with pen use, there was generally a high compliance. The investigators concluded that PD patients with motor fluctuations and dyskinesias can successfully complete an electronic diary (Lyons, Lambrecht, Esnaashari & Pahwa, 2003). Self-assessment of motor function and quality of life in Parkinson's Disease was obtained, allowing the patients to stay in their home environments. The sampling was performed every two hours over a 12-hour period on 8 non-consecutive days during 1 month. One of the advantages of this approach was the high compliance. The hand-held PC was connected to a cellular phone, so that all diary data and patient compliance data, and technical performance (battery function) could be monitored through a secured Web site (Nyholm, Kowalski & Aquilonius, 2004).

There have been other applications in the medical field and these include: Rated subjective complaints during treatment of seasonal allergic rhinitis (Koop & Mösges, 2002); Patients with overactive bladder (Quinn, Goka, & Richardson, 2003); *Coping with new treatments for cancer: A feasibility study of daily diary measures* (Sherliker & Steptoe, 2000); *Electronic collection of health-related quality of life data: Validity, time benefits, and patient references* (Bliven, Kaufman & Spertus, 2001). In 16 women with threshold or subthreshold anorexia and bulimia nervosa, the feasibility of ecologic momentary assessment (EMA) was examined. Eighty-eight percent of the sample completed the recording of their eating disorder behaviors for 4 weeks (Stein & Corte, 2003). Such real-life assessments may be beneficial in supporting intervention strategies.

The Life Chart Method in Psychiatry was originally introduced 100 years ago by Magnan and by Kraepelin, and further developed by Post and Leverich to form the NIMH Life Charting in bipolar disorders. This method was adapted for use in long-term monitoring. First results of a feasibility study with an electronic diary for bipolar patients were reported. Mood, social function and impairment, duration of sleep, medication, life events, comorbid symptoms, etc., were assessed daily in the Palm LifeChart Study, an international validation project (Schärer et al., 2002). Another study applied the ChronoRecord Software to collect self-reported data from patients suffering from bipolar disorder. This method is based on home-based computer technology that can be transported for application in hand held- and telemedicine (Whybrow et al., 2003).

Intensive time-sampling approaches may be useful in assessment of depression and quality of life (QoL) because of their variability in daily life. The experience sampling method (ESM) was used to assess effects of antidepressant treatment on the quality of life, as measured from moment to moment in daily life (mQoL), and related aspects of daily experience. Primary care patients with a diagnosis of major depressive disorder were randomly assigned to imipramine (N = 32) or placebo (N = 31) treatment for 6 weeks. Treatment-related increases in frequency and severity of physical complaints were associated with lowered mQoL, especially in treatment dropouts. Despite greater clinical improvement at week 6, imipramine patients did not report greater increases than placebo patients in mean mQoL ratings. At 18 weeks, remitted patients still showed deficits on ESM daily life measures relative to healthy controls, even though QoL had returned to normal on retrospective measures. *Effects of antidepressant treatment on the quality of daily life: An experience sampling study* (Barge-Schaapveld. & Nicolson, 2002).

Using the *experience sampling method*, daily activity, social behavior and negative affect were examined in a sample of individuals with a wide spectrum of psychosis-proneness scores. Participants were signaled 5 times per day for a 1-week period. Little evidence was found for a direct association between psychosis-proneness and specific behavioral profiles, but individuals with higher scores of psychosis-proneness reported spending more time doing nothing or waiting. Furthermore, findings indicated that psychosis-proneness was associated with an increase in anxiety when individuals were with friends and an increase in depressed mood in daily task situations. *The relation between social behavior and negative affect in psychosis-prone individuals: An experience sampling investigation* (Husky, France, Olivier & Swendsen, 2004).

A pilot study used electronic diaries in 16 children and adolescents with affective disorder and 5 controls. Subjects' mood, thoughts, and behaviors were assessed by multiple daily assessments using modified EMA software for brief interviews carried out on cellular phone by the study staff. Wrist actigraphy was also employed. The study was completed by 17 participants and showed the potential usefulness of this approach. *Measuring mood and complex behavior in natural environments: use of ecological momentary assessment in pediatric affective disorders* (Axelson et al., 2003).

Usability and cost-effectiveness of mobile computer-assisted psychometric testing was evaluated in the psychosomatic clinic (inpatients and polyclinic patients). On the basis of nine standard personality questionnaires and mood checklists, this assessment sought to compare the computer-assisted tests with the corresponding paper-and-pencil versions. A total of 6,000 patients between 1989 and 1996 participated in the assessment. The findings revealed considerable advantages associated with computer-assisted testing: rate of acceptance among patients, improvement of data organization, cost-effectiveness. No significant effects on data distribution, data structure, and stability coefficients were seen (Rose, Hess, Hörhold, Brähler & Klapp, 1999; Rose et al., 2002).

As compared to self-administered questionnaires, the computer-assisted self-interviewing (CASI) can have many advantages, especially when sensitive questions are asked or very special populations are concerned. CASI can be part of a personal interview in which the interviewer hands the computer over to the respondent for specific questions or a computerized version is used and the disk is sent by mail. *Computer-Assisted self-interviewing tailored for special populations and topics* (De Leeuw, Hox & Kef, 2003). Audio computer-assisted self-interviewing (A-CASI) as a mode of data collection was compared to either a computer-assisted interviewer-administered personal interview (CAPI) or to a mixed CAPI/A-CASI interview. In the latter, 'sensitive' portions (dealing with stigmatized behavior) of the questionnaire were self-administered through A-CASI, while the remaining portions were interviewer-administered. A-CASI was associated with greater reporting of potentially stigmatized drug, sex and HIV risk behaviors on a moderate number of questions. Moreover, a large majority of participants who used A-CASI would like to be assigned to this method of data collection in future interviews. *Audio-computerized self-interviewing versus face-to-face interviewing for research data collection at drug abuse treatment programs* (Perlis, Des Jarlais, Friedman, Arasteh & Turner, 2004).

3.4 Retrospective Recall and the Negative Retrospection Effect

The recall-bias in retrospective ratings of mood, coping and symptoms has been a research issue in laboratory experiments investigating hindsight and in conventional questionnaire studies. Diary studies of this kind mostly compared instantaneous day-time self-reports with retrospective global ratings reported either in the evening of the same day or the next day (Section 2). To date retrospection effects for longer periods of between several days and a number of weeks have rarely been examined.

A previous investigation using an electronic diary emphasized more clearly the uniformly *negative* tendency of this retrospection bias (Käppler, 1994; see Section 2). A second study was designed for further evaluation of retrospection effects in 61 students over a period of two days. The general findings on the negative retrospection effect were replicated and, depending on the particular item, a medium to large effect size was noted (Käppler et al., 2001). Consistent with this was the finding that a significant correlation between the magnitude of the negative retrospection effect and the personalit

dimension Emotionality (Neuroticism) was found. Subjects with a high degree of Emotionality are known to experience depressed mood, many somatic complaints, and a problematic illness behavior as evidenced in representative surveys (for example, Fahrenberg, Hampel & Selg, 2001).

Subsequent research also used the MONITOR system and samples of university students, employees, and patient groups. In each study the negative retrospection effect was observed (Ebner, 2004; Fahrenberg & Myrtek, 2005; K ppler & Rieder, 2001). These investigations were also directed at a number of specific issues. Since the negative tendency appeared to be a characteristic feature of "negative" mood items, such as feeling depressed, and appeared to be less apparent or completely missing in "positive" items, such as those pertaining to being active, special care was taken to include more positively worded adjective rating-scales. The length of interval for retrospection (couple of hours, one day, one week) was examined and statistical relationships were evaluated, especially response distribution, scale-midpoints, restriction of range, and ceiling effects, initial value dependency, and tendency towards the mean. In one study the participant's comments describing how they arrived at their retrospective ratings were also assessed. 33 students were monitored for seven days. A remarkably low stability (intra-class coefficients) of the retrospection effect was noted. This finding contradicts the assumption of a consistent association with personality traits. The correlation between the negative retrospection amount and Emotionality was evident only for the first day of the monitoring (Fahrenberg et al., 2002).

Another investigation with 64 students monitored over two days examined the potential effects of scaling (numerical vs. visual analog scales) and the design included also a short initial training in the use such rating scales (vs. written instructions). Self-ratings of the person's confidence in his or her own ratings (high vs. low) were also obtained. The hypothesis that there is a cognitive heuristic for preference of scale-midpoints for self-ratings in case of uncertainty was tested by comparing (1) self-reports associated with high or low degree of self-confidence, and (2) retrospective mood ratings with predictions of mood for the next day. Again, the negative retrospection effect was replicated. Neither the hypotheses regarding psychometric issues nor the possible role of item format were confirmed. The findings on heuristics of judgment and the inclusion of more "positive" items were not revealed here. None of the other conditions contributed significantly toward a better understanding of the retrospection effect (cf. Fahrenberg & Myrtek, 2005).

It was concluded that there is a substantial negative retrospection effect and this may be regarded as an essential finding in psychological assessment. A straightforward explanation is not available at present. The findings are compatible with the notion that retrospection is indeed a complex process of memory recall and comprises multiple and overlapping effects.

The general position reviewed so far appears to be in line with that in other published research. The equivalence in weekly recall and averaged momentary reports in pain was investigated in 68 patients with chronic pain. The patients completed both weekly recall and momentary reports over a 2-week period and assessed their change in pain over the 2 weeks. Between-person correspondence between weekly and momentary reports was generally moderate to high, but within-person correspondence was low. Judged change was only weakly related to changes over a week computed from weekly recall or from average momentary reports. Given the importance of within-person change for treatment studies, these results indicate a serious bias in weekly recall and averaged momentary reports of pain. *Understanding recall of weekly pain from a momentary assessment perspective: absolute agreement, between- and within-person consistency, and judged change in weekly pain* (Stone, Broderick, Shiffman & Schwartz, 2004). Concurrent findings were reported from other investigations. *Do we know how we cope? Relating coping reports to global and time-limited retrospective assessments* (Todd et al., 2004); *Clinical pain in chronic widespread pain: selected methodological issues* (Gendreau et al., 2003); *Daily mood reports in hindsight: Results of a computer-assisted time sampling study* (Hank, Schwenkmezger, & Schumann, 2001); *The occurrence of recall bias in pediatric headache: A comparison of questionnaire and diary data* (van den Brink, Bandell-Hoekstra & Abu-Saad, 2001); *A comparison of coping assessed by ecological momentary assessment and retrospective recall* (Stone et al., 1998).

A series of investigations replicated and extended the previous findings in confirming the presence of recall-error in such self-reports. It was found, moreover, that self-ratings were *negatively* distorted when summarized in the evening or the following morning. Obviously, neither the average rating nor the retrospective global rating can be considered the “valid” data since both reflect multiple psychological aspects of state and state change. Nonetheless, the retrospection bias may severely undermine the validity of self-ratings. It is concluded that a direct data acquisition, especially by means of the ambulatory assessment methodology, is preferable whenever possible (Fahrenberg et al., 2002; Gorin & Stone, 2001).

3.5 Performance Tests – In-field Psychometric Testing

Based on large-scale assessment studies in secondary school students and other populations, Buse and Pawlik (1994; Pawlik and Buse, 1996) developed a battery of performance tests and an item pool suited to ambulatory assessment studies. The ambulatory assessment methodology was utilized in research on the situationism – interactionism – traitism controversy. The previously used data from questionnaires, for example, concerning anxiety responses in various situations (done from memory), may be heavily biased due to recall errors and a general lack of ecological validity.

With the exception of this pioneer work the development and use of psychometric tests to assess in-field performance and essential contextual variables has been rather slow, although many of the existing computer-assisted methods of this kind, for example, tests of neuropsychological functions, perceptual and cognitive performance, can be transported to hand-held computers.

Cognitive performance of judges on working days with different job demands was investigated using the AMBU portable test device. Six tests were selected from the Test Battery Measuring Mental Activation (see Section 3.2), each taking a maximum time of about two minutes. The 27 judges were examined on two consecutive days, a court day and a day at the office, according to a balanced cross-over design with five test sessions per day. The hypothesis was that a higher degree of mental workload was detrimental to cognitive performance, whereas adrenaline excretion as a biochemical stress indicator was elevated when emotional strain was high. No systematic differences were found in cognitive performance between days, adrenaline excretion was higher on court days. The investigators discussed the possibility that differences in workload were too small to alter cognitive performance. *Computergestütztes ambulantes Monitoring der kognitiven Leistung sowie Adrenalinexkretion bei Richtern und Richterinnen an Arbeitstagen mit unterschiedlichen Dienstaufgaben* (Buse, Wegner, Koops & Baur, 2004).

The MONITOR software was supplemented to include a Go/NoGo-paradigm and a working memory test for the investigation of change in attention during everyday life in relationship to time of day and self-rated hours of optimum performance. Sixty-one students participated in this investigation with five self-reports each day for two consecutive days. Subjective state variables showed clear within-subject correlations, but the correlations were negligible between subjective state and performance on both in-field tests of attentional performance. Self-rated Morningness-Eveningness types showed significant differences in their diurnal change in working memory performance. A retrospection effect, that is, a negative bias in self-ratings made in the evening or morning following the day being assessed, was reported. *Ambulatory assessment of diurnal changes with a hand-held computer: Mood, attention, and morningness-eveningness* (Fahrenberg, Brügger, Foerster & Käppler, 1999; Hüttner, 2002). Another example is the development of the Implicit Association Test which uses reaction times to measure implicit associations among concepts or between concepts and attributes. This test was programmed to run on personal digital assistant devices inside or outside the laboratory. Reliability was found to be similar to that of the original desktop computer version. It was concluded that such methods can be applied to study hard-to-reach populations in unusual settings (Dabb, Bassett & Dyomia, 2003).

4 Physiological Monitoring and Psychophysiology

4.1 Ambulatory Monitoring in Medicine and Psychophysiology

Innovative methodology and expanding application

Monitoring, ambulatory: The use of electronic equipment to observe or record physiologic processes while the patient undergoes normal daily activities. – This MEDLINE key concept is in use since 1995 and its introduction reflects the increase in the number of publications.

A broad spectrum of physiological variables has been measured in daily life, mostly by non-invasive methods. In some instances, invasive techniques have been used also, such as glucose monitoring, intra-arterial BP measurement, monitoring of bladder function or pH-monitoring in gastroenterology. Blood pressure and the ECG enjoy by far the largest number of references in the literature on ambulatory monitoring, and actigraphy (multiple accelerometry) is presently under rapid development.

Ambulatory monitoring is applied predominantly in the medical field and to a much lesser extent in the behavioral sciences and in psychophysiology. The present account includes selected empirical studies, reviews and, also, a number of significant articles published before the year 2000.

Ambulatory monitoring progressed especially in those domains where the benefits were evident:

- ambulatory monitoring of blood pressure (e.g., Pickering, 1991, 2002);
- ambulatory electrocardiography for detection of arrhythmias and ischemic episodes (e.g., Heilbron, 2002);
- ambulatory electroencephalography for outpatient seizure identification (e.g., Chang, Ives, Schomer & Drislane, 2002; Gilliam, Kuzniecky & Faught, 1999; Liu, Zhang & Yang, 2002; Tatum et al., 2001);
- home sleep studies and polysomnography (e.g., Li & Flemons, 2003; Penzel & Peter, 2003);
- ambulatory recordings of movement and movement pathologies (see below).

Notable is how rapid the growth in the use of ambulatory blood pressure monitoring has been, although the basic features of oscillometric BP measurement with an arm cuff have hardly changed over the last two decades. Only a few BP monitors record both oscillometric and the traditional auscultatory (Korotkoff sound) methods (e.g. Colin device). Still less common is the application of a BP monitor with an integrated position sensor (Mallion et al., 2000). A number of devices did become available for self-measurement of arm, wrist or finger BP at home.

The 24-hr BP monitoring is nowadays indispensable in the diagnosis of hypertension and in the adjustment in dosage of anti-hypertensive medication. Ambulatory BP monitoring is reviewed here from two perspectives. First, the phenomenon of office hypertension still appears to be an important issue and is in itself confirmation of the necessity of ambulatory monitoring. Second, reactivity in everyday BP is an essential issue in psychophysiological research. BP changes and concurrent changes in subjective and behavioral data were investigated in normotensive and hypertensive subjects. The possible role of emotions and job stress in the development of elevated BP and hypertension was investigated in a number of studies.

Accelerometry (actigraphy) is another notable domain which especially profited from the advent of new sensor technology. Physical activity, posture and motion can be measured more precisely than ever before. Again, the practical advantages are evident, for example, in indirect measurement of energy expenditure, in recording of movement patterns and movement pathologies. In the latter case, this involves monitoring and evaluation of physical therapy of certain movement disorders. Accelerometry contributes further to behavioral research in many respects. Only a few of the potential applications have been tried so far.

Ambulatory monitoring methodology was further applied in psychophysiological research. Noteworthy is the development of interactive monitoring strategies whereby data acquisition is triggered by real-time analysis of certain events.

4.2 Ambulatory Blood Pressure

General Context

It would, at first sight, seem to be a rather simple task for a physician to obtain reliable blood pressure readings in his or her practice. However, measuring the *valid* BP instead of an accidental, casual BP is a challenging task. The encountered difficulties originate from the regulatory dynamics of blood pressure that reflect the adjustments of BP to momentary demands either in terms of physical activity, thermoregulation, etc., or in terms of behavioral demands. For instance, BP measured when climbing stairs would be of some, but comparatively little importance for the determination of diagnosis or the dosage of medication. In view of the regulatory dynamics of BP, it is essential to know the context of measurement precisely. BP is clearly different to many other symptom measures because it requires additional information on the momentary behavior and emotional state of an individual at the time of measurement. The use of casual BP readings could be otherwise extremely misleading in research or in decisions on medication in hypertension.

There is however growing evidence from clinical and follow-up studies indicating that dynamic aspects in BP regulation, that is, variability and reactivity, may have incremental validity in the prediction of hypertension and morbidity. It has been proposed that BP level and reactivity are to some extent controlled by different mechanisms. Bio-behavioral theories assume that exaggerated BP reactivity plays an important role in the etiology of primary hypertension. The mean arterial pressure may be less important here than pressure change, duration of sustained elevation, slow recovery, or sustained BP level during sleep (for a review Pickering, 1991, 2002; Zanchetti, 1997). The specific task of psychophysiological research is to evaluate the role of psychological factors in diurnal BP profiles and to substantiate bio-behavioral theories in the etiology and therapy of hypertension. The assessment strategy here must essentially focus on BP level, as well as spontaneous BP variability and event-contingent reactivity.

In practice, that is, with respect to feasibility and cost-benefit, the general attitude in medicine is to refer to a 24-h ambulatory monitoring of BP which gives an overall picture of BP level. This may suffice if the assumption is valid that an average day (awake, working time, and sleep) was being recorded. Research would further necessitate a higher resolution in time and the evaluation of the typicality of the recorded day, based on self-ratings (normal versus exceptional day) or based on additional concurrent assessment of behavior, physical activity, measures of ambient parameters, etc.

BP Research, Office Hypertension, Masked Hypertension

Recent articles on blood pressure research are cited in the following to illustrate the continuing commitment of researchers to refinement of methods and evaluation of practical issues in several large-scale surveys, and working toward Consensus Conferences on an international basis. This lively agenda is very apparent in a particular journal *Blood Pressure Monitoring*, besides additional coverage in a number of journals dedicated to Hypertension. In the present context, studies on anti-hypertensive drugs (medication) and predominantly clinical aspects are not discussed.

The benefits (and the necessity) of ambulatory monitoring are most strikingly demonstrated with respect to "Office Hypertension". Large epidemiological studies, moreover, have shown that the *masked* hypertension is also a fairly frequent phenomenon. In masked hypertension, the BP readings taken by the physician are seemingly normal but there is, in contrast, an elevated BP level in everyday life. A higher prevalence was observed among older adults, females and non-smokers. The clinical significance and prognostic value of BP and heart rate reactivity to the physician's visit still appear to be uncertain. The determinants of white coat hypertension and of masked hypertension, as well, have attracted more research recently. *Prognostic value of ambulatory blood pressure recordings in patients with treated hypertension* (Clement et al., 2003). *Determinants of white-coat hypertension* (Dolan et al., 2004). *White coat effect: Semantics, assessment and pathophysiological implications* (Parati & Mancia, 2003); *The white-coat effect is unrelated to the difference between clinic and daytime*

blood pressure and is associated with greater reactivity to public speaking (Palatini et al., 2003); Masked hypertension: how can the condition be detected (Palatini, 2004); The phenomenon of "masked hypertension" detected by blood pressure self-measurement in elderly treated hypertensive patients (Bobrie et al., 2004); Detection of masked hypertension by home blood pressure measurement: is the number of measurements an important issue? (Mallion et al., 2004); Direct access ambulatory BP monitoring - the Edinburgh experience (Richards, Sutherland Gough & Padfield, 2004). A recent follow-up study in patients with isolated office (IO) hypertension (office BP >140 and/or 90 mmHg, daytime BP <130/80 mmHg) revealed that such patients show a high rate of progression towards sustained hypertension over a 3-year period. Basal LV hypertrophy and/or preclinical diastolic dysfunction were the only markers of a greater risk of becoming hypertensives. *Isolated office hypertension: a 3-year follow-up study* (Grandi et al., 2005).

The psychophysiological and clinical aspects of masked hypertension and office hypertension are still under scrutiny. In general, this line of research has a strong resemblance to laboratory-field-comparisons and the question of external validity and generalizability in psychological testing. BP measurement appears to be a case for generalizability studies, and, requires appropriate assessment strategies. Thus, BP measurement provides an excellent field for the behavioral scientist and for the development of new strategies and multivariate analyses (cf. Fahrenberg, 2005).

The reliability of blood pressure measurement in everyday life is an important issue: *Reliability of ambulatory blood pressure monitoring* (Palatini, 2001); *Ambulatory blood pressure variation in normotensive subjects in relation to the sitting or standing position* (Mallion et al., 2000); *The relationship between electronically monitored physical activity to blood pressure, heart rate, and the circadian blood pressure profile* (Mansoor, White, McCabe & Giacco, 2000). *Electronic activity-monitor-derived sleeping and awake times and diurnal variation of blood pressure* (O'Shea & Murphy, 2000); *Ambulatory blood pressure monitoring: is the daytime period enough for making clinical decisions?* (Suarez, del Arco & Garcia-Polo, 2003).

The many research findings in this important area of medicine paved the way for conferences aimed at improving Guidelines: *Proceedings from a Consensus Conference on Self-Blood Pressure Measurement. Devices and validation* (O'Brien, De Gaudemaris, Bobrie, Agabiti Rosei & Vaisse, 2000); *Consensus Conference on Ambulatory Blood Pressure Monitoring participants. Blood pressure measurement in research* (Parati et al., 2002); Luders et al. (2005). *Langzeitblutdruckmessung – Statement der Deutschen Hochdruckliga e. V.*

Frohlich et al. (1994) published the American College of Cardiology Position Statement – Ambulatory Blood Pressure Monitoring. "Ambulatory blood pressure monitoring has become a mature, clinically applicable technology, with available standards developed by the Association for the Advancement of Medical Instrumentation and the British Hypertension Society. American and international consensus meetings have developed clinical indications and guidelines for this procedure." (1994, p. 1511)

Laboratory-field comparison

Research on psychophysiological ambulatory monitoring has to some extent been concerned with laboratory-field comparison. The essential question is whether individual differences in BP elicited by standard laboratory tasks can predict BP level and reactivity in natural settings. This issue obviously has many practical implications concerning, for example, the reliability of diagnostic findings and the external validity of laboratory research. The majority of studies seem to agree that predictability of real-life measurements based on laboratory measurement is, contrary to some expectations, low (for reviews cf. van Doornen & Turner, 1992; van Doornen et al., 1994; Fahrenberg, 1996b; Pickering, 1991, Turner et al., 1994).

Laboratory-field correspondence in BP and heart rate were examined in 335 healthy adults. A multilevel modeling approach was employed to detect the correspondence between laboratory and ambulatory measures and to identify the essential circumstances under which high correspondence may be most clearly observed. Laboratory measures of cardiovascular reactivity were followed by six days of ambulatory blood

pressure monitoring and electronic diary reports. Adjustment for posture, activity, and other effects was based on self-report data. Compared with low reactors, high laboratory systolic blood pressure (SBP) reactors showed larger increases in SBP during periods of high task demand or low decisional control in daily life. High diastolic blood pressure (DBP) reactors showed larger increases in ambulatory DBP during situations rated as being both low in control and high in demand *Correspondence between laboratory and ambulatory measures of cardiovascular reactivity: A multilevel modeling approach* (Kamarck, Schwartz, Janicki, Shiffman & Raynor, 2003).

Several methodological issues are involved here, such as reliability and stability of BP measurement itself (with respect to single and aggregate measures), differentiation between level, variability, and reactivity aspects, selection of appropriate laboratory tasks, definition of baseline, response scaling, initial value dependency, and specification of criterion measures (criterion settings) to be predicted by single or composite measures derived from BP measurement. Laboratory-field comparisons may be less convincing in those cases where it remains unclear exactly which specific criterion measures need to be determined when assessing the comparative reliability, generalizability, and ecological validity.

Generalizability

The basic question in generalizability theory is clear: to what extent can we rely on a particular measure and how many measures should be taken and aggregated to achieve such and such generalizability coefficients? The consistency of individual differences in BP measurement across settings and time periods was evaluated in a number of studies, mostly in normotensive student samples and in hypertensive patients.

These G-studies are suited to the estimation of sources of variance, but how does this clarification help decision making in a particular context? We have to acknowledge that there is no general answer to this question since there is no finite single criterion. Brunswik's Lense Model would suggest obtaining a number of criterion variables which represent the domain of BP-related decisions and outcomes. Thus, we are confronted with a multi-referential issue (Fahrenberg, 2005). In the present context, it must suffice to point out that the generalizability issue is very real and, thus, the laboratory-field discussion in BP research has exemplary value.

Body Position, Motion, and Blood Pressure

Generalizability of measures is but one aspect. The unwanted variance due to posture and physical activity is another issue. BP variability in daily life is to some extent determined by physical activity. Gross body movement may serve as a fairly valid index of energy expenditure, although some conditions (isometric work, pressing) may involve high energy expenditure and subsequent increase and decrease of blood pressure without much apparent movement. Multi-channel recordings confirmed this assumption and showed that change in physical activity, in posture and motion indeed affected BP. In a psychophysiological context, activity-related BP changes in the order of 10 to 30 mmHg are crucial since BP changes that are observed in psychophysiological research are usually of this size. *Ambulatory blood pressure variation in normotensive subjects in relation to the sitting or standing position* (Mallion et al., 2000); *Reliability of ambulatory blood pressure monitoring* (Palatini, 2001); *The relationship between electronically monitored physical activity to blood pressure, heart rate, and the circadian blood pressure profile* (Mansoor, White, McCabe & Giacco, 2000); *The influence of physical activity on the variability of ambulatory blood pressure* (Leary, Donnan, MacDonald & Murphy, 2000).

The effect size in BP caused by everyday life activities is currently under discussion since two studies reported only comparatively small activity-related portions of variance as compared to effects on heart rate. Blood pressure and heart rate were monitored in 27 subjects during daytime and physical activity was measured with four accelerosensors on trunk and legs. Increasing activity from very low to moderate level caused an average response in systolic BP of about 12 mmHg and in heart rate of 16 bpm (Cavelaars et al., 2002). A subsequent study measured intra-arterial BP and computed hemodynamic parameters from the pressure waveforms. Means of cardiovascular measures increased linearly with increasing levels of activity. Overall percentages of variance explained by activity were: in systolic BP 32 %, diastolic BP 28 %, heart rate 56 %,

and stroke volume 44 % (Cavelaars, Tulen, van Bommel, Mulder & van den Meiracker, 2004a, 2004b). These studies suggest that daily activities were moderate determinants of BP but main determinants of heart rate.

Substantial effects of change in posture and activity were found in a 24-ambulatory monitoring study in 40 students. Calibrated multiple accelerometry was used for measurement of physical activity and detection of posture and movement pattern. Differences were found, for example, between sitting, lying, and standing position, walking and climbing stairs. The means for systolic BP, diastolic BP, and heart rate were: Sitting 129/78/77, Standing 130/82/81 Lying 113/61/59, (right side 103/56/60, left side 114/63/58), Walking 142/86/87, Stairs up 146/89/91. The observed association between the index of physical activity derived from the tri-axial accelerosensor was larger for heart rate than for BP. The within subject correlation, pooled for 40 subjects, was .37, for systolic BP, .40 for diastolic BP, and .74 for heart rate (Fahrenberg & Foerster, 2002; Prill & Fahrenberg, 2006).

The nightly recovery in BP, that is, dipping, normally amounts to about 10% or more with the onset of sleep. Results of a number of studies suggested that target-organ damage is more pronounced in non-dippers, those in whom the difference is less than 10 %. The use of arbitrarily defined daytime and night-time periods, as opposed to precise estimates of sleeping time and awake time, could limit the accuracy of estimates of diurnal variation of blood pressure. In 102 consecutive patients undergoing ambulatory blood pressure monitoring, the dipping/non-dipping status of each subject was assessed using three different techniques: activity monitor, diary and default data using the pre-set daytime and night-time periods (23.00 and 7.00). The numbers of non-dippers assessed by these three methods were 6, 12, and 21. The technique used to define periods of wakefulness and sleep appears to be an essential aspect here. *Electronic activity-monitor-derived sleeping and awake times and diurnal variation of blood pressure* (O'Shea & Murphy, 2000).

Generally, objective indication about bed-rest is an essential prerequisite in studying the recovery process in nightly BP. In recent research on BP recovery during sleep many authors seem to neglect the issue of body position during sleep although body rotation from the left to the right side may introduce an arbitrary BP change in the order up to 15 mmHg. This difference is caused by height differences concerning arm cuff and level of the heart, that is, hydrostatic effects (Fahrenberg & Foerster, 2002; Pickering, 1991). Thus, BP "dipping" can be mistakenly assumed because of body rotation. A modern tri-axial accelerosensor fixed at the Sternum would suffice to assess the critical conditions.

The impact of participating in 24-hr ambulatory blood pressure monitoring on physical activity was examined in 24 working men and women. The level of physical activity was measured by use of tri-axial accelerometers at the day of the BP monitoring and alone for a separate day and evening. Physical activity was significantly reduced during the monitoring day. This is due in part to regular periods of immobility during BP measurement and diary completion and partly to more general self-imposed restrictions on activity. This pattern has implications for the representativeness of ambulatory BP monitoring. *Ambulatory Blood Pressure Monitoring Is Associated With Reduced Physical Activity During Everyday Life* (Costa, Croyley, Griffith & Steptoe, 1999)

Ambulatory blood pressure monitoring is a good example that both an index of the over-all physical activity and the detection of posture and motion are essential aspects in a thorough evaluation of BP variability in daily life. It should be noted that the ambulatory monitoring equipment commonly used for 24-hour ECG or blood pressure recordings does not permit measurement of physical activity. The patients are required instead to indicate change of body position, exercise, etc., by entries in a diary. However, concurrent recordings of physical activity appear to be superior to this method in terms of a precisely timed evaluation of cardiovascular reactivity. Such recordings could indicate whether a sudden rise in blood pressure was caused by standing up, by physical exercise, or whether this change was possibly caused by a strong emotional response or mental effort. For obvious reasons, a single actometer worn on the wrist or an actometer integrated in a recording device attached to a belt would not be the best choice for indicating the amount of physical exercise.

4.3 Psychophysiological BP Research

Methodology

Paper-and-pencil diaries and concurrent ambulatory BP recordings were employed by numerous authors to investigate psychophysiological relationships. Assessment using computer-assisted diaries and the measurement of physical activity, however, was initiated by a few research groups about 15 years ago. Furthermore, a multilevel (multi-modal) assessment approach was developed and tested in a series of studies (Fahrenberg, 1996b; Heger, 1990b; Käppler, 1994). This method consists of multi-channel recordings of BP, heart rate, physical activity, and – concurrent to each blood pressure measurement – a self-report on setting, behavior, emotional state, and experience, obtained by an electronic diary (Casio PB 1000, Psion Series 3). Furthermore, a small portable audio-recorder was employed to record specific events and comments in everyday life.

Multi-method assessment strategies of this kind, using hand-held PC instead of written diaries, were likewise developed, for example, by Kamarck et al. (1998). Computer-assisted psychophysiological ambulatory assessment has obvious advantages and appears to be superior to paper-and-pencil diary studies in this field. However, this approach does have shortcomings. Physical activity and posture have to be taken into account if a psychophysiological interpretation of findings is intended, and, eventually, a sudden change in ambient temperature. Physical activity appears to add much more unwarranted variance than does change in posture. Post hoc controls of such effects on cardiovascular measures are possible to some extent by statistical procedures such as cross-correlation or regression techniques. An alternative would be the segmentation of records according to amount of activity present. Some investigators still use the participants' self-reported activity when adjusting for effects of physical activity. Such data are questionable and measurement of physical activity is highly preferable. However, at least one channel for recording activity is required, and two or three channels were preferable.

Many investigators concluded that substantial relationships exist between blood pressure changes and emotions, activities, effort and stress phenomena. The basic issue is whether or not such BP reactions contribute to the development of hypertensive disease.

Personality, Emotions, Job-Stress, and BP

Originally, psychological research of hypertension was concerned with speculations on the etiological role of personality traits. Later-on, specific emotions, such as anger and hostility were indicated as causes of elevated blood pressure and chronic hypertension. According to meta-analyses, such hypotheses were for the most part not substantiated (Jorgensen et al., 1996; Myrtek, 1998; Schum, Jorgensen, Verhaeghen, Sauro & Thibodeau, 2003). However, "positive results" are reported now and again (e.g., Fredrickson et al., 2000). Some of the issues in methodology were discussed in previous reviews which underlined the psychophysiological approach: *Ambulatory monitoring of blood pressure in daily life: A tool for investigating psychosocial processes* (Steptoe, 2001); *Continuous assessment of finger blood pressure and other haemodynamic and behavioral variables in everyday life* (Schmidt & Jain, 1996); *Concurrent assessment of blood pressure, physical activity, and emotional state in natural settings* (Fahrenberg, 1996b). Among the recent contributions are: *Job strain in relation to ambulatory blood pressure, heart rate, and heart rate variability among female nurses* (Riese, van Doornen, Houtman, de Geus, 2004); *Is job strain a major source of cardiovascular disease risk?* (Belkic, Landsbergis, Schnall & Baker, 2004); *Psychosocial demands and ambulatory blood pressure: a field assessment approach* (Kamarck et al., 2002); *Correspondence between laboratory and ambulatory measures of cardiovascular reactivity: a multilevel modeling approach* (Kamarck, Schwartz, Janicki, Shiffman & Raynor, 2003); *Cardiovascular reactivity and development of preclinical and clinical disease states* (Treiber et al., 2003); *Partner interactions are associated with reduced blood pressure in the natural environment: ambulatory monitoring evidence from a healthy, multiethnic adult sample* (Gump, Polk, Kamarck & Shiffman, 2001); *Objective characteristics of jobs affect blood pressure at work, after work and at night* (Rau, 2001); *Effects of work stress on ambulatory heart rate, heart rate variability,*

and blood pressure (Vrijkotte, Riese & de Geus, 2001); *Task demands and the pressures of everyday life: Associations between cardiovascular reactivity and work blood pressure and heart rate* (Steptoe, Cropley & Joeke, 2000).

A comprehensive study was designed to investigate the association between mild hypertension as defined by both ambulatory and clinic blood pressure measurements and measures obtained by personality questionnaires. The ambulatory monitoring comprised a sample of 283 men between the ages of 30 and 60 years, controlling for age, race/ethnicity, and body mass index. No consistent differences were observed between participants with mild hypertension and those with normal blood pressure on any of the psychological variables assessed, including Type A behavior pattern, state and trait anger, anger expression, anxiety, symptoms of psychological distress, locus of control, or attributional style. "These null results suggest that situational, biological, and perhaps behavioral factors are the primary determinants of mild hypertension and that the predictive significance of psychological or dispositional factors is low or negligible in those without overt cardiovascular disease." (Friedman et al., 2001, p. 19). "Given these moderators, the authors conclude that a traditional view of personality causing EH is untenable and that, not incorporating multifactorial, synergistic approaches is likely to obscure associations of personality-behavior with EH." (Jorgensen, Johnson, Kolodziej & Schreer, 1996, p. 293).

The ambulatory assessment approach for examining relationships between psychosocial stress and cardiovascular risk was evaluated and compared to global self-report and laboratory-observation methods. An ecological momentary assessment (EMA) protocol was developed to measure daily life experiences along several psychosocial dimensions including Social Conflict, Task Demand, Decisional Control, Negative Affect, and Arousal. This methodology was used in a large community sample in conjunction with ambulatory blood pressure (ABP) monitoring and measures of subclinical cardiovascular disease. Findings indicated that each of these psychological aspects appears to be a trigger for cardiovascular activation. Individual differences in physiological responsiveness to these dimensions of daily experience, associated in some cases with laboratory-based assessments of cardiovascular reactivity. In several instances, diary ratings were associated with stable between-person differences in ABP readings. Some of the characteristics were related to measures of subclinical atherosclerosis. The predictive validity of these daily life assessments was compared to traditional global self-reports. The advantages and potential future directions for use of daily experience sampling in studies of health and behavior were discussed. *Psychosocial stress and cardiovascular risk: What is the role of daily experience?* (Kamarck et al., 2005).

Overcommitment to Work and Coping

A longitudinal study assessed associations between favorable changes in chronic stress and reduced cardiovascular and neuroendocrine activation in everyday life. Financial strain and reported improvement in financial strain were analyzed from 160 men and women age 47 to 59 years who participated in ambulatory monitoring (T1) and again, three years later (T2). Improved financial strain was associated with lower ambulatory systolic pressure (not with diastolic BP). The cortisol awakening response was also reduced in men who reported, but there were no differences in the slope of cortisol decline over the day or in evening values. The findings were controlled for T1 ambulatory systolic pressure (cortisol level, resp.), gender, socioeconomic position, age, smoking, body mass index, and T1 financial strain. *Changes in financial strain over three years, ambulatory blood pressure, and cortisol responses to awakening* (Steptoe, Brydon, Kunz-Ebrecht, 2005).

Conflicting evidence came from a cohort study. High perceived job strain and cardiovascular high reactivity to a stress test do not appear to be major risk markers for future high BP in healthy, young adults. A cohort of 209 healthy subjects completed a follow-up study for progression to hypertension outcome. The high-strain group, representing 20.9% of the subjects, was compared with the remaining subjects. Similarly, the subjects with the highest BP stress reactivity were compared with the remaining subjects. Progression to hypertension was reached by 93 subjects. Survival estimates revealed that neither high strain nor high reactivity increased the incidence of progression to hypertension. End-of-follow-up 24-hour ambulatory BPs were similar and confirmed the findings. Age, alcohol, salt diet, body mass index, and occupation did not influence the results. *Neither perceived job stress nor individual cardiovascular reactivity predict high blood pressure* (Fauvel et al., 2003).

Ambulatory monitoring was used to assess the psychophysiological correlates of effort-reward imbalance and over-commitment to work in 197 working men and women aged 45 to 59 years. Salivary cortisol was sampled on waking, 30 minutes later, and then at 2-hour intervals. Blood pressure was measured every 20 minutes, using ambulatory methods. Effort-reward imbalance and over-commitment to work were assessed with standard questionnaires. Cortisol responses to waking were positively associated with over-commitment in men, after adjustment for age, socioeconomic position, smoking, time of waking up, and job demands. Over-commitment predicted systolic blood pressure over the day in men after adjustment for age, smoking, body mass index, physical activity, and job control. Neither effort-reward imbalance nor over-commitment predicted physiological responses in women. *Effort-Reward Imbalance, Overcommitment, and Measures of Cortisol and Blood Pressure Over the Working Day* (Steptoe, Siegrist, Kirschbaum & Marmot, 2004).

An ambulatory monitoring study examined the effects of work stress on 24-hour profiles of the pre-ejection period (PEP), a measure of cardiac sympathetic activity, obtained from ambulatory measurement of the impedance cardiogram. A total of 67 male white-collar workers participated on 2 workdays and 1 non-workday. Based on self-reports, work stress was defined according to Siegrist's model as (1) a combination of high effort and low reward at work (high imbalance) or (2) an exhaustive work-related coping style (high over-commitment). High over-commitment was associated with shorter absolute PEP levels during all periods on all 3 measurement days, reduced wake-to-sleep PEP differences and reduced PEP variability. Findings suggested that over-commitment to work was associated with an increase in basal sympathetic drive. *Overcommitment to work is associated with changes in cardiac sympathetic regulation* (Vrijkotte, van Doornen & de Geus, 2004). The 24-hr levels of ambulatory BP and heart rate were measured in two groups of male veterans: 19 with chronic posttraumatic stress disorder (PTSD) and 17 who never met criteria for PTSD. The relationships between diagnostic status, basal cardiovascular activity, and cardiovascular reactivity to stress were examined. Hierarchical linear modeling analyses revealed that the PTSD group showed greater BP reactivity during times of affective distress (taken from activity logs) and had higher resting HR than the non-PTSD group (*Twenty-four-hour ambulatory assessment of heart rate and blood pressure in chronic PTSD and non-PTSD veterans* (Buckley, Holohan, Greif, Bedard & Suvak, 2004).

In an attempt to investigate psychophysiological aspects of religious coping, a 24-hour ambulatory monitoring of BP was obtained from 155 men and women (78 African American and 77 white) on a typical workday. Coping style, negative affect, social support, stress, and health behaviors were also assessed. Multiple regression analyses, controlling for demographic variables, revealed a significant religious coping by ethnicity interaction for ambulatory and clinic BP. Religious coping was not related to BP among whites. Among African Americans, however, higher levels of religious coping and social support satisfaction were associated with lower awake and sleep BP. *Religious Coping, Ethnicity, and Ambulatory Blood Pressure* (Steffen, Hinderliter, Blumenthal & Sherwood, 2001).

The experience of loneliness (self-concept) and assumed psychophysiological concomitants were investigated in lonely and in nonlonely young adults. Ambulatory blood pressure and impedance cardiography were obtained and reports of activities, appraisals, interactions, and health behaviors. Results suggested that loneliness predicted higher TPR and lower CO during a normal day. Loneliness did not predict differences in time spent alone, daily activities, or health behaviors but did predict higher stress appraisals and poorer social interactions. *Loneliness in everyday life: cardiovascular activity, psychosocial context, and health behaviors* (Hawkey, Burlison, Berntson & Cacioppo, 2003).

The relationship between questionnaire assessed marital-role quality, self-reported stress, cortisol levels, and ambulatory blood pressure was investigated in 105 middle-age adults (67 men, 38 women) who had previously taken part in the Whitehall psychobiology study. Ambulatory monitoring and saliva sampling were carried out over a working day. Marital-role concerns were related to all three stress indicators and results did not vary by gender. The findings may suggest that there are influences of domestic strain on biological function over the working day and evening in addition to the carryover of work stress into domestic life. *Marital-Role quality and stress-related psychobiological indicators* (Barnett, Steptoe & Gareis, 2005). In view of the many psychological hypotheses that seek to explain elevated blood pressure, the genetic factors must not be overlooked. It is well known from epidemiological research that hypertension has a strong hereditary component as evidenced by studies in offsprings from hypertensive parents, siblings and twins. This was also confirmed by data from ambulatory monitoring. *Heritability of daytime ambulatory*

blood pressure in an extended twin design (Kupper, Willemsen, Riese, Posthuma, Boomsma & de Geus, 2005). Ambulatory monitoring revealed also that heart rate variability measures are highly heritable traits that can be used to support genetic association and linkage studies relating to genetic variation influencing cardiovascular disease risk. This conclusion came from an investigation of 772 healthy twins and singleton siblings who participated in 24-hr ambulatory ECG recordings. Two HRV-indices were used. *Heritability of ambulatory heart rate variability* (Kupper et al., 2004); *A genetic analysis of ambulatory cardiorespiratory coupling* (Kupper et al., 2005).

Interactive Monitoring of BP and ECG

ECG (Holter-) 24-hr monitoring for the detection of ischaemic episodes, arrhythmias, etc. is standard equipment in cardiology. Real-time analysis of the ECG may lead to innovative methods of interactive monitoring. *Ambulatory monitoring of the digitized electrocardiogram for detection and early warning of transient myocardial ischemia in angina pectoris* (Barry, Campbell, Nabel, Mead & Selwyn, 1987). Thus, occurrence of myocardial ischaemia detected in the ECG can be employed for prompting the patient and obtaining a self-report on antecedent activities and experiences: *Symptomatic myocardial ischaemia (heart pain) is linked to the psychological context in daily life. Implications for a clinical use of interactive monitoring* (Kinne, Droste, Fahrenberg & Roskamm, 1999). Also, the ST-segment depression can be used to trigger the measurement of BP. *Simultaneous recording of blood pressure and ST-segment with combined, triggered ambulatory 24-h devices* (Uen, Vetter & Mengden, 2003; Uen et al., 2003).

Psychophysiological BP monitoring is basically directed to assess individual phasic reactivity caused by emotions or stress in daily life. Since BP variability in daily life is to some extent caused by physical activity, the metabolic and non-metabolic effects are confounded. A newly developed method of multiple accelerometry allows the control such unwanted variances by continuously detecting posture, general activity, and distinct movement patterns. Contingent to episodes of additional heart rate (AHR, see below), an indicator of emotional reactivity, BP measurements can be triggered and participants prompted to enter their current self-report in a hand-held PC. To evaluate both new methods for BP research, a 24-hr ambulatory monitoring was performed with 40 normotensive student subjects, designed to include a standard setting for a controlled comparison (Library vs. Cinema). The findings indicated that in the Cinema higher values of AHR were elicited. However, group differences in BP were not observed. Accelerometry was useful for demarcation of bed-rest and activity, and for classification of BP measurements according to posture and activity (Fahrenberg & Foerster, 2002; Prill & Fahrenberg, 2006).

Finger Blood Pressure

The Finapres™ and Portapres™ methodology (TNO, BioMedical Instrumentation) has opened an essentially new window for the investigation of blood pressure dynamics. The higher resolution in time (beat-to-beat analysis) as compared to intermittent oscillometric measurement is an important advantage; however, the doubtful precision of finger blood pressure measurement appears to be a serious drawback. Reviews by Imholz, Wieling, van Montfrans and Wesseling (1998) and Silke and McAuley (1998) regarding the Finapres/Portapres methodology stated that the precision, especially in systolic blood pressure measurement, was not sufficient when compared to intra-arterial measurement.

Studies that employed the Portapres-System in psychophysiological research in daily life and in the laboratory were: *Ambulatory 24-hour monitoring of brachial and finger blood pressure in normotensive and hypertensive males* (Seibt, Berndt, Knöpfel & Scheuch, 2001); *Non-invasive beat-to-beat blood pressure monitoring: new developments* (Parati, 2003); *Continuous finger monitoring of blood pressure: advantages, problems and perspectives* (Parati, 2000); *Fifteen years experience with finger arterial pressure monitoring: assessment of the technology* (Imholz et al., 1998); *Socioeconomic status and hemodynamic recovery from mental stress* (Steptoe, Willemsen, Kunz-Ebrecht & Owen, 2003); *Diagnostic value of simultaneous non-invasive continuous, ambulatory finger blood pressure and electrocardiogram monitoring in a patient with hypertrophic obstructive cardiomyopathy* (Boon, van Goudoever, Huijskes, Piek & van Montfrans, 2002).

The measurement precision was also evaluated by obtaining continuous recordings with two devices at the same time. The recordings were made in 31 normotensive students under conditions of rest, during ergometer work, and recovery, all in supine position. The recording devices included two Portapres Model 2.0, two SpaceLabs Mod 90207 and the Vitaport 2. The agreement of measurements was examined by testing the mean difference of measures referring to the agreement plot difference vs. mean of methods. The mean difference between measures from both devices seemed to be negligible, however, the large confidence interval indicated a low precision of single measures. Obviously, the accuracy and precision of oscillometric measurements were superior to the finger BP measurements. The findings showed that the discrepancies were not due to a constant offset that might be disregarded in practice. In conclusion, BP measurements obtained with the Portapres™ Model 2.0 should be explicitly stated as *finger* blood pressure. It is up to the user to decide whether to use this device in research studies in which better time resolution is desirable and the obvious drawback in measurement precision can be tolerated. Standard oscillometric measurements may be included in continuous finger blood pressure recordings to provide reference values (Fahrenberg, 2000). Recordings of finger blood pressure were made in 40 hypertensive patients during a psychosomatic interview pertaining to recent emotions, social conflicts, and related themes. The patients were particularly keen to view a video-playback of this recording and to evaluate and discuss the dynamics of "their" blood pressure reactions (Schäfer et al., 2005).

The interactive monitoring methodology developed by Myrtek et al. (1988, 2001) to assess additional, that is, non-metabolic, heart rate, was adopted for the definition of "additional systolic blood pressure". A pilot study used continuous recordings of systolic finger blood pressure (Portapres Method) in five healthy subjects who went to a cinema and attended an action movie. This methodology proved to be feasible and revealed more insight in the dynamics of blood pressure behavior (Fahrenberg & Foerster, 2002).

Conclusions and Perspectives

Recordings in daily life necessarily include unwanted variance caused by physical activity. The evaluation of blood pressure changes has advanced with the availability of reliable accelerometric methods. The valid assessment of 24-hr recordings requires a reliable segmentation of rest phases and activity (night/day), and moreover, the detection of the amount of physical activity, of posture, and even body rotation during sleep. Although well known, the BP-activity correlation so far had little influence on the design of devices. Blood pressure monitors used in 24-hr monitoring do not measure physical activity. Patients are therefore instructed not to move during the measurement and to make diary notes to report periods with physical activity and to register the time of bed-rest. It is up to the physician to attempt the interpretation of the 24-hr BP profile.

The separation of specific effects and estimation of effect sizes may be difficult in ambulatory recordings because changes in physical activity, posture, and motion are obviously related to certain types of behaviors, interactions, etc. Furthermore, the patients' behavioral reactivity to being monitored may play a more important role than previously assumed.

The 24-hr blood pressure recording is both in research and application the most prominent field in ambulatory monitoring. The clinical benefits of this methodology for diagnosis and treatment of hypertension and other diseases are especially evident. Psychophysiological ambulatory monitoring studies have contributed to our understanding of blood pressure variability and reactivity under naturalistic conditions.

Following the decline in support for the psychosomatic theories that related hypertension to personality traits, such as hostility, Type-A-behavior, or specific emotions like anger, the leading role played by these theories in guiding research on hypertension has been largely superseded by stress theories of hypertension. Exaggerated cardiovascular reactivity to work-related stressors or incomplete recovery after work has been proposed as a likely mechanism underlying this increase in risk of hypertension.

Self-reports on emotion and perceived stress may correspond with noticeable BP changes in daily life. There is however no consistent relationship here because the incidence of emotions is often re

ported without obvious increase in heart rate or BP. Interactive monitoring studies indicated that self-reports on momentary emotions in everyday life were not often accompanied by significant heart rate changes and vice versa (see Section 4.5). It may be concluded that relationships between blood pressure changes and self-reported emotions or episodes of stress are likewise inconsistent. Neither patients nor healthy subjects are generally aware of their momentary BP or acute BP changes. The mechanisms that trigger off subjective feelings of emotion or strain and cardiovascular activation are not well understood at present.

The effects of physical activity on BP and heart rate are obvious and should be accounted for when interpreting the investigated psychological effects of physical activity on BP. Furthermore, the inconsistencies in psychophysiological BP research relating to hypertension may be due, in part, to limitations of psychological methods and the presence of a number of basically confounded effects. At present, personality traits are usually assessed by questionnaires. Such self-reporting is of a subjective nature and susceptible to retrospection effects and social stereotypes. Especially the attitudes to health and the awareness of hypertension, or to being at risk for hypertension, may add to subjective appraisal.

Research findings in this field often appear to be doubtful because the psychological variables, mostly from questionnaires, are assumed to be empirically valid. Job stress is defined often as perceived stress, feeling of time pressure, or daily hassles. Job stress-strain was also investigated with respect in the context of Karasek's concept concerning job demand/control latitude, or Siegrist's concept relating to imbalance high effort and low reward at work and an exhaustive work-related coping style (over-commitment). The pertinent issue is whether a particular questionnaire is employed in this research or whether objective work load was independently assessed by observation or behavioral measurement. Much of the previous research used only self-reports. From a methodological point of view, such investigations have little chance to control for the role of naïve concepts of stress and health. The naive stress theory may be so consistently integrated in the population's health belief system that findings from interview or questionnaire methods appear to be basically confounded from the onset.

There are inherent limitations in measuring blood pressure because the conventional technique is not capable of measuring BP continuously, with the result that short-lasting increases in BP will usually be overlooked, even though such variability may be a feature of emotional reactions. Large surveys have pointed out to a number of objective factors which are correlated with risk of cardiovascular disease. Among them are: age and gender, body mass index, alcohol, nicotine, salt diet, inactive, sedentary lifestyle, and certain co-morbidities, such as diabetes. All of these factors are strongly related to differences in behavior, and partly to occupation and socioeconomic status (demographic variables), leisure time activities, etc. This diversity of factors is confounded and post hoc statistical adjustments may be insufficient to control for all these confounded effects. This may explain the contradictory state of affairs that is so characteristic for this research domain. Some studies seem to indicate a sizeable association of ambulatory blood pressure and hypertension with job stress-strain, whereby some of the important intervening factors were controlled for. There is contradictory evidence also and meta-analyses can hardly contribute to clarifying the situation because of the impact of confounding effects and difficulties in post-hoc adjustments for such unwanted variance.

Ambulatory BP recordings are exemplary in many respects. Besides the obvious benefits in clinical practice many lessons can be learned from these developments with respect to stepwise refinement of assessment strategies and control for unwanted variance.

4.4 Physical Activity, Posture, Movement and Movement Disorders

General context

The recording of posture and motion is a basic aim in behavior observation and measurement. These measures are also highly important as secondary variables because they allow physical activity and movement artifacts to be detected in physiological recordings, for example, in blood pressure or heart rate recordings.

The conventional methodology made use of wrist-worn actometers, tilt-switch transducers, mechanical pedometer, piezo-ceramic sensors, and other electronic devices to register movements. Actometer devices are suitable for many applications and they are easier to apply than recordings of the electromyogram, and more convenient than video tape analysis. The measurement of activity in psychology, psychophysiology, and medicine was evaluated in a number of reviews (Bussmann, 1998; Fahrenberg & Myrtek, 2001b; Freedson & Miller, 2000; Mathie, Coster, Lovell & Celler, 2004b; Patterson et al., 1993; Stanley, 2003). However, the methodology of actigraphy (actometer recordings) and movement analysis has experienced an essential break-through in the last decade because a new type of sensor became available and appropriate algorithms for detection of posture, movement and movement pathologies were developed. Actigraphy is the traditional term used for a variety of measurement techniques.

Physical activity is defined here as gross body movement that usually involves, in varying degrees, the upper and lower extremities and the movement of the trunk, neck, and head. The design of the assessment of physical activity will depend on the specific aims of a given study. Among these are:

- measurement of the subject's activity level for the 24-hour period;
- detection of change in body position, for example, lying supine, sitting, standing, body rotation, for example, during sleep, and movement behaviors, for example, walking, climbing stairs, transition from sitting to standing, postural sway, falls;
- quantification of gait, that is, spontaneous step frequency, length of stride and vigor of walking pace;
- detection of more specific movements, for example, using a tool, typing a keyboard, detection of finger and arm movement (gestures) or head movement such as nodding during a conversation;
- diagnosis of movement disorders, such as hand tremor in Parkinson's disease, restless legs syndrome, the monitoring and evaluation of physical training in patients with movement pathologies, in clinical rehabilitation programs;
- detection of recording segments of bed rest (sleep) and segments of behavioral activity during the day, which is important for evaluation of, for example, blood pressure profiles;
- measurement of overall physical activity in which multi-site accelerometer output is integrated to derive a composite index to represent momentary energy expenditure.

Methodology

The progress in the assessment of movement and posture resulted from three developments:

(1) The wide bandwidth of new piezoresistive (for example, ICSensor Model 3031, Analog Devices ADXL202) and piezocapacitive sensors paved the way for the development of a new methodology with

calibrated accelerometers. The DC signal output, that is, signal output < 0.5 Hz, allows the assessment of change in position in relation to the gravitational axis, that is, inclination in degrees, and the AC signal output > 0.5 Hz is used to represent acceleration in terms of the gravitation along the sensitive axis of the device (g or milli-g).

(2) The development of pocket-sized digital data recorders has especially facilitated multi-channel ambulatory monitoring and 24-hour recording of activity in daily life.

(3) The increase in computer capacity that enabled advanced methods of signal analysis, such as joint time (amplitude) – frequency analysis, and specific methods of filtering. Software has been developed for automatic detection of motion patterns in multi-channel recordings.

Multi-channel (multi-site) accelerometry with calibrated sensors is thus a very promising methodology, and researchers are becoming increasingly aware of the many advantages this approach has to offer and of its potential fields of application in psychology and medicine (see Bussmann, 1998; Jain, Martens, Mutz, Weiß & Stephan, 1996; Veltink & van Lummel, 1994). The capabilities of accelerometry in monitoring human movement and strategies for various modes of monitoring were also discussed by Freedson and Miller (2000) and Mathies et al. (2004).

Compared to EMG recordings, accelerometry has some practical advantages. EMG recordings usually require abrasion of the skin and application of an electrolyte. Properties of the skin-electrode system exhibit systematic and time-dependent changes. Such limitations may become especially evident in clinical investigations that involve repeated measurement designs and long-term recordings. The processing of the EMG

raw signal requires certain assumptions such as those concerning stationarity and filter settings. Accelerometry appears to have major advantages, especially the ease in application of sensors.

Indeed, the majority of investigations so far have only employed the conventional sensors and were therefore unable to use the DC-component as an indication of posture (inclination). In addition, the subject samples studied were usually small. Posture and motion patterns do exhibit a remarkable inter-individual variability. Therefore, a larger number of subjects is required to investigate such patterns. The selection of a minimal sensor configuration would be of practical interest in this context. – Again, as with BP measurement, this Section focuses on the methodology and psychophysiological research questions.

Basic issues

Multi-channel accelerometry was recently evaluated in a number of ambulatory monitoring studies. The evaluation indicated the importance of the following questions raised: Which algorithms are suitable for the *detection of motion patterns and posture*, and which *sensor placements* would provide a minimal configuration to assess a broad spectrum of functional activities? A third issue was the choice of a sensor placement or a sensor configuration for a *valid prediction of general physical activity and energy* expenditure (for reviews, see, Fahrenberg & Myrtek, 2001b; Westerterp & Plasqui, 2004; Patterson et al., 1993).

With a few exceptions, previous classification studies referred only to a small number of motion patterns. It is clear that in addition to standing, sitting, lying, walking, climbing stairs, further behaviors should be included (Bussmann, 1998; Bussmann, Tulen, van Herel & Stam, 1998; Foerster, Semja & Fahrenberg, 1999): samples of walking at normal and fast pace, the discrimination between walking and climbing of stairs. Transitions from lying to standing position or falls may be of interest, and subtypes of lying, that is, lying on the right or left side, supine or with back supported, and a preferred position at sleep onset, are necessary to monitor bed rest and nightly body rotation.

Algorithms for detection of posture and motion patterns

Several suggestions have been made as to how to achieve an adequate data reduction and to differentiate between a variety of dynamic activities under investigation. The development of pattern recognition systems based on different strategies was proposed. However, only two approaches have been used to a greater extent. *Fixed-threshold classification.* Motion patterns, for example, lying supine, standing, walking, climbing stairs, can be differentiated by applying a threshold to the signal of the thigh accelerometer. The threshold is derived from empirical studies and is used for all subjects. The discrimination between more classes of motion patterns requires a greater number of threshold values and appropriate normative studies (Bussmann, 1998; Bussmann et al., 1998, 2001; Lyons, Culhane, Hilton, Grace & Lyons, 2005).

Reference-pattern based classification. The detection of motion patterns can be improved if individual reference patterns for each postural and activity condition are obtained by an initial recording of the essential patterns under investigation. This standard protocol consists of a fixed sequence of behaviors, recorded for at least 30 s each, allowing for individual differences of movement and some deviations in positioning of the sensitive axes, accounting for individual morphology. In the case of such a standard protocol, multivariate analyses and pattern similarity coefficients can be used for the detection and labeling of an actual segment, that is, motion pattern with reference to the standard protocol (Fahrenberg et al., 1997; Foerster, 2001; Foerster & Fahrenberg, 2000; Foerster, Smeja & Fahrenberg, 1999).

In view of these considerations, the use of a reference-pattern based classification rather than a fixed threshold classification is recommended whenever possible. The standard protocol takes less than a minute of recording time for every posture and motion. The protocol can be easily adapted to specific subsets of behaviors and the strategy is highly flexible since certain reference patterns may be included later, if necessary, after conclusion of monitoring. Further refinement was achieved by a hierarchical strategy which classifies postures and subsequently uses reference patterns for the discrimination between subsets of dynamic activities. Calibration refers here, firstly, to the standard protocol which provides the basic reference patterns, and, secondly, to the calibration procedure regarding each piezoresistive sensor and recorder channel.

The increase in the number of sensors and axial representations of movements raised the question about the choice of a sensor configuration sufficient to detect the major classes of posture and motion correctly. The answer will depend partly on the actual selection of movements and functional activities, although the main classes of posture and a set of basic motion patterns may be regarded as core patterns. Which sensor

placement gives the minimal configuration for detection of these core patterns? An extended configuration using a larger number of sensors may be able to detect, for example, essential subtypes of moving or lying in bed, and may therefore be preferable for a full 24-hour recording.

Sensor placement

The flat design of today's accelerometers permits the placement of sensors on many parts of the body, even on the distal phalanx of the finger. The sensors can be placed as follows: *Sternum*. Three uni-axial sensors placed adjacently at the sternum about 5 cm below the jugulum, the sensitive axes pointing in a vertical (1), sagittal (2), and transversal (3) direction, that is, in the z-, x- and y-direction, respectively. *Thigh*. Frontal aspect of right (4) and left (5) thigh, distal from m. rectus femoris, about 5 cm above the patella, the sensitive axis of the sensors roughly perpendicular to the surface, that is, to the frontal aspect of the sternum and the frontal aspect of the thigh. The positioning must be designed with care, especially for uni-axial sensors, because the response characteristics depend on the degrees of inclination between axis and direction of movement (acceleration). The Vitaport/Varioport (Becker Meditec, Karlsruhe, Germany) or the Acitivity Monitor (Temec Instruments, Kerkrade, NL) and other systems of comparable technical capacities can be employed. (For more details see the original publications).

Five-sensor configuration. An almost perfect concordance was found between the behavior protocol in the laboratory and the classification based on calibrated accelerometry with a five-sensor configuration. The overall agreement was impaired only by 3.2 % misclassifications, most of which concerned the discrimination between sitting upright/leaning backward and the discrimination between dynamic activities, that is, walking, and climbing stairs (Foerster & Fahrenberg, 2000). The sternum sensor proved to be superior in estimating pace, the signal amplitude of walking represents, however, the vigor of stride.

Two-sensor configuration. With this configuration, that is, z-direction of the sternum sensor and x-direction of the right thigh, the agreement for classes of lying, standing, moving, and sitting, was almost perfect, indicating only 1.3 % misclassifications. Since the sternum sensor x-direction (sagittal) and the y-direction (transversal) were disregarded here, subtypes of walking, of sitting, and of lying could not be distinguished, but the two-sensor configuration was clearly sufficient for differentiating between four basic classes (sitting, standing, lying, moving) in ambulatory monitoring.

Thus, a sensor configuration for standard accelerometric detection of frequently occurring posture and motion patterns was proposed for use with the Vitaport/Varioport systems (Foerster, 2001). The methodology developed here can be easily adopted to account for further motion patterns on condition that appropriate variation regarding the sensitive axes of sensors exist and such motions are included in the standard protocol.

The findings from these method studies conducted at Freiburg University basically correspond with the findings reported by the Rotterdam Group (see, Bussmann et. al., 2001) that used multiple accelerometry with three piezoresistive sensors and the stand-alone Activity Monitor (AM). Both research programs showed that a large variety of static and dynamic motion behaviors can be correctly detected by multi-channel accelerometry, appropriate signal processing, and statistical analysis.

A similar approach around a binary hierarchical decision tree was recently developed. The classifier was examined in 26 subjects in a controlled laboratory study. For a set of basic movements, the sensitivity of every classification exceeded 87%, and the specificity exceeded 94%. *Classification of basic daily movements using a tri-axial accelerometer (Mathie, Celler, Lovell & Coster, 2004a)*.

The time has come for cross-laboratory standardization of accelerometry and guidelines, concerning algorithms and the optimal sensor configurations, like the standard ECG leads in cardiology.

The number of steps per time period is an important ambulatory measure describing an individual's locomotor function, with implications for psychological and physical health. Key applications in neurology, psychiatry, psychopharmacology, and sports, behavior or rehabilitation medicine make it desirable to improve step detecting devices. An algorithm that detects, classifies and counts steps related to walking, running and shuffling motion was presented. Data is recorded using the (LifeShirt, VivoMetrics, Inc., Ventura, CA, USA) ambulatory monitoring system which captures also breathing information from respiratory inductive plethysmography (RIP) sensors embedded in a light garment, and acceleration signals from a dual axis accelerometer. Since these signals may often contain noise and artifact due to soft tissue movement or exter

nal vibrations they are filtered and autocorrelated. The autocorrelation coefficients allow for clearer detection and classification of the cyclic motion during walking, running and shuffling movements. The results have demonstrated an effective locomotor-monitoring and accurate estimates of frequency and intensity of steps and shuffles and help classify daily locomotor activities, especially in Parkinson's Disease. *Classification of locomotor activity by acceleration measurement: validation in Parkinson disease* (Keenan & Wilhelm, 2005).

A method was developed for the estimation of spatio-temporal gait parameters. The inertial measurement unit is composed of one biaxial accelerometer and one rate gyroscope, and it reconstructs the sagittal trajectory of a sensed point on the instep of the foot. A gait phase segmentation procedure was devised to determine temporal gait parameters, including stride time and relative stance, stride length, walking speed, and incline. *Assessment of walking features from foot inertial sensing* (Sabatini, Martelloni, Scapellato, Cavallo, 2005). Gait cycle parameters were measured by a tri-axial portable accelerometer over the lower trunk during timed walking over a range of self-administered speeds. Signals were analyzed by an autocorrelation procedure to obtain cadence, step length, and measures of gait regularity and symmetry, whereby speed-dependent gait parameters could be transformed by curvilinear interpolation. *Estimation of gait cycle characteristics by trunk Accelerometry* (Moe-Nilssen & Helbostad, 2004). Ambulatory monitoring confirmed laboratory studies that the preferred step frequency is approximately 120 steps/min and that humans exhibit a preferred cadence at this step frequency during extended periods of uninhibited locomotor activity. *Marching to the beat of the same drummer: the spontaneous tempo of human locomotion* (MacDougall & Moore, 2005).

A number of method studies deserve to be mentioned although the findings that sometimes pertain to further and more specific issues and applications can not be presented in detail: *Posture and motion analysis by ambulatory accelerometry* (Bussmann, van den Berg-Emons & Stam, 2001); *Analysis and decomposition of accelerometric signals of trunk and thigh obtained during the Sit-to-Stand movement* (Jansen, Bussmann, Horemans & Stam, 2005); *Relationships between a novel upper limb activity monitor and four other instruments to determine functioning in upper limb complex regional pain syndrome type I*. (Schasfoort, Bussmann & Stam, 2005); *Assessment of posture, motion, and hand tremor by calibrated accelerometry* (Foerster, 2001); *Objective monitoring of physical activity using motion sensors and heart rate* (Freedson & Miller, 2000); *The use of the Actiwatch-Neurologica system to objectively assess the involuntary movements and sleep-wake activity in patients with mild-moderate Huntington's disease* (Hurelbrink, Lewis & Barker, 2005); *Reliability and validity of the combined heart rate and movement sensor Actiheart* (Brage, Brage, Franks, Ekelund & Wareham, 2005).

There may be further developments stemming from the use of miniature gyroscopes to detect true inertial angular rate, that is, three-dimensional rotation. The location of the gyroscope is not critical since there is no response to "tilting" as seen in accelerometer use. *The development and test of a device for the reconstruction of 3-D position and orientation by means of a kinematic sensor assembly with rate gyroscopes and accelerometers* (Giansanti, Maccioni & Macellari, 2005); *Measuring orientation of human body segments using miniature gyroscopes and accelerometers* (Luinge & Veltink, 2005).

Application

Actigraphy has been used also in sleep research for assessment of sleep duration and segmentation of phases of rest. Some of the findings indicated that the actigraphy was less reliable in detection of body position and activity than polysomnography which also included a number of EMG- and EEG-channels. However, only some of the previous investigations used the new sensor type and advanced software programming: *Sleep detection with an accelerometer actigraph: comparisons with polysomnography* (Girardin, Kripke, Cole, Assmus & Langer, 2001); *Sleep Duration, Illumination, and Activity Patterns in a Population Sample: Effects of Gender and Ethnicity* (Girardin, Kripke, Ancoli-Israel, Klauber & Sepulveda, 2000); *The role of actigraphy in the study of sleep and circadian rhythms* (Ancoli-Israel et al., 2003). Accelerometry has obvious advantages for sleep recordings at home because it is easier to apply than the EMG.

Accelerometry was applied in the analysis of disturbed motor function in patients, for example, neurological disorders or stroke patients. Recent studies demonstrated the advantages of this methodology and practical benefits in physical therapy and rehabilitation, because feedback was provided also to the patient on

improved motor performance, thus exerting positive effects on awareness of progress in training and in gaining more self-confidence. Examples of such applications are: *Accelerometry in clinical psychophysiology* (Tulen, Volkens, Stronks, Cavelaars & Groeneveld, 2001); *Ambulatory accelerometry to quantify involuntary movements and tics in the syndrome of Gilles de la Tourette* (Tulen, Groeneveld, Romers, de Vries & van de Wetering, 2001).

A remarkable number of method studies and applied research in rehabilitation medicine was contributed by the Rotterdam Group, that is, Bussmann, Stam and co-workers. Examples for such studies in patient groups were: *Level of activities associated with mobility during everyday life in patients with chronic congestive heart failure as measured with an "activity monitor"* (van den Berg-Emons, Bussmann, Balk, Keizer-Oster & Stam, 2001); *Daily physical activity and heart rate response in people with a unilateral trans-tibial amputation for vascular disease* (Bussman, Grootsholten & Stam, 2004); *Sensitivity and reproducibility of accelerometry and heart rate in physical strain assessment during prosthetic gait* (Bussmann, van den Berg-Emons, Angulo, Stijnen & Stam, 2004); *Does aerobic training lead to a more active lifestyle and improved quality of life in patients with chronic heart failure?* (van den Berg, Balk, Bussmann & Stam, 2004).

The measurement of the physical activity that a subject performs spontaneously could be a useful, above all when applied to objective measurement of disability, particularly in patients with disease-related functional impairment. *Ambulatory system for the quantitative and qualitative analysis of gait and posture in chronic pain patients treated with spinal cord stimulation* (Paraschiv-Ionescu, Buchser, Rutschmann, Najafi & Aminian, 2004). Patients with lower back pain showed a lower activity pattern compared with controls, lower walking step frequency, more lying and less standing time, reduced activity, especially in the evening. *Assessments of activities of daily living with an ambulatory monitoring system: A comparative study in patients with chronic low back pain and non-symptomatic controls* (Spenkelink, Hutten, Hermens & Greitemann, 2002). Accelerometry provides an objective, real-world index of upper-extremity rehabilitation outcome and has good psychometric properties. *Ambulatory monitoring of arm movement using accelerometry: an objective measure of upper-extremity rehabilitation in persons with chronic stroke*. (Uswatte, Foo, Olmstead, Lopez, Holand & Simms, 2005).

Accelerometry was used to assess the relationship between the physical activity level and time spent on activities of various intensities in children. A better understanding of physical activity in children appears to be essential for education and prevention about physical (in)activity in childhood. *Physical activity pattern of children assessed by tri-axial accelerometry* (Hoos, Kuipers, Gerver & Westerterp, 2004). The purpose of another study was to document the age and gender-related physical activity levels on a sample of 157 school children, aged 8 to 15 years-old. The Computer Science Application (CSA) activity monitor was used as an objective measure of daily physical activity. Each student was scheduled to wear the CSA 3 times during the week of monitoring. Age and gender-related physical activity was reported. *A descriptive study in children using Accelerometry* (Santos, Guerra, Ribeiro, Duarte & Mota, 2003). Health benefits of a physically active lifestyle are often discussed. Accelerometry is a valuable tool for the assessment of activity patterns and may be useful to highlight periods of inactivity, for example, relating to physical education in schoolchildren, or for intervention designs in overweight subjects and obese patients. *Physical activity patterns in normal, overweight and obese individuals using minute-by-minute Accelerometry* (Cooper, Page, Fox & Mission, 2000).

Health benefits of a physically active lifestyle are often discussed. A sample of 200 children was monitored using a 24-hour ECG monitoring device during normal weekdays and the percentage of heart rate reserve was used to estimate the amounts of physical activity at different intensities. The findings suggests that these children were not engaged in sedentary behavior but did not experience the ideal amount and type of physical activity usually believed to benefit the cardiopulmonary system. Public health strategies should be adapted to such findings. *Patterns of physical activity defined by continuous heart rate monitoring among children from Liege* (Massin, Bourguignon, Lepage & Gerard, 2004); *Study of cardiac rate and rhythm patterns in ambulatory and hospitalized children* (Massin, Bourguignon & Gerard, 2005); *Fundamental movement skills and habitual physical activity in young children* (Fisher, Reilly, Kelly, Montgomery, Williamson, Paton & Grant, 2005).

The feasibility of using accelerometry to monitor human movements and to detect changes in functional status in the elderly in an unsupervised home setting was examined. A waist-mounted, wireless tri-axial ac

celerometer was used. A pilot study was carried out with six healthy subjects aged 80-86 years. Subjects wore the device every day for two to three months. Important movement variables were measured and subjects were monitored for incidence of falls and for general level of activity (energy expenditure). There was a moderate correlation between weekly self-reported health status and energy expenditure. All subjects found the system comfortable to wear and high compliance rates were observed. *A pilot study of long-term monitoring of human movements in the home using accelerometry (Mathie et al., 2004); Comparative effects of two physical activity programs on measured and perceived physical functioning and other health-related quality of life outcomes in older adults (King et al., 2000) Unterstützung präventionsmedizinischer Ansätze mit Hilfe von telemedizinischem Monitoring (Bolz, 2005).*

Tremor and Restless-Legs

Clinical studies on the course of tremor and appropriate medication necessitate repeated measurement designs that may include, besides standardized rest and postural tremor tests, long-term recordings. 24-hour ambulatory monitoring would further facilitate the investigation of how tremor activity is affected by change of posture, by time of day and night, and, possibly, by emotional and behavioral events. Patients with moderate tremor amplitude may be significantly disabled if their tremor is constant, whereas other patients may be disabled because of intermittently severe tremor.

In the past, a number of ambulatory recordings of wrist activity and day-to-day variability were made in patients with Parkinson's disease. In clinical studies of tremor, electromyographic recordings prevailed. Only EMG-recordings allow differentiation between essential tremor and Parkinson's disease tremor by using cross-correlation analysis of agonist-antagonist activation pattern. A datalogger for EMG recordings was developed and the validity of long-term electromyography in the quantification of tremor was examined (Spieker, Boose, Breit & Dichgans, 1998; cf. Tremor Analyzer, CSM, Filderstadt, Germany). But, multiple accelerometry appears to have a number of advantages over this approach.

Continuous ambulatory multi-channel accelerometry was employed in a clinical study for the assessment of the core features of PD, that is, hypokinesia, bradykinesia, and tremor. A self-assessment scale of such symptoms was the criterion. Measures showed limited sensitivity and specificity for motor complications in individual PD patients. In the group of PD patients, comparing the "on" with the "off" state of medication yielded statistically significant differences for tremor only. *Accuracy of objective ambulatory accelerometry in detecting motor complications in patients with Parkinson disease (Hoff, van der Meer & van Hilten, 2004).* Ambulatory multi-channel accelerometry was employed for the assessment of resting tremor in patients with Parkinson's Disease while simultaneously measuring hypo- and bradykinesia and body position. *Ambulatory objective assessment of tremor in Parkinson's disease (Hoff, Wagemans & van Hilten, 2001); Classification of locomotor activity by acceleration measurement: validation in Parkinson disease (Keenan & Wilhelm, 2005); Actigraph analysis of diurnal motor fluctuations during Dopamine agonist therapy (Katayama, 2001).*

Calibrated multiple accelerometry was employed in monitoring patients with Parkinson's Disease who participated in a rehabilitation program for four weeks. Frequency and duration of tremor, and, moreover, tremor amplitude can be derived from the accelerometer signal. The 24-hr protocol further depicts posture and movement behavior, and, possibly, heart rate. Such recordings provide means for a thorough inspection of the course of symptom change during day and night, and of particular tremor episodes and possible antecedents, as well as, medication: *Joint amplitude and frequency analysis of tremor activity (Foerster & Smeja, 1999); 24 hr assessment of tremor activity and posture in Parkinson's disease by multi-channel accelerometry (Smeja et al., 2000); Tremor in Parkinson's disease: 24-hr monitoring with calibrated accelerometry (Thielgen, Foerster, Fuchs, Hornig & Fahrenberg, 2004).*

One of the investigations dealt with the relationship between rest and postural tremor tasks and tremor during monitoring and examined the changes during the course of treatment in 20 patients with Parkinson's disease. The most pronounced tremor activity was noted during the initial tasks for assessment of rest and postural tremor under distraction, and the lowest during the night segment. The regression analyses generally indicated a moderate to high "laboratory-field" relationship, in which the measures taken from the postural tremor test under distraction provided the best predictor variable in laboratory-field comparisons. On average, tremor decreased from the beginning to the end of the rehabilitation program which consisted of physical therapy and adjustment in dosage of medication. It is noteworthy that in a few patients there was an in

crease instead of decrease in tremor from first to second recording. Distinct psychophysiological episodes in which the tremor was obviously enhanced by emotional activation or mental effort were rarely observed. The ambulatory monitoring is a suitable method to further investigate such relationships and to objectively assess the external validity (generalizability) of treatment effects (Thielgen et al., 2004).

Accelerometry lends itself also to recording of restless-legs syndrome. Feasibility studies suggest that this methodology detects episodes of periodic leg movement (PLM) during night and occurrences during the day with sufficient reliability. *New actigraph assessment method for periodic leg movements* (Kazenwadel et al., 1995); *24-Stunden-Monitoring des Restless-Legs-Syndroms mit multipler kalibrierter Akzelerometrie* (Prill, Foerster, Voderholzer, Hornyak & Fahrenberg, 2003); *Role of portable sleep studies for diagnosis of obstructive sleep apnea* (Boyer & Kapur, 2003); *The clinical neurophysiology of the restless legs syndrome and periodic limb movements. Part I: diagnosis, assessment, and characterization* (Henning, 2004); *Initial demonstration of the accuracy and utility of an ambulatory, three-dimensional body position monitor with normals, sleepwalkers and restless legs patients* (Gorny, Allen, Krausman & Cammarata, 2001). The general lower limb activity measured by three-channel actometry is a promising objective measure of restless legs syndrome (RLS) severity. In 15 RLS patients both, nocturnal lower limb activity and controlled rest activity decreased significantly during the clinical trial of a new medication in parallel with the subjectively reported relief of RLS symptoms. *Actometry in measuring the symptom severity of restless legs syndrome* (Tuisku, Holi, Wahlbeck, Ahlgren & Lauerma, 2005).

Measures of behavior suited for assessment in daily life

Besides gross motor behavior, posture and motion, many more aspects of behavior can of course be measured in everyday life to assist in objective behavior analysis. A range of interesting variables could be obtained continuously by accelerometer recordings. Such target behaviors may include specific patterns of movement, for example, using a tool, typing a keyboard, individual features of gait, etc. Noteworthy is a class of behaviors, which represent the expression of emotion and social interaction: Gesture, that is movement of hand, arm, and head movement, or nodding during a conversation. An interesting application is the measurement of head movement behavior in everyday face-to-face communicative interaction (Fahrenberg et al., 2002) which was previously a laboratory-based method only (Altorfer et al., 2000). However, only a few pilot studies have been reported so far. This is also the case with voice signal or the temporal pattern of speech recorded via a throat micro or walkman recorder (Heger, 1990b; Käppler, 1994; Krüger & Vollrath, 1996).

Conclusions and Perspectives

The analysis of posture and motion based on accelerometry is a valuable methodology appropriate for application in many research and applied fields. One-channel uncalibrated actigraphy such as wrist actometer, may still be useful in behavior analysis, however, the accelerometry using calibrated sensors and refined strategies in signal analysis and pattern classification clearly has many advantages. The refinement of the methodology will include, for example, the assessment of gait, of limb or head movements, of stability of posture, and the detection of movement disorders by specific filtering techniques and templates. The tentative use of certain parameters or motion patterns, detected on-line, for feedback and control of behavior, for example, in rehabilitation of patients with movement disorders, and applications of this kind appear to be within the range of possibilities of this methodology. The investigation of movement disorders appears to be a promising research orientation.

It is worth mentioning how useful a small tri-dimensional accelerometer fixed at the sternum (frontal aspect of mid-thorax region) can be in behavior analysis. The reliability of the software detection of motions and postures was established in repeated measurement designs and the validity and reliability of the classification procedure was successfully evaluated against behavior observation in the laboratory (videotaped in some instances) and in daily life (ambulatory monitoring and participant observation). Accelerometers are a valuable tool for research and can be utilized both in conjunction with other techniques and as stand-alone devices. Further integration and development of techniques for these devices will extend their application in the study of movement. At present, the multi-channel accelerometry and classification of static and dynamic motion behaviors is used only in a few institutions.

The actual posture and the pattern of motion basically provide a frame of reference for the evaluation of many behaviors, symptoms, and physiological changes. For example, the assessment of resting condition vs. walking or climbing stairs appears to be an essential aspect in the psychophysiological investigation of cardiovascular change and energy expenditure under naturalistic conditions. The potential benefits of this methodology is evident when a graphic 24-hr protocol depicts the multi-channel score of behavior measurement: Posture, motion including specific movements, index of physical activity, heart rate, and further channels, with time resolution of, for example, 30 sec or 5 minutes. In psychophysiological monitoring, such protocols may contain also self-reports on settings, activities, mood or symptoms, intermittent measurement of blood pressure, medication and particular events, etc. Such recordings provide the framework for a thorough inspection of behavioral events, subjective state, and symptom-context relationships in everyday life.

4.5 Psychophysiological Investigations

In psychophysiological research a fundamental controversy in methodology has become increasingly evident, and ambulatory assessment has contributed much empirical evidence to this issue. Originally, strategies in psychophysiological research assumed that subjective reports on emotional state and concurrent autonomic measures were basically related. But empirical investigations revealed that the correlations between self-reports on subjective state (arousal, stress, emotion, somatic complaints) and physiological measures were low or negligible. The findings obtained from a series of multivariate and multi-modal studies on many subject samples confirmed earlier conclusions (especially by Lacey, 1967, and by Hodgson & Rachman, 1974). The obvious lack of covariation, that is, "response fractionation", should be acknowledged and accounted for in assessment strategies and in evaluation of traditional theories. The findings clearly provide evidence for the distinction of emotion as a feeling and emotion as autonomic activation (Fahrenberg & Myrtek, 2005). This result was generally confirmed by extensive investigations that employed interactive ambulatory assessment (Myrtek, 2004).

There is clear evidence from these investigations that theories assuming consistent and unitary patterns of subjective and autonomic aspects of emotion have to be revised. The response fractionation as the prevailing fact in psycho-physiological research as yet is not generally recognized by all investigators. Thus, a split in assessment methodology is obvious as a consequence of this. In some projects the search for explicit psycho-physiological correlations is continuing while other researchers are convinced that such consistent patterns of emotion are more or less an exception to be observed, perhaps, under condition of extreme arousal.

Ambulatory Assessment at the Workplace and in Leisure Time Activities

In applied physiology and ergonomics in the past, a number of investigations were conducted that used standard laboratory equipment moved to and installed at the workplace. However, bulky electronic apparatus and connecting cables did impose clear restrictions on the subject's behavior. The development since then of lightweight portable recorders that allow for monitoring of the electrocardiogram or blood pressure without restrictions on mobility has facilitated the application of ambulatory assessment methodology. There are a number of reviews on methods, especially psychophysiological methods in human engineering and work physiology, but the new techniques such as electronic diaries and physical activity monitoring have to date been rarely employed. Multi-method strategies that include self-reports, cardiovascular measures and detection of movement are still an exception and are greatly outnumbered by retrospective studies using questionnaires or by laboratory experiments (cf. Backs & Boucsein, 2000). Real-time measurement of variations in workload and task demands, actual performance, and behavioral and physiological changes are still an exception. Nonetheless, it is expected that ambulatory assessment methodology will essentially contribute innovative and ecologically valid approaches to many issues in the applied environments (Fahrenberg & Wientjes, 2000).

General context

Workplace settings are settings in which all manner of activities involved in the pursuit of an occupation take place. Such settings might include a surgeon's operating theater or an artist's stage, man-machine operating

systems or the field of special services (e.g., pilots, parachute jumpers, astronauts, aquanauts, firemen, military services). Activities in workplace settings might also include driving and commuting or involve work under extreme conditions, such as high altitude or high/low humidity. Other applied environments might include personnel assessment (e.g., personnel selection and/or assessment centers), commercial outdoor and teambuilding programs (evaluation of training programs), public transport (e.g., workload studies among employees, and studies of fear of victimization among employees and users), environmental design (for example, evaluation of the public's response to shopping centers, buildings, public safety measures such as video cameras), simulated and virtual environments (e.g., simulator or virtual environment validation by way of comparison of subjective or physiological responses in simulated environments with responses to the real task environment), and scenario simulations (e.g., playing of disaster-scenarios by civil or military authorities).

Workplace assessments usually require special attention to task demands, performance, and load. The demand measures form the counterpart of the performance measures; they specify the task or demand requirements of the environment (input), while the performance/outcome measures define the way the operational output is assessed. Load measures, which are often the prime focus of ambulatory studies, can only properly be interpreted in the context of task requirements, on the one hand, and performance, on the other (cf. Backs & Boucsein, 2000). In many studies, task demands are only assessed with subjective techniques. This approach is not adequate because there may often be, for various reasons, a considerable difference between the objective workload and the subjective evaluation by the employees. Hence, it is in most cases desirable to obtain objective data on task demands. Performance measures may often be obtained in a quantitative manner, by measuring relevant task performance or output parameters (chosen on the basis of a task analysis). The operationalization of demand as well as performance measures deserves very careful consideration. It is often necessary to consult experts and to carry out an operational task analysis in order to obtain sufficient insight into the relevant specifications.

Among the more recent studies were the following:

Task requirements were used to classify jobs according to high strain, low strain, and jobs conducive to personal development. Effects of these job characteristics on psychophysiological outcomes were assessed in 241 employees by using 24-hr ambulatory assessment of blood pressure, heart rate, and mood. Employees working in jobs advantageous to personal development perceived the highest job demands and decision latitude, they also showed increased diastolic BP at work and strong unwinding at night. Although self-reports about job characteristics did not differ between low- and high-strain jobs, employees exposed to high-strain jobs had higher systolic and diastolic BP during work and more often a disturbed relaxation phase (Rau, 2004). Another study examined the associations between Positive Affect (PA) and Negative Affect (NA) Scales, cardiovascular activation, and physical activity in 145 female and male white collar workers. PA and NA decreased over the day up to the evening. There was a significant relationship between the diurnal curves of PA and HR. Furthermore, intraindividual differences were found for heart rate and for systolic blood pressure which were related to the individual lowest (minimum) and highest (maximum) PA- and NA-values (Triemer, 2002).

Further examples for ambulatory assessment at the workplace were: *Psychophysiological monitoring of air traffic controllers: Exploration, simulation, and validation* (Vogt & Kastner, 2001); *Psychophysiological responses under exceptional stress: Air traffic control during the Duesseldorf airport fire on April 11th 1996* (Vogt & Kastner, 2002); *In-flight psychophysiological monitoring* (Wilson, 2001); *Heart rate monitoring in an academic test situation* (Zeier, Häseli & Fischer, 2001); *Overcommitment to work is associated with changes in cardiac sympathetic regulation* (Vrijkotte, van Doornen & de Geus, 2004); *Messung und Kontrolle mentaler Fahrerbeanspruchung* (Piechulla, 2006); *Ambulantes Monitoring zur Erfassung der Beanspruchung von Mainzer Grund- und Hauptschullehrkräften* (Schönhofen & Schwerdtfeger, 2006).

The need for work site surveillance of blood pressure in both healthy persons and in hypertensive patients is clear. Yet there are few studies that use the advantages of interactive ambulatory assessment strategies to obtain valid accounts of stress-strain processes during work and leisure time (see below, Myrtek, 2004).

Clinical Studies

Ambulatory monitoring of patients with panic disorder and other anxiety states was the outstanding research issue. Evaluation of behavior therapy and findings from ambulatory monitoring suggested that the subjective evaluation plays an essential role in this disorder, that symptoms in manifest behaviors were less evident, while recorded heart rate reactions were often negligible (Hodgson & Rachman, 1974; Margraf, 1990). Such results place great emphasis on the necessity of revising of theories of anxiety, and of diagnosis and therapy evaluation. Subsequently, the interest in psychophysiological studies of this kind and attempts toward more refined assessment strategies appeared to wane. This impression was confirmed by an analysis of published articles in behavior therapy of anxiety states (Fahrenberg, 2000b).

Despite the preceding, physiological measurement under naturalistic conditions may eventually reveal higher concordance. Physiologic responses of patients with anxiety disorders and self reports to everyday events were recorded in 26 patients with Panic Disorder (PD) and 40 with general Anxiety Disorder (GAD), both without substantial co-morbidity, and 24 controls. Participants underwent four 6-hour recording sessions during daily activities. Physiologic and subjective data were recorded every 30 minutes and during subject-signaled periods of increased anxiety or tension or panic attack. Patients with anxiety disorders rated higher on subjective and somatic anxiety symptoms than did controls. The main differences between patients with PD and GAD were a heightened sensitivity to body sensations and more frequent button presses. The findings suggested that dysfunctional information processing during heightened anxiety is an essential aspect. *Somatic symptoms and physiologic responses in generalized anxiety disorder and panic disorder: an ambulatory monitor study* (Hoehn-Saric, McLeod, Funderburk & Kowalski, 2004).

Panic disorder (PD) and coronary artery disease (CAD) often co-occur, and CAD patients with comorbid PD suffer greater cardiovascular morbidity and mortality relative to CAD patients without PD. It is widely assumed that reduced heart rate variability (HRV), a non-invasive measure of cardiac autonomic modulation, is an important predictor of adverse cardiac events. Twenty patients with and 20 patients without CAD underwent 48-h electrocardiographic monitoring. Power spectral analysis of HRV indicated that CAD patients with PD exhibited significantly smaller Low frequency/High frequency ratios, which may reflect lower sympathetic modulation, compared with non-PD patients. *Heart rate variability in coronary artery disease patients with and without panic disorder* (Lavoie et al., 2004).

Psychophysiological research pertaining to anxiety disorders was reviewed by Wilhelm and Roth (2001). The DSM-IV criteria for anxiety disorders include physiological symptoms. Such symptoms are evaluated by subjective reports only. The authors defend the strategy of the three-systems approach that somatic measures, as well as verbal and behavioral ones are indispensable in anxiety diagnosis. The obvious lack of concordance between such measures is well-known in psychophysiology. The assumption is that the concordance can be improved by restriction to specific anxiety disorders and disease-specific functions instead of multiple autonomic measures. Recent research was cited in support of such correspondence of self-reported and physiologically measured breathing irregularities in panic disorder. *Respiratory psychophysiology of clinical anxiety outside the laboratory: Assessment of end-tidal pCO₂, respiratory pattern variability, and transfer function RSA* (Wilhelm, Alpers, Meuret & Roth, 2001); *Taking the laboratory to the skies: Ambulatory assessment of self-report, autonomic, and respiratory responses in flying phobia* (Wilhelm & Roth, 1998); *Psychophysiological measures during exposure in driving phobics* (Alpers, Wilhelm & Roth, 2005); *Salivary cortisol responses during exposure treatment in driving phobics* (Alpers, Abelson, Wilhelm & Roth, 2003).

The modulation of pulmonary function by mood states in the daily life of 20 asthmatic patients and 20 non-asthmatic control subjects was investigated. After a laboratory session in which various emotions were induced by films, participants kept mood diaries, including regular spirometric self-assessments, for at least 3 weeks. Episodes of strong negative or positive mood were selected from these diaries and compared with conditions of relative affective neutrality. Findings indicated that pulmonary function of asthmatic patients is negatively affected by strong mood states in daily life. Airway effects of negative emotion induction, particularly depression, can predict changes in pulmonary function in response to negative mood in the field. *Emotion and pulmonary function in asthma: Reactivity in the field and relationship with laboratory induction of emotion* (Ritz & Steptoe, 2000).

Available monitoring systems allow for continuous (invasive) measurement of glucose level. The clinical trials directed at improving therapy in Type 1 Diabetes include issues in practical management of the chroni

cally ill. The awareness of hypoglycaemic states is a crucial aspect. Laboratory and ambulatory studies reported remarkable inter- and intra-individual differences and it is essential to maintain an adequate hypoglycaemia awareness. Using a marker channel or a hand-held PC the patient's reports on hypoglycemic episodes or estimates of momentary glucose level can be assessed during glucose monitoring in everyday life. Such studies revealed substantial differences in the number of noticed and unnoticed hypoglycaemic episodes. However, the evaluation of such reliability estimates have to consider a number of confounding variables: *Assessment of hypoglycaemia awareness using continuous glucose monitoring* (Kubiak, Hermanns, Schreckling, Kulzer & Haak, 2004); *Ambulatory assessment of hypoglycemia unawareness in Type 1 Diabetes* (Kubiak, 2006; Kubiak & Hermanns, 2001); *Entwicklung und erste empirische Überprüfung eines stationären Interventionskonzepts zur Behandlung von Typ 1 Diabetikern mit Hypoglykämieproblemen* (Kubiak, 2003); *Improvement in Diabetes control with a monitoring system based on a hand-held, touch-screen electronic diary* (Tsang et al., 2001). Ambulatory methodology is suited to evaluate the effects of patient education and training in self-management. Further monitoring studies are desirable to examine changes in glucose level and concurrent changes in emotional state and cognitive functioning, and, to assess objective and subjective cardiac symptoms in Diabetes patients.

Ambulatory monitoring is suited to a wide scope of applications. Further examples were: *Ambulatory monitoring of menopausal hot flashes* (Freedman, 2001); *Physiological and affective responses to family care-giving in the natural setting in wives versus daughters* (King, Atienza, Castro & Collins, 2002); *Cigarette smoking, ambulatory cardiovascular monitoring, and mood in Vietnam veterans with and without chronic posttraumatic stress disorder* (Beckham, Gehrman, McClernon, Collie & Feldman, 2004).

Interactive Monitoring

The development of recorder equipment suitable for on-line (real-time) analysis led to innovative research strategies. The Freiburg Monitoring System FMS methodology was developed for use with Vita-port/Varioport-Systems. The FMS allows for a multi-channel and interactive ambulatory assessment of heart rate, additional heart rate, heart rate variability, and physical activity indicating energy expenditure. Accelerometry is employed to detect posture and movement and serves also the adjustment of heart rate, thus accounting for differences in physical activity. Amplitudes of P-wave and ST-segment are also measured. An algorithm is capable of detecting episodes of additional heart rate that are elicited by emotional activation or mental effort, as opposed to heart rate increases caused by metabolic demands. This real-time algorithm further allows for triggering the participant to enter a self-report on momentary subjective state and activities to a hand-held computer, either when an episode of additional heart rate is detected or at random. *Freiburger Monitoring System (FMS). Ein Daten-Aufnahme- und Auswertungssystem für Untersuchungen im Alltag: Emotionale Beanspruchung, Körperlage, Bewegung, EKG, subjektives Befinden, Verhalten* (Myrtek, Foerster & Brügger, 2001).

The algorithm has been employed since 1988 in a series of investigations to detect emotional and mental strain in everyday life that included workplace and leisure time activities. "The connection between acute emotional arousal and heart rate is well known, both from poetry and from the evolutionary survival reflex known as the fight-flight reaction. The connection between stress and disease is also well known. What is less well known is that the heart reacts to nearly all stimuli, independently of physical exertion, during both the day and the night. These changes, known collectively as the "additional heart rate" or aHR, are mostly unconscious and to date have been hard or impossible to study in real life.

The *Freiburg Monitoring System*, allows heart rate changes not associated with physical activity to be assessed objectively, in real-life situations, and to be compared with individuals' subjective feelings at the time. The recent research has involved more than 1,300 subjects of various ages, both male and female, including white- and blue-collar workers, train and bus drivers, dispatchers, university students, schoolchildren, heart disease patients, and patients with cardiac neurosis and rheumatic diseases, and has looked at topics such as the perception of emotions, the perception of the heart in healthy subjects and patients, stress and strain at the workplace and during leisure time, and physiological monitoring during the night." (Myrtek, 2004)

On-line measurement of additional heart rate. Methodology and applications (Myrtek & Foerster, 2001); *Heart and emotion. Ambulatory monitoring studies in everyday life* (Myrtek, 2004); *ECG changes,*

emotional arousal, and subjective state. An ambulatory monitoring study with CHD patients (Myrtek, Frölich, Fichtler & Brügger, 2000); Fernsehen, Schule, Verhalten. Untersuchungen zur emotionalen Beanspruchung von Schülern (Myrtek & Scharff, 2000); Psychophysiologische Untersuchungen zum gestörten Schlaf (Myrtek, 2002); Assessment of stress and strain components with the Freiburg Monitoring System (Myrtek, Foerster & Piech, 2003); Emotions in everyday life. An ambulatory monitoring study with female students (Myrtek, Aschenbrenner & Brügger, 2005).

Results pertaining to the otherwise evident independence of self-reports on emotions and cardiovascular changes are of particular interest. Many episodes of additional heart rate that were registered in the absence of physical activity changes were not accompanied by subjective changes, tension or feelings. A significant association was observed only for self-reported anxiety/fear and additional heart rate. The majority of the real time assessments of heart rate increases were "silent" and the majority of self-reports on momentary emotions had no counterpart in heart rate changes. The underlying mechanisms are not known at present. The findings suggest that interoception of cardiac function may be insufficient since most subjects have no awareness of either heart rate changes or BP changes. Thus, contextual judgments, causal attributions, stereotypes and cognitive sets may be effective (Myrtek, 2004). These results were obtained by an innovative methodology in real life and confirmed earlier findings on response fractionation.

The innovative interactive methodology was used in psychophysiological monitoring in outpatients with Borderline Personality Disorder (BPD). The ambulatory assessment methodology appears to be especially suited to research on BPD because frequent arousal states and emotional lability are significant aspects of this disorder. The investigation was conducted partly at the University of Freiburg and at the University of Seattle. A 24-hr monitoring was performed with 48 female BPD patients and 48 controls. The Vitaport recorder, MONITOR software for electronic diary, and the FMS-algorithm for detection of episodes of additional heart rate were employed. As compared to controls, patients reported higher frequency and intensity of emotions and of aversive tension states in daily life. However, significant differences in emotional heart rate was observed only in a subgroup of non-medicated subjects. The findings also revealed discrepancies between actual self-reports on emotions and retrospective ratings. The findings suggest that a comprehensive multi-modal assessment is required to adequately depict the specific condition of BPD. Interactive monitoring is a promising methodology for psychiatric research. *Ambulantes psychophysiologisches Monitoring in der psychiatrischen Forschung (Ebner, 2004); Ambulantes psychophysiologisches Monitoring in der psychiatrischen Forschung. Eine Untersuchung der Borderline-Persönlichkeitsstörung (Ebner-Priemer, Bohus & Linehan, 2006).*

4.6 Advances in technology

The advances in micro-processor technology and storage capacity paved the way for multi-channel recordings and – another innovative step – led to the on-line analysis of medically important changes, for example, the immediate detection of ST-depression in the ECG. There can be little doubt that further progress in medical instrumentation and computer-technology will permit even more physiological functions to be measured non-invasively and unobtrusively in daily life. Some physiological measures require the use of methods by the patient him or herself such as glucose measurement in Diabetes or electronic peak-flow measurements in Asthma patients. Data of this kind can be entered in a hand-held computer during ambulatory monitoring and assessment. Ambulatory assessment of cortisol in saliva requires the filling of a salivette, time-stamped to secure compliance.

Some hand-held computers allow for audio recordings for a couple of minutes, depending on storage capacity. Digital dictating systems have a capacity up to 240 minutes in long play mode. A recording device called the Electronically Activated Recorder (EAR) was developed for sampling naturalistic daily activities and conversations. The digital device records for 30 sec once every 12 min for 2-4 days (Mehl, Pennebaker, Crow, Dabbs & Price, 2001). In psychological and psychophysiological research, so far, little use was made of digital mini-cams or web-cams for recordings of the videostream of behavior.

Measurement of Ambient Parameters

Environmental as well as meteorological features can play an important role in the subjective evaluation of

settings and in physiological adjustments. Certain variables that can be objectively measured include ambient temperature (room and out-door), noise level, brightness, moisture, barometric pressure, whereby, high-precision pressure sensors also can be used to detect differences in height, for example, in climbing stairs (cf. Ebner, 2004; Fahrenberg et al., 2002). Environmental telemeter systems and newly developed recorders allow for the continuous measurement of such ambient parameters (Mutz & Becker, 2006).

Recorder/Analyzer and Software

Today, more than a dozen recorder/analyzer systems are available – not to mention the even greater number of BP-recorders, long-term ECG recorders/analyzers, and EEG-recorders. Only a few devices are multi-purpose recorder systems and can be applied to a variety of research questions that require different recording channels. Besides the devices for 24-hr or long-term monitoring, a wide range of portable (mobile) equipment designed for in-field measurement does exist (see Internet sources for Ambulatory Recorders, Ambulatory Monitors, Equipment in Medicine and Telemedicine; and for a short overview, Fahrenberg et al., 2002). Data logging technology in ambulatory medical instrumentation, especially with respect to advances in sampling rate, storage capacity, was reviewed, for example, by Anderson and Lyons (2001). At present, there are five devices which appear to be widely used. The software development is more or less specific to each recorder system.

- Vitaport and Varioport (Becker Meditec, Karlsruhe, Germany). The evolving "family" of multi-purpose and of more specialized devices was portrayed in a number of articles (*Towards a comprehensive technology for recording and analysis of multiple physiological parameters within their behavioral and environmental context* (Jain, Martens, Mutz, Weiß & Stephan, 1996; *Some new developments in ambulatory assessment devices* (Stephan, Mutz, Feist & Weiss (2001a); *Feasibility of ambulatory sleep diagnosis* (Stephan et al., 2001b). At present, the Varioport is available in several versions (Weiss & Mutz, 2004; Mutz & Becker, 2006). Extensive software was developed for Vitaport/Varioport: (1) BIO 29 Package for a broad spectrum of cardiovascular measurements, further autonomic and motor functions, including the detection of posture and movements (Foerster, 1998, 2001), and (2) the Freiburg Monitoring System FMS, which includes also the on-line measurement of additional heart rate and the algorithm for interactive monitoring (Myrtek, 2004; Myrtek et al., 2001; www4.psychologie.uni-freiburg.de/einrichtungen/Psychophysiologie/).
- Vrije Universiteit Ambulatory Monitoring System VU-AMS (Division for Instrumentation of the Department of Psychophysiology, Free University, Amsterdam, www.psy.vu.nl). The VU-AMS is used for the ambulatory 24-hour recording of cardiorespiratory physiology in human subjects. Main variables measured are heart period, heart period variability, pre-ejection period, respiration rate, respiration depth, stroke volume and cardiac output. A large scale ensemble averaging of ambulatory impedance cardiograms was developed (de Geus & van Doornen, 1996; Riese et al., 2003; Vrijkotte, Riese & de Geus, 2001).
- Activity Monitor (supplied by Temec Instruments BV, Kerkrade, NL, www.cuci.nl/~temec/). At the Department of Rehabilitation of the Erasmus University Rotterdam an innovative Activity Monitor (AM) has been developed. (www.erasmusmc.nl/rehabilitation/content/Activity_monitoring). With this instrument it is possible to measure objectively, long-term (> 48 hrs) and in detail the physical activities (postures, posture transitions, movements, including wheelchair driving) during normal daily life. The AM consists of 4 to 6 accelerometers, attached at the legs, trunk and arms, a portable recorder and the kinematic software package (Bussmann et al., 1998, 2001).
- LifeShirt (VivoMetrics, Inc., Ventura, CA, USA; www.vivometrics.com). The LifeShirt is a system with three inductive plethysmographic sensors embedded in a garment, a single lead ECG and a dual axis accelerometer that measures posture and levels of activity and aids filtering movement artifact. LifeShirt enables continuous monitoring of respiration from the rib cage and abdomen areas, and captures thoracocardiograph (TCG) signals from the thorax at the level of the left ventricle. This TCG sig

nal provides a non-invasive index (estimate) of the stroke volume of the heart. *A system for ambulatory measurement of respiratory and cardiac function* (Wilhelm, Roth & Sackner, 2003); *Respiratory sinus arrhythmia, cardiac vagal control and daily activity* (Grossman, Wilhelm & Spoerle, 2004); *Detection of speaking with a new respiratory inductive plethysmography system* (Wilhelm, Handke & Roth, 2003); *Improving estimation of cardiac vagal tone during spontaneous breathing using a paced breathing calibration* (Wilhelm, Grossman & Coyle, 2004); *Continuous monitoring of cardiac output from TCG signals* (Keenan, 2004); *Classification of locomotor activity by acceleration measurement: validation in Parkinson disease* (Keenan & Wilhelm, 2005).

- Cardiopres-2 (TNO TPD Biomedical Instrumentation, Amsterdam, NL; www.bmi-tno.nl; since 2005, cf. www.bmeeye.com/). The Portapres method was refined. The Cardiopres-2 enables the ambulatory measurement of continuous non-invasive finger blood pressure, respiratory patterns and diagnostic multi-channel ECG (e.g. Boon et al., 2002).

Also noteworthy are multi-channel recorders: EEG-Holter set (TEMEC Instruments, Kerkrade, NL, www.cuci.nl/~temec), PAR-PORT/F (PAR Medizintechnik GmbH, Berlin, Germany, www.par-berlin.com), and PhysioModul (med-NATIC, München, Germany, www.med-natic.de).

New safety and life support systems have been developed to detect emergency situations of elderly persons living alone. The system employs a dual axis accelerometer and a mobile phone. If the patient is in an inactive state for 5 minutes after falling, or for 64 minutes without previously falling, then the system automatically alarms the emergency service. *A new microcomputer-based safety and life support system for solitary-living elderly people* (Miyachi et al., 2003); *New concepts and technologies in home care and ambulatory monitoring* (Dittmar, Axisa, Delhomme & Gehin, 2004). It has been pointed out that highly portable computing devices such as those that can easily be worn (belt, wrist, and head-mounted) and handheld have great potential for military use (Tappert et al., 2001).

Telemedicine applications should be mentioned in this context (see, Leopold, 2001; Weiss & Mutz, 2004; Internet sources for the Medicine Technology Market), although progress appears to be much slower than initially expected. A number of realistic projects appear to be currently in progress, for example, mobile medical information systems and information support for ambulant health worker, real time classification of ECG on a PDA, and so forth. Less realistic and more questionable is the development of "wearable" computers and some of the speculations associated with these computers regarding long-term monitoring in applied environments. Telemedicine technology and telemedicine applications, which actually are means of data transportation, are not included in the present review.

5 Computer-assisted Self-monitoring and Self-management

A hand-held PC may be useful in the diagnostic assessment of a variety of behavior disorders. Self-monitoring consists of observing and recording one's behavior and subjective state. It is the first step in self-management. Such computer-assisted methods have indeed the potential to support self-management of drinking, smoking, and of eating disorders, and more generally to facilitate self-management in chronic illness, in neuropsychological training, in health care of the chronically ill, in patient education, and in behavior therapy. The portability and implementation in the patient's own environment as and when symptoms occur are among the benefits provided by the advances in these methods.

The computer-programs based on a hand-held PC can be used as a component of behavioral therapy: this was the message conveyed by a number of recently published pilot studies. The basic intention of this approach is evident from the following statement by Newman, Consoli and Taylor (1999): "This is the first report of a palmtop computer program developed to increase the efficiency and cost-effectiveness of cognitive behavioral therapy for generalized anxiety disorders. The computer program offers advantages to researchers, therapists, and clients. These advantages include continuous, unobtrusive collection of process data on treatment adherence as well as on the impact of cognitive-behavioral therapy techniques in the client's natural setting. In addition, the computer extends treatment beyond the therapy hour and motivates clients to comply with homework assignments by prompting practice of cognitive behavioral strategies." (p. 597).

Since the pioneering work from Burnett, Taylor and Agras (1985) and Newman, Kenardy, Herman and Taylor (1996) on the use of hand-held computers as an adjunct to cognitive-behavior therapy, considerable research and application has been put into practice in diverse fields of behavior therapy and in self-management in the chronically ill.

Recent developments were reported in a special issue, *Journal of Clinical Psychology*, edited by Newman (2004): *Technology in psychotherapy: An introduction (Newman)*; *Computer-aided CBT self-help for anxiety and depressive disorders: Experience of a London clinic and future directions (Gega, Marks & Mataix-Cols)*; *Using technical innovations in clinical practice: The Drinker's Check-Up software program (Squires & Hester)*; *Internet-based cognitive behavioral therapy for tinnitus (Andersson & Kaldo)*; *Palmtop computer-assisted group therapy for social phobia (Przeworski & Newman)*; *Respiratory feedback for treating panic disorder (Meuret, Wilhelm & Roth)*; *Computer and Internet applications for psychological treatment (Tate & Zabinski)*.

There are further reviews on the growing literature and advantages as well as on methodological challenges (Anderson, Jacobs & Rothbaum, 2004; Fahrenberg, 2003). Computer-assisted or computer-delivered interventions were also discussed with regard to the incorporation of other technologies such as expert systems, virtual reality, and the internet. Their shortcomings and implications for further research in this area are also presented (Bobiez & Richard, 2003). *Self-help and minimal contact therapies for anxiety disorders: Is human contact necessary for therapeutic efficacy? (Newman, Erickson, Przeworski & Dzus, 2003)*.

Assessments in everyday situations provide useful information about the interplay of environmental factors and internal states in smoking, drinking and other addictions. On four days, 57 smokers used an electronic diary to record situations and moods at times of smoking and at control nonsmoking occasions. Self-reports of settings, activities, consumption, social context, and moods were specifically related to smoking. Obviously, conditioning and learning processes play a role in smoking and should be considered in smoking cessation programs. *Situations and moods associated with smoking in everyday life (Shapiro, Jamner, Davydov & James, 2002)*.

A computer program was developed to include a diary function for ongoing self-monitoring of anxiety as well as guidance on the practice of relaxation, cognitive restructuring, and self-control desensitization. This program was originally designed to treat individuals with generalized anxiety and was implemented in a group of individuals with a primary diagnosis of general anxiety disorder or social phobia. Outcome data of a case study suggested that the treatment was highly effective for this client group as well as others with a diagnosis of social phobia or general anxiety disorder. *Palmtop computer-assisted group therapy for social phobia (Przeworski & Newman, 2004)*.

Hand-held computers may provide an innovative and effective approach in self-management of eating disorders. *The use of palmtop computers in the treatment of bulimia nervosa* (Norton, Wonderlich, Myers, Mitchell & Crosby, 2003); *An ecological momentary assessment of relapse crises in dieting* (Carels, Douglass, Cacciapaglia, & O'Brien, 2004); *The effect of the timing and spacing of observations in longitudinal studies of tobacco and other drug use: temporal design considerations* (Collins & Graham, 2002); *The use of ecological momentary assessment approaches in eating disorder research* (Smyth et al., 2001); *Immediate antecedents of cigarette smoking: an analysis from ecological momentary assessment* (Shiffman et al., 2002).

Another field of application is the computer-assisted training of cognitive and motor performance. *Electronic memory aids for outpatient brain injury: follow-up findings* (Kim, Burke, Dowds, Boone, & Park, 2000). Twelve patients with brain injuries underwent outpatient treatment using hand-held computers to assist with memory dependent activities in their everyday lives. Nine patients found this program useful during supervised trials, seven of nine patients continued the use after the treatment trial had ended.

Daily recordings of mood and symptoms can assist in self-management in the chronically ill. Examples are bipolar psychiatric disorder and migraine. In bipolar disorder, the detection of increasing tendency towards hypomania can help to warn patients. The detection of subclinical episodes is based on change in sleep, life events, change in medication evaluation of therapy, and attitude to illness (Lifechart study, Schärer et al., 2002). Premonitory non-headache symptoms (cognitive and physical symptoms) in migraine can be assessed and used in prediction of migraine, whereby some symptoms may have the character of specific warning signals: *Premonitory symptoms in migraine: An electronic diary study* (Giffin et al., 2003); *Ambulatory monitoring of diurnal changes in pain disorder, migraine and rheumatoid arthritis* (Godaert, Sorbi, Peters, Dekkers & Geenen, 2001); *Towards an objective quantitative assessment of daily functioning in migraine: a feasibility study* (Tulen, Stronks, Bussmann, Peppinkhuizen & Passchier, 2000). Based on such ambulatory assessment, self-management tools were developed and will become available.

In telemedicine, of course, there are many more pilot studies and applications of this kind. Current developments mean that bi-directional wireless interactive assessment will provide participants and investigators as well as patients and therapists with improved means of communication and that, given the pace of progress, they will sooner or later have access to computer facilities for real time monitoring, data transfer, feedback or assistance at high-risk workplaces or for assisting the chronically ill.

Psychophysiological Strategies

From the onset, physiological recordings were seen as means to obtain objective measurement of certain psychological states, such as emotion or mental effort. However, the relationships proved to be intricate. Simple and straightforward assessment strategies were not available. Multivariate research now provides clear evidence for the distinction between emotion as a feeling and emotion as autonomic activation. A tight coupling of such functions appears to be rather an exception than the rule. The obvious lack of covariation, that is, "response fractionation", should be acknowledged and taken into account in assessment strategies, especially in clinical studies. Psychological and physiological episodes may coincide; however, many investigators have reported fundamental exceptions to this in "quiet" physiological reactions and in subjective symptoms without apparent somatic changes (see Section 4.5).

The so-called triple-response model is often referred to in the theoretical literature. This concept necessitates in, for example, anxiety research and therapy, the assessment of subjective (verbal), behavioural and physiological measures. However, a refined analysis across systemic levels and subsequent analysis of correlation and contingency (symptom-context) is still an exception in the field of behavior medicine. Besides symptom measures and physiological changes in ambulatory assessment, such protocols may contain also self-reports on settings, activities, and events. Such recordings provide the framework for a thorough inspection of symptom-context relationships in everyday life, and facilitate the search for antecedent activities and experiences that trigger off the symptom.

Anxiety

Psychophysiological research pertaining to anxiety disorders was reviewed by Wilhelm and Roth (1996, 2001, see Section 4.5). Individual profiles of psychological and physiological anxiety responses are required

to indicate distinct therapeutic approaches and to assess progress in behavior modification. Advances in ambulatory monitoring methods will contribute to such aims.

In 14 agoraphobic patients and 9 controls psychophysiological recordings of heart rate, electrodermal activity, respiration, and activity were made in standardized agoraphobic situations before and after brief standardized cognitive behavioral treatment. The agoraphobic situations patients showed slightly higher psychophysiological activation and a reduction of that reaction after therapy. However, the large variance between subjects suggested significant individual response patterns. Examples of prototypic responses were concordance, asynchrony, prolonged activation, and negative concordance. Only one of these responses is in accordance with the cognitive model of panic attacks and fits also into the habituation model of exposure therapy. *Psychophysiologie der Expositionstherapie – eine Pilotstudie bei Patienten mit Agoraphobie und Panikstörung* (Ebner, Angenendt & Wilmers, 2001).

Asthma, Diabetes, and Hypertension

Asthma and Type 1 Diabetes are among those chronic illnesses that could profit from computer-assisted methods in self-monitoring and self-management. An individualized asthma education program was based on symptom perception and electronic ambulatory assessments. The program evaluation demonstrated a superiority of the new program in several medical and psychological parameters over a well-standardized group education program. *Giving feedback to asthma patients. Ambulatory monitoring in patient education* (Leopold & Schandry, 2001).

Available monitoring systems allow for continuous (invasive) measurement of glucose level. The clinical trials directed at improving therapy in Type 1 Diabetes include issues in practical management of the chronically ill. The awareness of hypoglycaemic states is a crucial aspect. Laboratory and ambulatory studies reported remarkable inter- and intra-individual differences and it is essential to maintain an adequate hypoglycaemia awareness. Using a marker channel or a hand-held PC the patient's reports on hypoglycemic episodes or estimates of momentary glucose level can be assessed during glucose monitoring in everyday life. Such studies revealed substantial differences in the number of noticed and unnoticed hypoglycaemic episodes. However, the evaluation of such reliability estimates have to consider a number of confounding variables: *Assessment of hypoglycaemia awareness using continuous glucose monitoring* (Kubiak, Hermanns, Schreckling, Kulzer & Haak, 2004); *Ambulatory assessment of hypoglycemia unawareness in Type 1 Diabetes* (Kubiak, 2006; Kubiak & Hermanns, 2001); *Entwicklung und erste empirische Überprüfung eines stationären Interventionskonzepts zur Behandlung von Typ 1 Diabetikern mit Hypoglykämie-problemen* (Kubiak, 2003); *Improvement in Diabetes control with a monitoring system based on a hand-held, touch-screen electronic diary* (Tsang et al., 2001). Ambulatory methodology is suited to evaluate the effects of patient education and training in self-management. Further monitoring studies are desirable to examine changes in glucose level and concurrent changes in emotional state and cognitive functioning, and, to assess objective and subjective cardiac symptoms in Diabetes patients.

In view of the considerable amount of time and effort invested in psychophysiological BP research, it is noteworthy that comparatively little has been reported on how to use the evidence hereby accumulated on emotionally elicited BP increases in strategies of behavior modification. *The assessment of blood pressure variability in behavior modification: The identification of relevant situation and mood factors* (Mussgay, Niegot & Rüdell, 2001). Postmonitoring interviews suggested that hypertensive patients were generally interested to view their 24-hr BP profiles and concurrent psychological data (Franck, Herrmann & Fahrenberg, 1996; Schäfer et al., 2005). Such evidence may strengthen the motivation to better control of risk behaviors in Hypertension and may serve self-management.

The potential use of psychophysiological recordings was evaluated in a case study of a patient with hyperkinetic syndrome. A multi-channel recorder was used to register arm and leg activity, the ECG and electrodermal activity and a protocol of relevant behaviors was obtained within a family setting. Data collection of this kind may lead to refinement of diagnosis, of psychological hypotheses and deduction of useful therapeutic approaches (Roemer, von der Linde & Minsel, 2002).

6 Perspectives

Ambulatory Assessment is an emerging new methodology. Progress is obvious not only in instrumentation, but in assessment strategies, too. Computer-assisted methodology is used to assess self-reports, behaviors or physiological measures while the person/patient participates in normal daily activities. The assessment strategies include: continuous monitoring, monitoring with sampling methods, controlled assessment, interactive assessment and feedback strategies, bi-directional wireless interactive assessment, symptom monitoring and self-management, in-field psychological testing, and field experimentation.

Two basic issues are apparent:

(1) *Claim for ecological validity of data.* Computer-assisted diaries assess self-reports in daily life, that is, in the context of specific settings, and with exact timing. Such behaviorally-anchored momentary self-reports represent actual state and behavior. It is concluded that such data is generally more valid than questionnaire responses which are based on retrospection, that is, memory, and cognitive reconstruction of the past.

(2) *Higher technical reliability and efficiency of data acquisition.* Because the computer entries are automatically time-stamped, the participant's compliance is objectively recorded and, probably, enhanced. Compared to paper-and-pencil tests, there is superior efficiency of data collection and reduction of error in data handling.

Ambulatory assessment, like any other method, has its problematic aspects, concerning in particular how to account for multiple effects in the recordings, but the principal benefits are evident. The traditional view that sharply contrasted laboratory and field research should be superceded by a broader perspective. On the other hand, there are field experiments that actually employ a randomization of treatment. The laboratory experiment remains indispensable for the necessarily reductionistic testing of explanatory hypotheses. Furthermore, the laboratory may serve as a standard of reference for the evaluation and improvement of methods for observation and measurement.

Some of the results in ambulatory assessment substantiate theories and evaluations which rely on laboratory research. But it is obvious that there are other research findings that challenge previously held views. Ambulatory assessment has also been especially fruitful in generating new research questions. concerning, for example, the issue of behavior consistency or the discrepancies (response fractionation) between subjectively reported and measured workload or between reported emotion and cardiovascular change. Genuine research findings in pertinent fields speak in favor of further development and application of ambulatory assessment methodology.

Advances in Technology

A swift development in microprocessor technology during the last two decades has made possible the design of new instrumentation and, accordingly, new methodologies in medicine and the behavioral sciences. Multi-channel recorders/analyzers and special purpose devices for physiological measures and convenient hand-held computer for acquisition of psychological data are available. Such systems allow innovative research and practical application in many fields and essential findings have been obtained. The expectation is that the hand-held PCs and the recorder/analyzer for physiological measures will in future become smaller, cheaper and more refined. Further applications can therefore be anticipated that include new strategies in interactive monitoring and on-line feedback, monitoring and concurrent recording of audio and video signals (intelligently pre-processed before stored), monitoring of activity and location (GPS), new strategies in self-monitoring and self-management in chronic illness. It is hard at present to imagine to what extent specific expertise systems, and in particular, the wireless application protocol, mobile phone short message systems, and other developments in information technology, will direct the course of this methodology. For the time being we may only speculate about the consequences of such developments in information technologies for the health care system and, to some extent, on subsequent developments in applied fields of psychology.

The interplay between progress in information technology and the development of new research questions is plain to see. Innovative methodologies were developed to assess physiological and psychological parameters that were previously not accessible or were not accessible in a satisfactory manner.

Acceptance, Compliance, and Reactivity

There have been concerns raised from the beginning about the acceptability of hand-held PC, and doubt has been cast on the validity of monitoring in daily life. Ambulatory assessment depends on the favorable attitude of the participating subjects. It is essential that the equipment is readily accepted and that good compliance to instructions is established and sustained. If the ambulatory monitoring is part of a diagnostic process or a treatment program, the patient's compliance may be higher than in research projects. The ambulatory assessment should of course not cause major problems in the patient's interaction with the social environment.

Even in the past when the equipment was more obtrusive and uncomfortable, the feedback from participants of ambulatory monitoring studies was on the whole encouraging. A general acceptance of and indeed interest in these new methods was shown and this appeared to motivate the participants. Such compliance was reported by many investigators, although for some populations and some subjects this methodology appears to be less suitable. Following from this, the impression is that the acceptance of this methodology may be greater among study participants and patients than among mainstream psychologists and psychophysicologists.

Reactivity to the experience of being monitored may cause problems in interpreting any changes observed. Electronic diaries require repeated attention and accurate responding. However, the nearby hypotheses that frequent assessment of self-reports over time may result in an increasing number of missing data was not supported. On the other hand, 24-hr recording of the ECG or of physical activity is a passive condition in which there is probably little awareness of such monitoring except for having the device attached to the body. The effects of motivational and behavioral reactivity in ambulatory assessment (self-monitoring) should not be over-estimated. However, the variables which eventually influence the magnitude and direction of this reactive behavior change are not easily examined in real life.

Impact of Computer-Assisted Monitoring Methodology

The 24-hour electrocardiogram is now a widely used routine method in cardiology and, likewise, the ambulatory monitoring of blood pressure has become an indispensable tool. The more and more widespread application of this methodology can be attributed to its practical usefulness which was demonstrated by the increased validity of diagnosis and in many clinical trials. The benefits of ambulatory monitoring for diagnosis and management of cardiovascular diseases, and of more recent applications, for example, accelerometry in movement pathologies, EEG-seizure detection, polysomnograms and recordings of sleep apnea are beyond doubt.

In contrast, computer-assisted monitoring and assessment still appear to have had little impact in psychophysiology and psychology. A general scan through journals and congress programs (including symposia, papers, posters) will easily confirm the impression that these applications have largely stagnated. Standard textbooks on behavioral research methods, for example, Kerlinger and Lee (2000), although acknowledging the specific advantages and disadvantages of both laboratory and field research hardly refer to the new methodologies based on computer-assisted data acquisition and monitoring in the natural environment. An exception to this is Goldstein and Hersen (2000), who at least mention developments of this kind.

In spite of the pioneering work in the eighties, this methodology had little influence on present day mainstream research activities. Investigators seemed to be apprehensive about the possibility that hand-held PC and other monitoring systems might be met with little acceptance in study participants and patients. The slow speed in development and application of electronic diaries and innovative assessment strategies is evident. We may nevertheless anticipate that computer-assisted methodologies will be used more and more in many fields of psychology and behavioral medicine in order to attain a higher ecological validity and generalizability of findings.

The significant progress achieved in instrumentation and in the development of pocket-size computers and recorder systems has not however been echoed by a corresponding advancement in what has in fact been little more than a hesitating incorporation of instrumentation and systems in the research methodology in psychology and psychophysiology. Yet, the obvious ecological validity of such assessments and an increasing number of relevant findings should serve to encourage their further application. This is particularly the case when researchers are concerned with the practical utility of their findings, or put more specifically, a direct transfer from research to application.

7 References

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