Origins and Developments of Ambulatory Monitoring and Assessment

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Introduction

Portable data recorders have long been used in the behavioral sciences, but they were not particularly innovative developments of these fields. The recorders' mechanical and electronic components, such as keyboards, sensors, amplifiers, micro-processors and storage components, had already been developed for other applications and purposes. The adoption of this technology in medicine and behavioral sciences, was however followed by the birth of a new methodology notable for its specific design of data acquisition.

The technical progress in recording equipment has of course a longer history: from the mechanical data logger, and the electro-mechanical and electronic recording apparatus to the modern advancements of programmable hand-held PCs. These PCs allow for specific formats and hierarchical branching of the questions and are therefore particularly useful in psychological assessment. The medical instrumentation progressed from the analog (cassette) recorder for physiological measures to digital systems, enabled the signal input to be pre-processed, and which subsequently led to real-time detection of certain parameters of physiological changes. However, many of the computer-assisted methods were yet to be used. These options included the technically available interactive monitoring based on real-time analysis of recordings and contingent feedback, or the communication between portable systems and

a control center (via phone or internet). The use of new expert systems has been suggested to assist self-monitoring and self-management in chronic disease and in everyday life. Such systems are desirable in monitoring of man-machine systems and in exceedingly important, but high risk workplaces or in bedside monitoring of the critically ill. A more recent development of this kind has been the use of these applications in telemedicine (see Chapter by Leopold & Schandry, and Stephan et al., this Volume). Further technical progress can be achieved in the miniaturization of sensor devices and in more efficient (intelligent sampling strategy) storage for continuous long-term audio and video (minicam) recordings. This progress will open another door to new assessment strategies in behavior and symptom analysis.

The origins and developments of computer-assisted methodology in ambulatory monitoring could be reviewed from several perspectives. In the present context, however, the discussion seeks to provide a simple outline of the basic developments, and the obvious discrepancies in the acceptance of this new methodology between medicine and psychology. In psychology, there has been an apparent delay in adopting ambulatory monitoring and assessment. Nevertheless, we may anticipate that computer-assisted methodologies will increasingly be used in many fields to attain a higher validity and generalizability of findings in behavior assessment.

Since in most fields of application portable recording devices, that is, hand-held PC and digital recorders which use a small disk or memory card for data storage, are clearly preferred to on-line biotelemetry, the following discussion primarily refers to such recorders. Biotelemetry is useful, for example, in tracking wild-life or in applications which necessarily include real-time communication (telecommand, telestimulation).

Recorder/analyzer for physiological measures

The methodology for monitoring physiological measures in daily life (as an extension of bedside monitoring of the critically ill) was pioneered largely by Holter during the fifties. In the beginning, Holter used radio transmission (biotelemetry) to record animal ECG and EEG, and he subsequently employed a portable cassette recorder for continuous registration of the ECG in heart patients to detect segments of ST-depression (Holter, 1961, 1976). The Holter technique and “holtering” became a synonym for ambulatory monitoring of the ECG and other physiological recordings.

Portable recording systems had been used prior to the Holter technique. For example, motion during walking and running was registered using a

pneumatic sensing and recording system (Marey, 1895; cited from Bussmann, 1998). However, the method developed by Holter appears to have been the first project to have generated wide interest. The evident advantages of monitoring heart patients and other subjects like athletes outside the clinic and laboratory met with a positive reaction. The new methodology lends itself to the attainment of more reliable diagnoses and a more valid evaluation of treatment outcome, for example, by testing antiarrhythmic or anti-hypertensive medication.

The first recordings of intra-arterial blood pressure used tape recorders or biotelemetry (Bachmann, Thebis, Heynen & Graf, 1967; Bevan, Honour & Stott, 1969; cf. Meyer-Sabellek & Gotzen, 1988; O'Brien & Fitzgerald, 1991). At approximately the same time, an automatic device for the non-invasive measurement of blood pressure became available (Schneider, 1968). Pioneering work was also carried out by Sokolow and co-workers in San Francisco who developed a semi-automatic device consisting of an inflatable cuff and a tape recorder for Korotkoff sounds and pressure. In the years to follow, the clinical importance of ambulatory blood pressure monitoring became increasingly evident (Hinman, Engel & Bickford, 1962; Sokolow, Werdegar, Kain & Hinman, 1970; cf. Pickering, 1992).

The ECG and blood pressure enjoy by far the largest number of references in the literature to ambulatory monitoring. These references relate to clinical findings and to methodological issues, for example, technical developments, guidelines for application, and evaluation (quality control) of specific devices. The application is predominantly in the medical field and only to a much smaller extent in the behavioral sciences, for example, in psychophysiology or behavioral medicine (for overviews on ambulatory monitoring and assessment technology/methodology see Amlaner & Macdonald, 1980; Fahrenberg & Myrtek, 1996, 2001; Littler, 1980; Miles & Broughton, 1990; Pawlik & Buse, 1996; Pickering, 1991; Schneiderman, Weiss & Kaufman,1989; Stott, 1982; Suls & Martin, 1993; Turpin, 1985, 1990).

In the first generation, the monitoring systems used tape or cassette analog recorders, for example, the Oxford Medilog™ Series (Oxford Instruments, Oxford). The data analysis was performed off-line. The ISAM Conferences, initiated in 1975 by Stott et al. (Stott, 1976), showed a gradual transition from analog to digital technology and the development of computer-assisted methodologies. The advances in micro-processor technology and storage capacity soon 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 heart

rate changes or ST-depression in the ECG. These applications, of course, had been previously used for bedside monitoring of patients in critical care.

Among the first digital recorders/analyzers was the M2P (Deutsche Versuchsanstalt für Luft- und Raumfahrt, Oberpfaffenhofen, Germany). The innovative concept of the M2P was noteworthy despite its failure to be fully developed following the switching of research programs and termination of research funding: The loss of this and other such promising projects does not appear to be uncommon especially in this field. As an early precursor of digital recorder/analyzer systems a short account of this design provides an appropriate starting point (bearing in mind the own involvement in this project) for the following discussion.

M2P-Project

The M2P Multifactorial Analyzer for Continuous Long-term Assessment of Physiological Data at the Workplace ("Multifaktiorelles Meßsystem zur kontinuierlichen Langzeiterfassung physiologischer Daten am Arbeitsplatz") was developed by Kunz, Mertens, and Oeste (1980, 1982a, 1982b). It appears to be the first system, besides the Vitalog-System (Miles & Rule, 1982), to be intentionally designed as a digital analyzer consisting of several modules. Its development included the integration of a near sensor pre-processing and semi-conductor storage.

The project was initiated by the Institut für Arbeitsphysiologie, TU München (Prof. Dr. Müller-Limmroth, Dr. Strasser) and a project group (Dipl.-Ing. Mertens) at the Deutsche Versuchsanstalt für Luft- und Raumfahrt DFVLR, Institut für Nachrichtentechnik Oberpfaffenhofen. The funding for this project came from the program "Humanisierung des Arbeitslebens HdA" which was realized by the Bundesminister für Forschung und Technologie.

The project statement for the commissioned work included the following specifications:

(1) A device for long-term monitoring of physiological data at the workplace, suitable for application at various sites.
(2) A recorder and analyzer comprising on-line processing of signal input to obtain meaningful parameters in formats suitable for computer analysis.
(3) An ergonomically designed device that is portable and light-weight, exerts minimal influence on the subject and has control commands that are not accessible to the subject.
(4) Independence of mains and high-frequency transmission (telemetry).
(5) Easy to use and check.

The project statement clearly pointed to the role of the device as a mobile application in order to assess, for example, recovery times, lunch breaks, leisure time, sleep, and working time. Since a generally approved concept of the specific parameters to assess work strain did not exist, the device was to enable the measurement of many parameters thus allowing for empirical correlation and evaluation of data and, thereby preparing the way for effective and economic results. The general design and the selection of parameters was approved at a meeting (Oberpfaffenhofen, 14. 2. 1977) made up of participants from the fields of occupational physiology, medicine and psychophysiology.

A prototype M2P (CPU 6100, 3.145 Hz, 12 KB RAM, 12 KB EPROM, 8 bit AD 100ms, 16 channel multiplexer) with signal modules for ECG, EMG, EOG, was used by the Forschungsgruppe Psychophysiologie, University of Freiburg, between 1978 and 1981. Because a suitable semiconductor storage was not available at that time, the Medilog (Oxford Instruments) analog cassette recorder was used instead. Subsequent to a number of smaller method studies, a larger study was designed for evaluation of the M2P methodology. In 58 students enrolled in physical education, five channels (ECG,2 EMG, EOG and a marker channel) were recorded before, during and after a 1000 m run at the stadium and during sleep as well. The participants were also assessed in a pychophysiology laboratory using conventional technology. The laboratory-field comparison was repeated two months later. The essential findings and suggestions for the further development of the new methodology were published (Fahrenberg, Foerster, Schneider, Müller & Myrtek, 1984; 1986).

A series of subsequent studies was proposed to advance this new methodology. However the DFVLR/HdA project was short-lived, this being due to changes in research policies at that time. Although attempts were made to transfer this innovative technology to manufacturers in the field of medical technology, our efforts were to no avail, and the know-how which had been accumulated, and the financial investment from the large development funds between 1977 and 1982 were lost.

Subsequent developments

The development of the Medilog based on digital technology (Miles & Rule, 1982) has already been mentioned. During the eighties, a number of digital recorders/ analyzers emerged in Germany that used semi-conductor storage: the PHYSIOPORT and PAR-PORT (PAR -Natic, Berlin, see Kiparski & Massmann, 1982; Kiparski & Steffens, 1985).), the BIOPORT and MULTITALENT (Zak, Simbach), the LOGOPORT (Krüger & Vollrath, 1996) and the Cologne System Series VITAPORT (Vitaport GmbH,

Cologne, and Temec, Amsterdam, NL, see Stephan, Mutz, Langer, Schmitz & Wemschulte, 1989; Jain, Martens, Mutz, Weiß & Stephan, 1996) and the successor, VARIOPORT (Becker Meditec, Karlsruhe).

Today, more than a dozen recorder/analyzer systems are available from international manufactures – not to mention the even greater number of long-term ECG recorders/analyzers and the long-term-BP recorders. An overview of selected multi-purpose recorder systems is depicted in Table 1. Only a few systems have a multi-channel design, the advantage of which is that they can be applied to a variety of research questions that require different recording channels. Besides the devices suitable for ambulatory recordings and their use in 24-hr or long-term monitoring, a wide range of portable (mobile) equipment designed for in-field measurement does exist. For example, continuous finger arterial pressure (Portapres™, TNO, BioMedical Instrumentation, Amsterdam; see Imholz, Langewouters, van Montfrans, Parati, van Goudoever, Wesseling, Wieling, & Mancia, 1993; Wesseling, Settels & de Wit, 1986), measurement of respiration (Resptrace™), O2/CO2 gas exchange and energy expenditure, capnometry and pulse oximetry, polysomnography, cardio-respiratory polygraphic systems, 24 hour pH and motility testing, or fetal monitoring. Furthermore, monitoring systems have been designed for use by patients, for example, for use as blood glucose monitoring systems, respiration and asthma monitoring systems, long-term EEG and EMG monitors.

The pace of these and other developments is so fast that the reader may wish to refer to the *Journal of Medical Engineering & Technology* (Taylor & Francis, Publishers) and related journals or reports like the *International Hospital Equipment* (Elsevier, Publishers). The website of *Medica*, which is the largest medical instrumentation exhibition and trade fair, provides more information (www.medica.de). An overview of neither the device technology in digital recorder/analyzer systems nor the progress in ambulatory assessment of endocrine responses are within the scope of this chapter.

A wide selection of physiological variables have been measured in daily life, using mostly non-invasive methods. However, some investigators have made ambulatory recordings of arterial (inter-brachial) blood pressure or gastrointestinal functions. Even more specific sensor techniques and registrations have been used and conducted in medical research. However, the great majority of investigators have employed a few selected measures (for reviews see Fahrenberg & Myrtek, 2001; Fahrenberg & Wientjes, 2000).

The software support which is given by the manufacturers is more or less developed. On the one hand, there is tailor-made software for editing, post-processing (parameterization) of physiological signals, plotting software,

data conversion, etc., and on the other hand, there are also standard packages like LabVIEW™ and DASYLab™.

Hand-held PC for data acquisition in field studies

The need for ecological validity in psychological assessment, that is, recording behavior and self-reports under naturalistic conditions (daily life) was urged by Lewin, Brunswik, Barker and other pioneers (for overviews, see Fahrenberg & Myrtek, 2001; Patry, 1982; Pawlik & Buse, 1996; Perrez, 1994). The term ecological validity was introduced by Cicourel (1982) with respect to the agreement between interviews and actual behavior; operational definitions were not proposed by him.

In fact, at this point Cattell (1957) insisted, in his textbook on personality, on recording "life record (or in situ or criterion)" variables: "Indeed, there arises at this point the need for a proper development of measurement techniques particularly as they apply to L-data, both in terms of techniques and units and of frequencies and norms of ordinary everyday behavior ..." (p. 55). However, at that time, his large scale time series studies (P-technique research) extending over weeks and months had to be conducted without the facilitating use of a hand-held PC.

Methods of recording task demands and performance data have a long history in the applied fields (for example, time and motion studies). These and similar assessments have been conducted in differential, developmental, social and clinical psychology. To this end, event recorders for the timed registration of stimuli and responses found their use. Following the growing interest in behavior coding systems in the sixties, the trend toward behavioral assessment became evident in the seventies and eighties. This led to a corresponding increase in demand for new data acquisition technology. Thus, many researchers in psychology, ethnology and social science research developed mechanical, electromechanical and electronic devices (event recorder, data logger). Usually, simple push-button marker or numeric and alphanumeric keyboards were used for data input, rarely an acoustic trigger (voice key). For storage, simple mechanical counters, ticker tapes, punchcards, mark sense cards, and, from the beginning of the seventies magnetic tape recorders (analog cassette recorders) were employed. At the end of that decade semi-conductor storage components, portable PC, and, finally, the smaller hand-held PC were introduced (for overviews, see Farrell, 1991; Heger, 1990a; Mertesdorf, 1980; Pawlik & Buse, 1996; Rugh, Gable & Lemke, 1986; Sidowski, 1977; Totterdell & Folkard, 1992).

Devices consisting of a tailor-made encoder-recorder instrumentation are worth mentioning. These allowed digital data acquisition in field studies ready for computer processing. The Datapack System (Electro/ General Corporation, Minnetouka, MI) was widely applied, initially (1967) using a cassette recorder and later equipped with semi-conductor memory Datamyte 900 (Torgerson, 1977).

In this context, computer-assisted data acquisition is defined according to the following features: (1) The recording equipment is programmable in a basic assembler code or a higher language; (2) The data are stored in a standard format (e.g., ASCII); (3) an interface for data transfer (e.g., RS 232) is available. Portable devices including programmable clock, beeper and other controls were in use already in the late seventies (cf. Mertesdorf, 1980). The development of pocket-sized (hand-held, palm-top) computers then served to ease the acquisition of data considerably. A few years later, Elias (1984) included the Epson HX-20, Hewlett-Packard 75, and Sharp PC 1500 in his list of commercially available hand-held computers for data acquisition in ethnology.

Since 1975, the University of Chicago has been the scene of an alternative development involving Csikszentmihalyi and his collaborators (Csikszentmihalyi & Larson, 1987; de Vries, 1992). Repeated self-reports were elicited by beeper signals. The participants received booklets for the self-protocol, when signaled, of activities, mood, and other variables. Besides a conventional clock (Brandstätter, 1983) or a simple random timer (Hurlburt, 1979), investigators used a programmable wrist watch (e.g., Seiko RC-1000), programmable beeper (Hormuth, 1986) or paging systems (“doctor pagers”) to prompt the subject to respond to a questionnaire. The Experience Sampling Method ESM became well-known and has clearly encouraged further developments.

Computer-assisted methodologies, as compared to the ESM, appear to have many advantages, for example, in the flexible adjustment to various tasks, reliability and control of data acquisition, high memory capacity, or easy read-out.

A computer-assisted methodology for data acquisition in field studies was introduced by Pawlik and Buse (1982) in cooperation with the Zak GmbH (Simbach, Germany). The first version of this behavior recorder (8 KB RAM, programmed in assembler code, 16 keys for typing item codes) was further refined as the BIDATA (48 KB RAM, item text display, performance tests, sensors for recording heart rate and finger temperature). The present model, AMBU, is manufactured by PAR company (Berlin) and the features are: 1 MB RAM, 128x64 pixel display, 10 numeric and 5 control keys, 470 g weight, programming in Turbo Pascal or C) This methodology is well suited

to ambulatory assessment of settings, mood, and in-field performance testing (Buse & Pawlik, 1996; Buse & Pawlik, this Volume).

Other investigators have preferred to use the commercially available hand-held PCs instead. Noteworthy among these hand-held PCs and software developments were the Sharp PC-1360 employed for the COMRES (Perrez & Reicherts, 1989), and the CASIO PB 1000 which was used for both the protocol on setting, location, activity, and mood (Heger, 1990b; Fahrenberg, Heger, Foerster & Müller, 1991), and the symptom diary for anxiety patients (Taylor, Fried & Kenardy, 1990). The Atari Portfolio was selected for the SONET-CT diary for social network protocols (Perkonigg, Baumann, Reicherts & Perrez, 1993). The software for ambulatory psychological assessment (Heger, 1990b; Käppler, 1994) was refined to the MONITOR methodology for the Psion Series (Brügner, 1998; cf. Fahrenberg, Hüttner & Leonhart, this Volume). Meanwhile, a considerable number of other developments can be noted.

The OBSERVER software (Noldus, 1991) was introduced to ease the recording of behavior observations in field studies in animal and human ethology. This program is available for a number of hand-held PC, for example, Psion and Psion Workabout (cf. Albonetti, 1992; Hile, 1991). This methodology further consists of a Psiwin version and a behavior observation training course available on video cassette (Noldus Information Technology, 1995).

Software to facilitate the use of hand-held PCs in field studies has been developed in many institutions, more or less specific to certain studies. Flexible software systems suited to a variety of applications are still an exception (e. g., Behavior Observation System, Noldus Information Technology, AG Wageningen, NL; MONITOR for various types of self-reports, developed for use with the PSION series, Brügner, 1998; in-field performance testing, cf. Buse & Pawlik, 1996).

There are various sources of data: behavior (performance) measurement, behavior observation, self-reports on experiences, subjective state, etc., and, possibly, environmental aspects, like ambient noise or temperature, which can be recorded in field studies.

The application of a programmable pocket PC in ambulatory assessment has many advantages as compared to conventional paper-and-pencil methods:

- alarm functions for prompting the observer/subject at predefined intervals and a built-in reminder signal;
- reliable timing of input, delay of input, and duration of input;
- flexible layout of questions and response categories;

- branching of questions and tailor-made sequential or hierarchical strategies;
- concealment of previously recorded responses from the observer/subject;
- overcoming the recall-error.

The recall-error or retrospection effect has been a methodological issue in several studies. Even if subjects are told to monitor their stress responses, mood and symptoms several times daily, such questionnaire reports are often done from memory. A specific bias is evident when ratings made in the evening indicate more negative mood and unease than is to be expected from the actual ratings averaged across the day, that is, a *negative* retrospection bias (see Fahrenberg, Hüttner & Leonhart, this Volume).

Many applications for hand-held PCs (electronic diaries) exist, for example, job stress diaries (Rau & Triemer, 1999; Totterdell, Spelten, Smith, Barton & Folkard, 1995) and pain diaries (Lang, Ostermeier, Forster & Handwerker, 1991; Lewis, Lewis & Cumming, 1995; Smith & Safer, 1993); diaries can facilitate the diagnostic assessment of a variety of behavioral disorders (Shiffman, 2000; Shiffman et al, 1994; Suls & Martin, 1993; Wilz & Brähler, 1997; see Chapters in this Volume).

A higher technical reliability and ecological validity of computer-assisted recordings can be generally assumed compared with paper-and-pencil questionnaires and diaries that lack flexibility in data acquisition and exactness when timing responses.

Detection of posture and motion

The recording of posture and motion is another basic issue in the methodology of behavior observation and performance measurement. Calibrated piezoresistive sensors allow the separation of a DC-component indicating degree of inclination, that is, position, and an AC-component representing acceleration, that is, movement. Multi-channel accelerometry can be used for the measurement of posture, specific movements, tremor, gait, and other aspects of motor behavior. Moreover, an automatic detection of posture and motion during ambulatory monitoring can be achieved if an individual's characteristic patterns were obtained with, for example, a standard protocol for walking, standing, and sitting at the beginning of the assessment. Based on such multi-site accelerometry and ambulatory recordings, a continuous record of posture and movement can be achieved rather unobtrusively. In addition to this, accelerometry may be used as a method for the estimation of gross physical activity and energy expenditure. The detection of posture and motion was recently improved

and has attained a satisfactory reliability and validity (see Bussmann et. al.; Foerster; Tulen et al., this Volume).

To assist in objective behavior analysis, a range of interesting variables could be measured continuously. However, to date little systematic use has been made of these technically available options. Examples are:

- movement of the head measured by a small accelerometer placed beneath the chin to assess head movement, for example, nodding during a conversation;
- voice signal recorded via a throat sensor (micro);
- ambient conditions recorded via suitable sensors for light, noise, and temperature.

The temporal analysis of speech patterns, that is, speech chronometrics, was used in ambulatory assessment (Krüger & Vollrath, 1996). Behavior channels like nodding and voice (in case an audio recording is not possible) may be used as objective indicants of conversation and social interaction. Pilot studies were encouraging and speak in favor of further developing such methods. Some hand-held PCs allow for audio recordings up to a number of minutes, depending on storage capacity. Digital dictating systems have a capacity up to 240 minutes in long play mode.

In psychological and psychophysiologal research, so far, little use was made of digital mini-cams for recordings of the videostream of behavior. A mini-cam for mobile video transmission (range 300 m) has a housing 18 x 17 x 34 mm, objective lens 1.5 mm diameter. A digital web-cam is available with integrated web-server, that is, transmission via web-site activation or e-mail in JPEG-format.

Psychophysiological monitoring

The scope and the development of ambulatory monitoring was documented in the Proceedings of the International Symposium on Ambulatory Monitoring (Stott, 1976). Most applications were from the medical field, however, psychophysiological research involved in the assessment of behavioral and subjective correlates of physiological changes has since gradually emerged.

A psychological investigation of gradients of arousal in novice and expert parachutists by Fenz and Epstein (1967) was an early example of growing interest in research under naturalistic conditions. (A similar study actually using modern monitoring equipment was conducted by Roth, Breivik, Jørgenson & Hofman, 1996). Noteworthy projects include a field study on blood pressure responses elicited by emotions (Sokolow, Werdegar,

Cowan & Brenenstuhl, 1970), changes in heart rate during daily life and self-report on mood changes (Roth, Tinklenberg, Doyle, Horvarth & Kopell, 1976) and the recording of heart rate, physical activity and self-reports (Taylor et al, 1982). Nevertheless, the psychological data were still recorded by paper-and-pencil methods.

Monitoring methodology in psychophysiology requires the concurrent recording of the essential response channels. Because cassette recorders at that time had a substantial wow and flutter, which might cause deviations in the order of several minutes per hour, the necessary post-hoc synchronization required special care using a timer channel, marker, etc. Concurrent recordings of psychological data were made using a small set of keys placed on a watchstrap (Fahrenberg et al., 1984, 1986). The EMOPAD was a specific device for data acquisition and was designed for use with the VITAPORT 1 (Jain, Mutz & Mucha, 1992).

The BIDATA (Buse & Pawlik, 1994, 1996) and the MULTITALENT MT (Zak, Simbach, Germany) were probably the first systems designed as multi-channel recorders for psychological and physiological data. The MT (NSC 800 CPU) had three analog input channels, 20 keys for recording behavioral data, a display for item text, acoustic feedback, and a number of further options. Based on this device, Myrtek et al. (1988) developed the methodology of interactive psychophysiological monitoring (see below).

In 1987, a multimethod strategy for psychophysiological 24-hour monitoring of blood pressure reactivity was developed (see Fahrenberg, 1987, 1990, 1996; Fahrenberg, Heger, Foerster & Müller, 1991; Heger, 1990; Käppler, 1994). This method consisted of recordings of blood pressure, heart rate, physical activity, and respiration rate, and – concurrent to each blood pressure measurement – obtained a computer-assisted self-report on setting, behavior, emotional state, and experience. The equipment in these studies was made up of a four-channel recorder for physiological measures (Physioport, Par-Natic, Berlin), a pocket-sized computer (Casio PB 1000 or Psion 3a), and a dictating system (Walkman recorder, Sony WM 202)

Systolic and diastolic blood pressure were measured intermittently by the auscultatory method, employing a microphone and R-wave gating to detect Korotkoff sounds. During the day, a measurement interval of 30 minutes, with a random component of +5/-5 minutes, and, at night, an interval of 60 minutes (+5/-5) was used. The physical activity index was derived from continuous registration of an three-directional piezoelectric accelerometer. The pocket-computer provided a convenient medium for obtaining a self-report on setting variables and activities, as well as self-ratings of emotional state and level of physical activity. The setting protocol contained four

aspects (location, social context, posture, activities). The momentary state was assessed by means of ten seven-point adjective rating scales, and two retrospective ratings related to perceived stress and physical activity in the preceding interval. The pocket-computer was initially programmed to record self-reports at fixed intervals, for example, at intervals of 30 minutes, and subjects were instructed to give additional self-reports when relevant events occurred. In subsequent studies, subjects were instructed to give a self-report immediately after each BP measurement, which in turn was automatically initiated at intervals of 30 (±5) minutes. The dictating system – via a microphone fixed to the subjects' shirt or top – was used to obtain comments on the more specific aspects of behavior settings and events. Such information is also important for estimating the subject's time budget and for the segmentation and evaluation of the 24-hour-record (cf. Fahrenberg, 1996).

Controlled monitoring

The multi-method approach was applied in a number of studies on blood pressure reactivity to obtain 24-hour BP profiles. Although this equipment, in particular its weight and the noisy pump system imposed some restrictions, it was well accepted by nearly all participants and hypertensive patients. Concurrent recordings of physical activity provided means for a segmentation of recordings according to high or low activity. Energy expenditure and posture are essential sources of BP variance and require appropriate controls if BP level and sudden blood pressure surges are to be evaluated adequately. Thus, activity-controlled psychophysiological BP profiles were obtained under conditions of daily life. The methodology allowed for time sampling and for event sampling of blood pressure and subjective state, as well. Furthermore, standardized or semi-standardized measurement periods were included which served as a reference for inter- and intra-individual comparison. As part of the standard protocol in 24-hour monitoring, the subjects performed specific tasks: climbing a stair case, performing a mental test, and participating in a short interview.

Multimethod assessment strategies of this kind, using hand-held PC instead of written diaries, were likewise developed, for example, by Kamarck et al. (1998) and Schmidt and Jain (1996).

Interactive monitoring

The development of recorder equipment suitable for physiological and psychophysiological recordings and on-line (real-time) analysis led to innovative research strategies. Contingent to changes of certain physiological parameters, a patient can be prompted by a beeper signal to

record specific events, activities, or symptoms. Myrtek et al. (1988) and Myrtek, Brügner and Müller (1996) developed a new methodology for interactive monitoring of “additional heart rate” and concurrent assessment of subjective state change (cf. Myrtek & Foerster, this Volume). The on-line analysis of ECG changes were used also in detection and early warning of transient myocardial ischemia (Barry, Campbell, Nabel, Mead & Selwyn, 1987; Myrtek, Fichtler, König, Brügner & Müller, 1994; Kinne & Droste, 1996; Kinne, Droste, Fahrenberg & Roskamm, 1999) and in triggering a concurrent blood pressure measurement (Deedwania & Nelson, 1990).

General issues in methodology

Developments in research designs, measurement issues, sampling, and statistical data analysis have been discussed in other chapters of this volume, so that it may suffice here to refer to general issues of the ambulatory assessment approach as a whole.

The interplay between progress in information technology and the development of new research questions is evident. Innovative methodologies were developed to assess physiological and psychological parameters that were previously not accessible or were not accessible in a satisfactory manner, for example, only under the restrictions of the artificial laboratory settings and with highly questionable external validity. Such developments have stimulated new research questions leading to a mutual process of progression and refinement of hardware and software, and, moreover, promoting the development of new strategies in statistical data analysis.

Several issues are noteworthy in discussing the origins and developments of computer-assisted monitoring and assessment. Such issues include the choice between special-purpose or multi-purpose equipment, the acceptance of this methodology by study participants and patients, and the attitude of professionals and potential users regarding these innovations, exchange of know-how, attempts at standardization, and aspects of cost-benefits.

Special- and multi-purpose devices

A prevailing issue concerning the more recent application of monitoring is the question whether equipment which has to be specifically designed for a certain application is to be given preference to a readily available device which does not fulfill all the requirements of that applications. Special-purpose devices are available for certain applications in medicine, especially ECG and BP recorder. Such equipment is produced in a large

number and is less expensive than multi-purpose recorders. However, these convenient devices are limited in the sense that the selection of channels, operating characteristics and other features is pre-determined. ECG and BP recorders usually lack channels for concurrent registration of physical activity and psychological data.

Since research evidence has strongly affirmed that blood pressure variability and the effects of energy expenditure and body position (for example, standing upright, body rotation during sleep affecting the distance between cuff and heart level) are confounded, this unwanted (however unknown) variance should be controlled for in a more thorough evaluation of significant blood pressure surges. Ambulatory monitoring studies which have used multi-channel recordings have strongly suggested that the inclusion by manufacturers of at least one channel for a tridimensional accelerometer device would provide the necessary data for an adequate analysis of 24-hour recordings.

Equipment in modular, multi-purpose designs, on the other hand, may be more suitable in many fields of the behavioral sciences for monitoring and assessment because of its flexibility and adaptability to a range of research questions. These devices are probably more expensive and less well supported with application software.

In psychology, computer-assisted data acquisition by hand-held PC may require a choice between a general-purpose hand-held PC and a tailor-made system with, for example, software for recording self-ratings or responses to mental performance tests (cf. Pawlik & Buse, this Volume). A general-purpose hand-held PC will be less costly, but is not provided with the appropriate software. Software development, depending on the range of options required, may amount to a formidable task and most users would prefer to acquire such programs from other institutions or licenses, respectively. Such software developments were referred to in a number of chapters in this Volume.

Acceptance, compliance, and reactivity

From the beginning, there have been concerns raised about the acceptance of monotoring and the validity of monitoring in daily life has been questioned. Ambulatory assessment with a pocket PC or recorder depends on the favorable attitude and motivation 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 consent to the monitoring follows in the course of the interaction with the clinicians. For this reason, the attitude of patients may be different

and the acceptance of monitoring may be higher within the health care system than in research projects. The ambulatory assessment should not cause major problems with the social environment. A comprehensive post-monitoring-interview is recommended in order to obtain information on these essential aspects.

The book on “Microcomputers and Clinical Psychology” edited by Ager and Bendall (1991) discussed already many of the essential issues, applications and future developments in this domain. The contributions still referred to the use of stationary PCs, although the pioneer studies employing hand-held PC had been published already. These issues included, for example, computer-assisted assessment of psychological problems, computer-based neuropsychological assessment and cognitive rehabilitation, applications for people with learning disabilities, expert systems and the role of the clinical psychologist. A chapter on psychological aspects of the new technological age referred to client reactions to computerized assessment. In some cases there was a reluctant attitude or even computer-phobia and in others the favorable response of most clients was indicated.

The acceptance of the hand-held computer in field studies and of ambulatory monitoring in general appears to be much higher than initially anticipated by investigators (cf. Fahrenberg & Myrtek, 1996; 2001). The experience of being equipped with a new electronic device can be a motivating condition to participants. Furthermore, motivation can stem from the participation in a diagnostic procedure or research project and the willingness to learn about oneself: “Everybody is his own blood pressure (or stress) researcher.” However, it is understandable that at some workplaces and by some subjects this attitude is not shared. Certain environments will be less suited to ambulatory monitoring, however, the registration of the ECG and motion (actometer) are feasible in practically all conditions because these recordings are disguised to the public. Intermittent automatic blood pressure measurements, beeper signals, and the instruction to type a response into a hand-held computer may be a problem in some instances because they distract the participant or elicit positive or negative responses and comments from others. A computer-assisted method for obtaining self-reports and physiological measurements has the specific advantage of being able to register an protocol of the subject’s compliance and the exact timing of data acquisition.

Reactivity means that the method of observation and measurement itself is one aspect of the unwanted variance because of specific interactions such as awareness, adaptation, sensitization, and coping tendencies (cf. Haynes & Horn, 1983; Stern, 1986). Such reactivity may include a bias that

is common to a class of methods or specific to one method. Non-reactive methods are clearly an exception in psychological assessment and physiological measurement, indeed this an analogy to Heisenberg's uncertainty principle: the attempt to measure a phenomenon may distort this phenomenon.

Three aspects of reactivity, however, 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. At present, only a post-monitoring interview can reveal these effects and their actual evaluation is rather difficult. Little is yet known about the advisability of including a few control items and questions in the computer-assisted questionnaire that directly refer to actual (non-) compliance and method-dependent effects; for example, the subject's being irritated by the beeps or having specifically changed the usual routine.

Ethical issues

Ethical issues that are specific to ambulatory monitoring studies have hardly been discussed in the literature. The monitoring could be regarded as a case of "Big brother is watching you", that is, an invasion of privacy. Of course, the guidelines of ethics committees must be adhered to. Appropriate data protection is a concern because ambulatory assessment may violate privacy more easily than alternative methods (Schuler, 1982; Bersoff & Bersoff, 2000). Furthermore, persons not being assessed may become involved in the observation and evaluation of settings when these are being carried out. Obtaining the subject's informed consent before the recording starts is essential, but may be problematic since the exact course of daily activities and events cannot be anticipated. Moreover, it may be more difficult to explain the essential hypothesis of the investigation, variables, and methods of analysis in ambulatory studies than in the laboratory. Especially when psychological data and recordings of behavioral (motor) activities are obtained, the participants should be briefed about the kind of findings and conclusions that can be derived from such protocols. Thus, the post-monitoring interview is well suited to recalling specific events and discussing problematic aspects.

Cost-benefit

Ambulatory assessment methodology has certain advantages compared with stationary equipment. However, the recorder/analyzer will usually be more costly. The expectation is that cheaper devices, suitable for multi-channel physiological recordings, and cheaper pocket-PCs will be developed in future. Thus, a more extensive use of the ambulatory assessment technology is foreseeable as is already the case in single purpose ECG recorders or blood pressure recorders. The higher ecological validity of the ambulatory assessment will encourage such applications.

Exchange of know-how and training

The ISAM Meetings were initiated to provide the first opportunity of its kind for the presentation of new technologies and methodologies of ambulatory monitoring (Stott, 1976; Stott et al., 1978, 1982; Dal Palú & Pessina, 1986). Journals, devoted to this subject, included: *Biotelemetry and Patient Monitoring* (1972–1982, then, *Acute Care* 1983–1989), *Biotelemetry* (1974–1977), *Journal of Ambulatory Monitoring* (1988–1995), *Journal of Medical Engineering* & *Technology* (1976–), and *Blood Pressure Monitoring (*1996–).

A number of symposia on ambulatory monitoring have taken place at annual meetings of societies, like the Society for Psychophysiological Research, the European Federation of Psychophysiological Societies, and national congresses. On a smaller scale, there were a number of users' meetings over the years regarding, for example, the application of specific systems (like Vitaport-Meetings and Portapres Meetings in Germany, VU-AMS Workshops in Amsterdam, NL). At such workshops, participants from a wide range of institutions and disciplines met who would not normally attend the same annual congresses. The diversity of equipment and research interests, of course, is a severe handicap for in-depth cooperation. There is an obvious need for the exchange of know-how and training, however, this requires more time than is available for conventional workshops at larger congresses. Noteworthy was a training course on "Psychobiological ambulatory monitoring in health psychology", staged by the Research Institute for Psychology and Health (at Utrecht University and Leiden University, NL) in 1997.

Among these meetings were two workshops organized by the Forschungsgruppe Psychophysiologie, Psychology Department, Freiburg University, and funded by the Deutsche Forschungsgemeinschaft. These meetings were encouraging and the resultant manuscripts formed the core of the present volume and the previous book published in 1996.

Physiological measurement and monitoring, as in the laboratory, require specific training, technical assistance, and software development. This can

hardly be achieved in a sole person enterprise. It needs team work and adequate funding to foster a continuous development of skills and general competence. One may assume that over the years a large number of multi-purpose recorders were purchased but rarely used because it was realized only to late that the methodology needed is by no means as simple and convenient as in the case of BP or ECG recorders.

Acceptance and impact of computer-assisted monitoring methodology in psychophysiology and psychology

In medicine, the ambulatory monitoring of BP and ECG are now indispensable routine methods. The ever more widespread application of the new methodology can be attributed to its practical usefulness which was evident in the increased validity of diagnosis and in the external validity of therapy outcome evaluation – and in the fact that such applications were paid for by the insurance companies.

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. In psychophysiology, for example, over many years a nearly constant percentage of five or less per cent of posters refer to ambulatory monitoring methodology. It fits into this picture that the previous volume “Ambulatory Assessment” had only one review (Turpin, 1999) in international journals.

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 is Goldstein and Hersen (2000), who at least mention such developments.

This situation may be due to several reasons. In spite of the pioneer work in the late seventies and eighties, this methodology had little influence on present day mainstream research activities. Investigators seemed to be concerned with the possibility that hand-held PC and other monitoring systems might have little acceptance in study participants and patients. This attitude was put into words by van Egeren and Madarasmi (1988): “We initially considered using a small, hand-held programmable microcomputer to log diary information but abandoned the idea because the operation of these devices is too complex and the fear of computers on the part of some people too great to ensure reliable performance. Instead we developed the

mark sense diary card ...” (p. 180). However, was this attitude based on empirical evidence ?

The feedback from participants of ambulatory monitoring studies, even in the past, when the equipment was more obtrusive and uncomfortable, was on the whole encouraging. A general acceptance of and, in particular, interest in these new methods was indicated and appeared to motivate the participants. Such compliance was reported by many investigators (see above), although for some populations and some subjects this methodology appears to be less suitable.

The critical attitude seems to be based on theoretical preconceptions or even prejudice and is particularly noteworthy because of the enduring controversy in theoretical psychology about the dichotomy of artificial laboratory setting versus naturalistic observation. This controversy is often misleadingly paralleled with the a dichotomy of internal versus external validity. Both aspects of validity rightly have to be put under scrutiny in laboratory experimentation as well as in ambulatory assessment (for a more extended discussion see Fahrenberg, 1996; Fahrenberg & Myrtek, 2001; Patry, 1982; Pawlik, 1988).

Pawlik (1988, 1996) has pointed out that differential psychology and personality assessment might have taken a basically different course of development had the empirical approach initially been one of data acquisition in daily life instead of mental testing and laboratory experimentation. Of course, ambulatory assessment requires the elaboration of specific designs and strategies (see for example, Stemmler, 1996) and the development of appropriate statistical models for multi-level analyses and rather short time series (for example, Delespaul, 1992; Schwarz & Stone, 1998; Suen & Ary, 1989; Totterdell, Briner, Parkinson & Reynolds,1996; see also, Ott & Scholz; and Wilhelm, this Volume).

A rather reluctant attitude toward ambulatory monitoring and assessment of individual differences and testing hypotheses under naturalistic conditions may be further due to general assumptions derived from the philosophy of science and the logic of research. The general attitude is one of favoring the testing of theories under highly controlled conditions and not of deliberating to much on inductive approaches, that is, accumulation of empirical facts as raw material for subsequent theory building. This attitude may appear to be adequate in the natural sciences (which has undergone a long and very successful history of data gathering and inductive reasoning), but in the behavioral sciences an inductive-hypothetico-deductive strategy still is a useful approach. For a range of issues, ambulatory monitoring methodology has already shown that findings and conclusions based on laboratory experiments were hardly tenable on empirical grounds, provided

that the field studies have been seriously taken into account. Neither the dichotomy internal/external validity nor theory driven/data driven research are adequate descriptions of the basic methodological issues implied here, however, sometimes the discussion and probably the willingness to apply innovative methodology may be hindered by such views.

Following from this, the impression is that the acceptance of this methodology may be greater by study participants and patients than by mainstream psychologists and psychophysiologists. In Germany, for example, where basic research reports on large scale psychological and psychophysiological monitoring studies were published in the early eighties, the impact of these reports was hardly noticeable in spite of the availability of technically advanced equipment in the country. Not even in fields particularly suited to ambulatory assessment methodology, for example, diagnosis and evaluation in behavior therapy, investigation of symptom reports in chronic illness and psychiatric patients, or engineering psychophysiology, was a wide acceptance evident (for reviews, Fahrenberg, 2000; Fahrenberg & Myrtek, 2001; Fahrenberg & Wientjes, 2000).

Two further issues should be mentioned which could explain the hesitant and sceptical attitude of mainstream researchers: costs and necessary training. The price of a hand-held PC, of course, exceeds the cost of paper-and-pencil methods but is not really so high as to hinder its use when the advantages of flexibility of data acquisition, the high technical reliability and exact timing are to be taken into account. Ambulatory assessment methodologies need some training. However, the use of a PC is a common skill today.

Perspectives

During the last two decades, a fast development in microprocessor technology has enabled 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 PCs for acquisition of psychological data are available. Such systems allow innovative research and practical application in many fields and essential findings have been obtained. In medicine, ambulatory monitoring is an indispensable routine method.

There are two noticeable developments which probably exert an essential influence on the computer-assisted methods in medicine and the behavioral sciences:

— The arrival of the web-based mobile telecommunication (e. g., IMT-2000 and UMTS). The fusion of mobile and fixed networks will stimulate the evolution and progress toward universal mobile telecommunication systems. These new information technologies would allow for personal mobility and for access to, for example, experts and knowledge-based systems.

— The arrival of new patient monitoring equipment appears to revolutionize the way in which patient information is transmitted and used in the healthcare system:

"Healthcare institutions are progressively pursuing a reduction in patients lengths of stay as a means of achieving cost containment. Encouraging earlier ambulation while continuing to monitor the patients is just one of the methods applied to attain this goal. This has, in turn, stimulated the development and use of telemetry and telemedicine in both the hospital and home environments." (From a Report on European Patient Monitoring Device Market, 2000, provided by Frost & Sullivan, an international marketing consulting company.). Wireless technology will transform healthcare in many respects (Leopold, this Volume; Walsh, 2000). A bibliography of health care journal articles regarding *Professional and Patient Use of Palm Tops, PDAs, and Hand Helds* was provided by Stoddard, Arizona Health Sciences Library (stoddard@ahsl.arizona.edu).

The benefits of hand-held PC and internet technologies in clinical trials and the care of patients with chronic disease is the subject of an increasing number of publications. At present, we may only speculate about the consequences of such developing information technologies for the health care system and, to some extent, on subsequent developments in applied fields of psychology.

From self-monitoring to self-management

A hand-held PC may be useful in the diagnostic assessment of a variety of behavior disorders, for example, the assessment and self-management of drinking, smoking, and of eating disorders, in facilitating self-management in chronic illness, and moreover in neuropsychological training, in health care of the chronically ill, in patient education, and in behavior therapy:

- relaxation training (Baer & Surman, 1985);
- obesity (Burnett, Taylor & Agras, 1985, 1992);
- hypoglycemia in insulin-dependent diabetes mellitus (Cox et al., 1994; Schvarcz, Palmer, Berne & Bjork, 1991, see Kubiak & Hermanns, this Volume);
- in asthma patients (Osman et al., 1994; Leopold & Schandry, this Volume);

- in ambulatory computer-assisted therapy for anxiety disorder (Newman, Consoli & Taylor, 1999; Newman, Kenardy, Herman & Taylor, 1996).

Computer-programs that are 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 et al. (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 (GAD). The computer program offers advantages to researchers, therapists, and clients. These advantages include continuous, unobtrusive collection of data 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).

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. Such developments may include strategies for unrestricted and controlled monitoring, new strategies in interactive monitoring and on-line feedback, monitoring and concurrent recording of audio and video signals (intelligently pre-processed before stored), setting-dependent sampling, new strategies in self-monitoring and self-management in chronic illness. At present, it is hard to conceive to what extent specific expertise systems, and in particular, the wireless application protocol WAP, mobile phone short message systems SMS, and further developments in information technology will direct the course of this methodology.

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