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The Psychophysiological Laboratory

Psychophysiological measures have come out of the closet. A half century ago, psychophysiological tools were used by a highly specialized a group of scientists with specialized training and esoteric laboratories that resembled an electronics parts emporium. Today, however, such measures are used widely by nonspecialists as just one of many tools, in much the way they would select an implicit attitudes test, a behavioral coding scheme, or even a hierarchical linear model to address their research questions. In emotion research, the range of psychophysiological measures available is vast, including, as examples, skin conductance responses as measures of arousal (e.g., Hare, 1965) or fear conditioning (e.g., Öhman & Soares, 1994); myriad cardiovascular correlates of emotion (e.g., Chambers & Allen, 2002; Shalev et al., 1998); facial muscle activity as subtle measures of emotional valence (e.g., Cacioppo, Petty, Losch, & Kim, 1986); emotion-modulated startle responses (e.g., Curtin, Lang, Patrick, & Stritzke, 1998; Vrana, Spence, & Lang, 1988); electroencephalographic activity as a moderator or mediator of emotional response (e.g., Coan & Allen, 2004; Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003); and event-related brain potentials to index various aspects of emotional stimulus processing (e.g., Curtin, Patrick, Lang, Cacioppo, & Birbaumer, 2001; Schupp, Cuthbert, Bradley, Cacioppo, Ito, & Lang, 2000).

Advances in electronics and computer technology have made psychophysiological tools far more accessible to nonspecialists, which is generally a very positive development. However, many potential users of psychophysiological measures still may find themselves wondering what equipment and expertise is required to become a competent user of these tools. The aim of this chapter is to provide a pragmatic overview of how to set up a psychophysiological laboratory and to provide references to aid in gaining competence and expertise in using psychophysiological measures.

Basic Considerations

Before you embark on the journey toward using psychophysiological measures, a candid assessment of your abilities and interests may spare later aggravation. You might reasonably assess your preferences on a variety of dimensions:

- Would you prefer to invest in your own psychophysiology laboratory or to work collaboratively with an investigator who already has a psychophysiology laboratory?
- Would you prefer to develop into an independent psychophysiological investigator or work in collaboration with or receive consultation from established researchers?
- Assuming you wish to have psychophysiological capabilities in your laboratory, would you prefer to have a dedicated psychophysiology laboratory or a multipurpose space in which psychophysiological recording is possible?

- Would you make use of a laboratory that allows for the recording of many different measures or does your research require that you record from only a small set of physiological response systems?

In this chapter, we present a wide variety of psychophysiological laboratory options, allowing you to assess your level of technical savvy and willingness to futz with things, and then providing a set of options that range from "low-tech plug and play" to "high-tech do-it yourself" solutions.

Basic Laboratory Desiderata

A basic psychophysiology laboratory for collecting data consists of a place that is free of electrical and ambient noise, a set of equipment for presenting stimuli and collecting responses, a set of hardware for amplifying physiological signals and saving them in digitized form, and software for reducing the physiological signals to a format suitable for statistical analysis. Although rather simple by way of overview, a generic schematic is provided in Figure 24.1 to help in organizing your thoughts about the various components that are included in most psychophysiological laboratories. Many considerations exist for each of these components, and each is discussed in separate sections, with section headings noted in the figure.

Participant and Observation Rooms

Although not strictly required, it is often desirable to separate the participant recording area from the control room where the experimenter controls the recording equipment and stimulus presentation. By separating the participant from the experimenter and the experimental control equipment, it is less likely that distracting noises and activities will elicit physiological responses, and it is less likely that the participant will feel self-conscious about being observed during the recording session or that physiological responses will be otherwise altered by observation (e.g., Drummond & Mirco, 2004; Kline, Blackhart, & Joiner, 2002). Participant rooms, however, tend to make some participants uneasy, especially those individuals with claustrophobic tendencies. It is thus a good idea to ensure that such spaces are not unduly small (e.g., no smaller than 6 feet by 6 feet), that participants can easily communicate with experimenters via an intercom, and that participants are aware that they can easily exit the space if required.

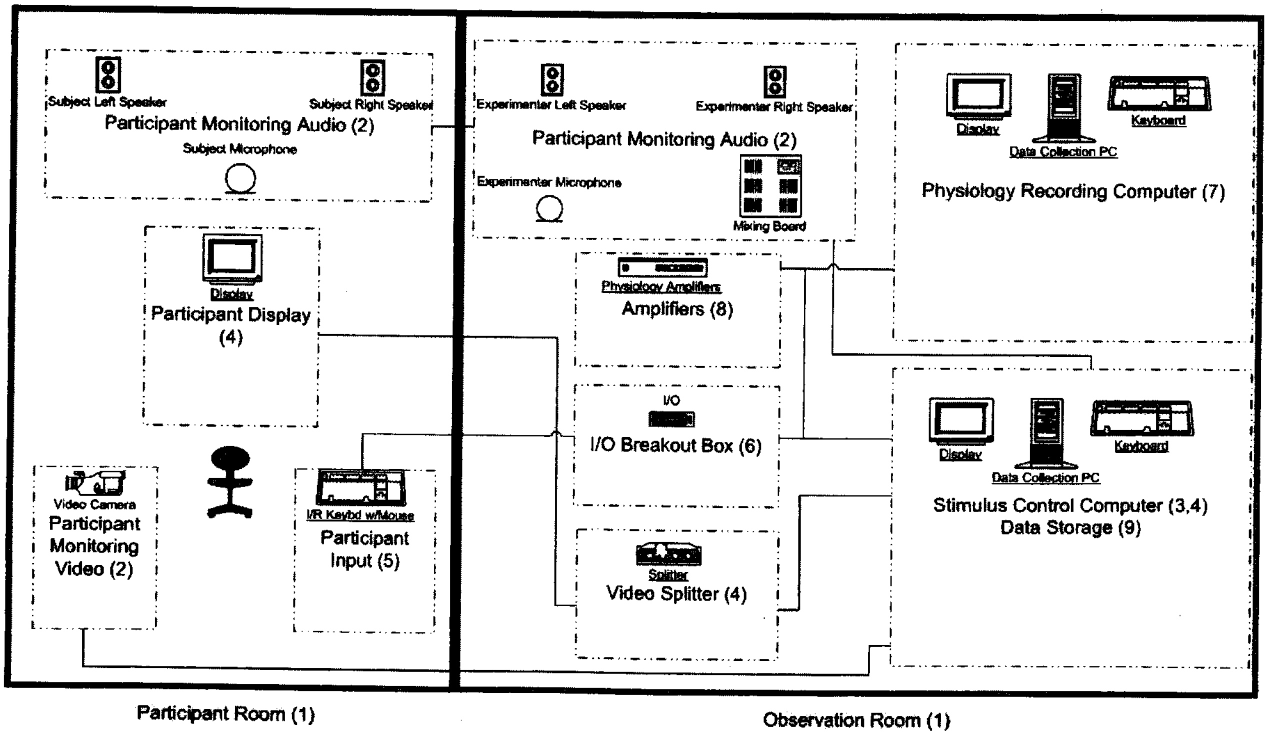

Figure 24.1. A schematic overview that includes the primary components present in most psychophysiological laboratories. Parenthetical numbers are provided for each component to indicate the section heading for relevant discussion in the text. *Section headings*: 1. Participant and observation rooms; 2. Participant monitoring; 3. The stimulus control computer; 4. Participant and experimenter displays; 5. Measuring behavioral response; 6. Digital input and output; 7. The physiology-recording computer; 8. Physiology amplifiers; 9. Data storage.

Although decades ago the separation of participant and experimenter often took the form of an electrically shielded room that was necessary to record clean signals free of ambient electrical noise, modern amplifiers are much better at recording in typical office settings, and such elaborate shielded chambers are seldom necessary from an electrical standpoint. These chambers, however, also provided a sound-dampened environment in which participants could easily attend to the tasks and stimuli at hand, free of other acoustic and visual distractions. This latter benefit can still be obtained by selecting a separate participant room and using sound insulating foam (such as that by Illbruck) to deaden noise.

If you are renovating an existing space by subdividing a room, pay attention to electrical and lighting locations to ensure that each room has separate a lighting control and contains electrical outlets. In a participant room, few outlets are needed, but often an outlet for a monitor and possibly a computer may be useful. On the other hand, if the renovation budget is limited, running high-quality grounded extension cables from the control room is an adequate option and may be preferred in that one can ensure that all equipment shares a common ground.

Another consideration in renovation is ensuring a means to pass necessary cabling between the participant room and the control room. If you are renovating a lab, you can ask that a PVC pipe or two be installed in the wall just a few inches above the floor allowing for cables to pass. The PVC diameter must exceed the largest cable end, and allowing for additional cables in the future is a wise strategy. A 2- or 3-inch diameter PVC pipe is likely to be suitable. Stuffing foam in the pipe after passing cables will provide sound buffering.

Of course, not everyone will have the luxury of a separate room for participants and experimenters. A single room can be made more suitable for psychophysiological recording by creating a separate space for the participant using room dividers such as a tri-fold screen (sometimes called Shoji screens) or by using one or two sides of an office cubicle divider. If you have a single-room setup, giving special attention to eliminating other noises—such as keyboards with loud clicks, loud computer fans, sound themes on computers, squeaky chairs, and other such nuisances—might reduce the extent to which sharing a room with the experimenter is distracting for the participant.

Adequate control of ambient temperature is another consideration in the psychophysiological laboratory. This is of special concern when recording autonomic signals, as peripheral physiological response systems may adaptively respond to help keep participants cool or warm, potentially confounding the recording of the signals of interest. Thus it would be desirable to have room-level control of the temperature, or at least control of the recording suite independent of the rest of the building. Finally, if you have an option, you may wish to consider locating the psychophysiology laboratory away from highly trafficked corridors or other sources of building noise. Similarly, selecting a location away from other large electrical equipment (e.g., HVAC units, elevator motors) in the building is desirable from the standpoint of reducing or eliminating electrical noise in your recorded signals.

Participant Monitoring

In designing the laboratory, it is important to implement audio and video capabilities for monitoring and interacting with the participant during an experiment. This will eliminate the need for the experimenter to physically enter the participant room to relay instructions or answer questions. Entering the participant room during an experiment is not only disruptive to the flow of the session but can possibly induce behavioral or movement artifact.

The laboratory audio system should provide for two-way communication between the participant and observation rooms. Off-the-shelf intercom systems are available, but care should be taken when selecting among these systems. Many only provide for one-way communication (e.g., baby monitors) or require users on both ends to press a button to be heard (e.g., "walkie-talkie" systems). Although it is reasonable for the experimenter to "push-to-talk," this is often not possible on the participant's end. Some two-way systems are not "full duplex," which means that they do not allow two-way communication simultaneously but only in sequence. These systems prevent the participant from being heard when the experimenter is talking, and vice versa, which may lead to awkward communication problems. Finally, problems may arise if the experiment itself includes audio stimuli. The experimental audio stimuli will likely be presented through a higher quality independent audio system (e.g., headphones), necessitating some redundancy, and in some configurations these two audio systems may interfere with each other. For example, if experimental stimuli are presented over headphones, the headphones may interfere with the participant's ability to hear task instructions presented via intercom speakers.

One easy and relatively low-cost way to achieve full-duplex, two-way communication that includes passive monitoring of the participant (i.e., no push-to-talk on participant's end) is to combine two systems. Passive-participant audio monitoring can be achieved with many one-way communication intercoms (and also many video monitoring systems, such as a Radio Shack 2.4GHz Black & White Wireless Surveillance System, catalog # 49-2534, or any number of systems from companies such as SmartHome). In the observation room, a push-button microphone for the experimenter can be input to the stimulus-control computer sound card, with the sound card output presented to the participant via attached computer speakers in the participant room. The audio system built into the computer can allow you to mix the sound of the microphone and that coming from the computer (e.g. MP3 files or CD or DVD) in such a way that both are at a comfortable level. Some sound cards also allow for both a microphone and "line" input so that sound from another source, such as a VCR or external source, can be mixed with experimenter-initiated instructions and other communication.

Alternatively, an integrated and flexible system for audio monitoring, recording, and presentation of experimental stimuli can be built using a good quality multichannel audio mixer-amplifier (e.g. Mackie 1202-VLZ Pro) connected to push-button (e.g., Shure MX412) and "always on" (e.g., Audio-technica PR044) microphones and speakers/headphones. This configuration will allow the presentation of computer-generated audio stimuli or video playback and experimenter instructions without requiring redundant speakers/headphones or switching wires between the computer and video player. Moreover, the audio-mixer amplifier can provide amplification of the sound card output if needed to achieve the required sound intensity for some stimuli (e.g., noise probes to elicit the startle reflex are often presented at or above 102dB, an intensity that many sound card/headphone combinations may not be able to achieve without addition of an amplifier). Another advantage to this is that all of the audio within the study can be sent from the output of the mixer into an audio or video recorder if recording of participant's verbal responses is required. A typical configuration for this integrated system is presented in Figure 24.2. Speakers/headphones in the participant room allow for the experimenter (or experimental stimuli) to be heard. A participant microphone picks up the audio from the observation room. Conversely, the speaker in the observation room allows the participant to be heard and the observation room microphone picks up task instructions and other communication from the experimenter. When selecting your microphones, it may be advantageous to select devices that do not require an internal battery to power the condenser element so as to avoid problems associated with a failed battery during a session. For example, one attractive option is to select dynamic condenser microphones that use phantom power (48vdc) supplied from the audio mixer.

When considering video monitoring systems, there exists quite a range in cost and features. For example, the Radio Shack wireless surveillance system mentioned earlier provides for static viewing of the participant in low light (via infrared technology) on a small black-and-white monitor that can be flexibly located in the observation room with wireless connection to the camera in the participant room. As mentioned, this system also provides for passive, one-way audio communication. In a more elaborate instance, some systems include a motorized camera to allow remote control of panning and tilting of the camera body, as well as lens adjustments of focus, telephoto–wide angle, and iris settings (e.g., Panasonic WV-NS324 Hybrid Unitized Network Color

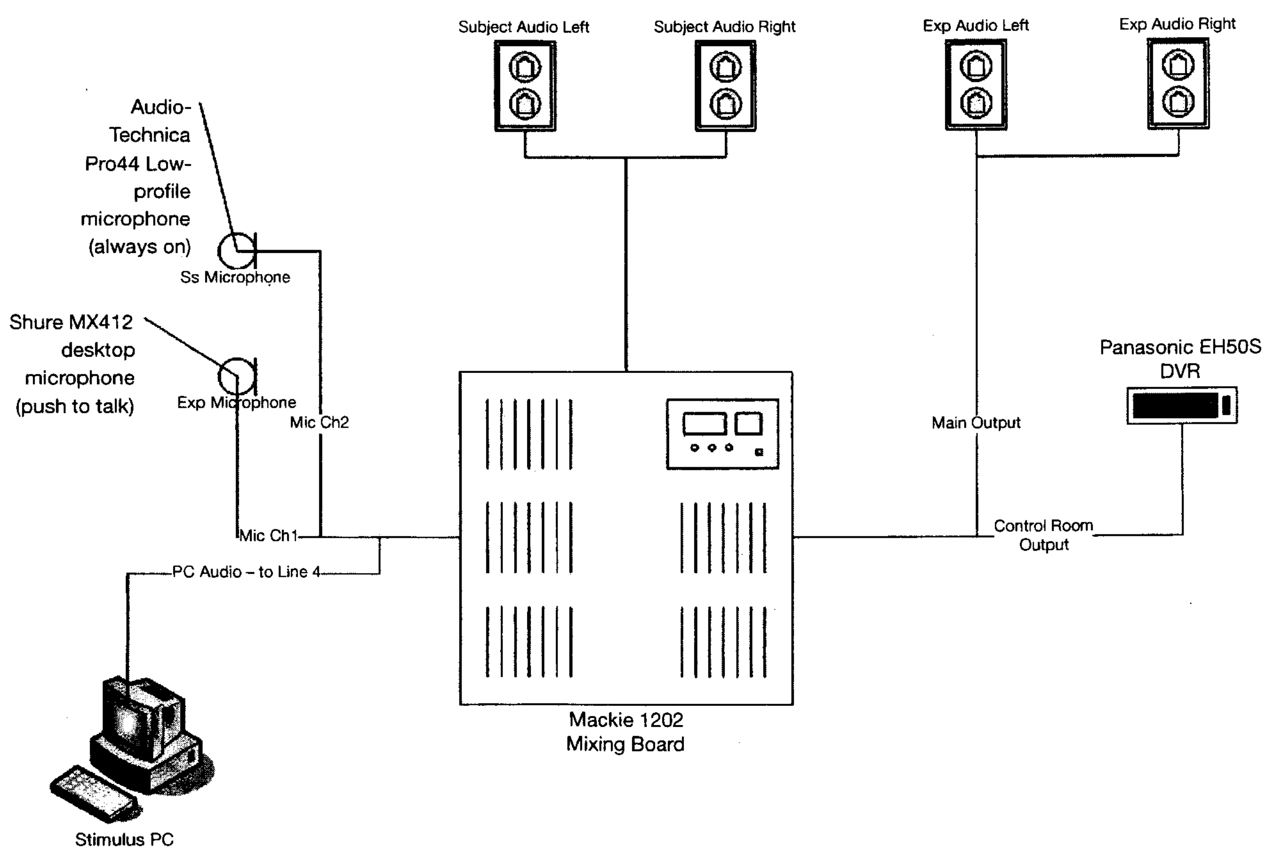

Figure 24.2. A schematic overview of a sample solution for audio monitoring, recording, and presentation of experimental stimuli.

Dome Camera with Pan, Tilt, Zoom; Sony SNC-RZ30N Network Camera). In addition, the signal from many video monitoring systems can be input to video recording devices (VHS, or digital video recorder) if subsequent coding of participant responding (e.g., facial display) is necessary.

Stimulus-Control and Physiology-Recording Computers

Although many configurations are possible, the most common configuration for display of stimuli with simultaneous recording of behavioral and physiological responding involves the use of two computers. The *stimulus-control computer,* described in this section, controls presentation and timing of the various stimuli (text, images, sounds, tactile stimuli, etc.) required by the task or paradigm used in the experiment. A second, *physiology-recording computer,* monitors and records the participant's physiology. In this configuration, communication between computers is typically unidirectional, from stimulus-control computer to physiology-recording computer. This communication is accomplished via parallel digital input-output (I/O) ports associated with each computer. In other words, specialized stimulus-control software running on the stimulus-control computer provides the overall control of the experimental events and informs the physiology-recording computer (by sending an event marker) each time an important event occurs (e.g., the presentation of a specific stimulus to the participant). Simultaneously, specialized physiology data acquisition software running on the physiology-recording computer passively records the participant's physiology continuously and saves event markers received from the stimulus-control computer into the physiology data record to indicate where in the physiology data stream various stimulus events occurred.

When configuring the stimulus-control and physiology-recording computers, you must make decisions about various issues, including operating system, CPU processing speed, amount of RAM, hard disk size, brand/model of video card(s), brand/model of sound card (if audio stimuli or sound recording will be used), method of I/O, type(s) of input devices (keyboard, mice, buttons, joysticks, etc), and type of case. However, personal computers are continually evolving, decreasing in cost, while at the same time being configured with more robust processor power, larger memory caches, and faster peripheral devices. It is the case now that features once found only in the costly, high-end, commercial work stations are now standard options in consumer-level personal computers of today. Thus the psychophysiologist interested in setting up a laboratory is faced with the choice between spending large sums of money for the top-of-the-line, high-end commercial work station versus finding low-cost machines on sale at local computer store or online retailer. The arguably best solution will address the specific functionality that is currently needed but also allow for the system to be flexibly upgraded as needs expand or as peripheral costs decrease. Given this, general guidelines can be offered on some of these decisions. For example, when selecting the computer case, make choices that support future upgrades. Select the minitower case over the cute, small footprint case. The former will more likely provide the option to add internal cards to communicate with peripheral hardware, a second hard drive to expand your storage needs, and perhaps a faster 1GB Ethernet card as your building network grows. Don't commit to a system that can't grow. When selecting CPU speed and memory size, it is certainly true that as software applications evolve, their demands for memory and processor speed increase. Therefore, it may make sense to spend a little extra for a faster CPU and increased memory. As you consider upgrades for these components, the relationship with price is nonlinear, with a large increase observed for the current fastest processes and largest memory options. The ideal cost-to-function ratio is often achieved by selecting an option just below the top one or two processor options.

It is not necessarily bad design to have different computers set up in the laboratory, each configured differently for the task at hand. In fact, it is recommended that data collection machines (both stimulus-control and physiology-recording computers) be dedicated to this use only, if possible. Installation of additional software or hardware for other purposes can often degrade the stability of the machine and increase system crashes that result in costly data loss. In contrast, the fastest computers are often not used for data collection but instead are dedicated to data reduction and processing. As these machines age and are no longer on the cutting edge, their role can be switched to tasks that require less power (for example, some stimulus-control software packages run quite effectively on older, slower computers) to save money. It is typically best to keep the operating system constant across computers, if possible, to ease transition from computer to computer and maintenance of security and other operating system patches. Moreover, consistent with stability concerns cited earlier, if a computer acquires a new role as a data collection machine, you should reinstall the operating system once any hardware changes have been completed.

Finally, before considering additional configuration options that are most relevant for the stimulus-control computer (sound card, video card, I/O cards, etc.), the most critical decision is the software used for control and timing of stimulus presentation. Many of these other decisions about stimulus-control computer configuration will be dictated by the requirements of the stimulus-control software.

Stimulus-Control Software

Stimulus-control software packages provide the psychophysiologist with control over the presentation and timing of the various stimuli presented to the research participant during an experiment. Typically, this software also monitors, measures, and records participants' behavioral responses. Numerous commercial stimulus-control software packages are available, and it is beyond the scope of this chapter to provide a comprehensive review of features included in these various packages and their relative advantages and disadvantages. As a starting point, however, contact information for many commonly used packages are listed in the section on software vendors in Table 24.1. Software packages can be broadly categorized into three groups: (1) stand-alone or independent stimulus-control programs (e.g., DMDX, E-Prime), (2) stimulus-control software that is bundled within a "turn-key" or integrated system that also includes physiological amplifiers and software for physiology recording (e.g., Acknowledge as part of Biopac system; Digital Media Player as part of Mindware system, Stim as part of Neuroscan system), and (3) general-purpose programming languages (e.g., C/C++, Pascal, Visual Basic) used to control stimulus and timing. Given that commercial packages specifically designed for stimulus control (preceding categories 1 and 2) are now widely available, relatively inexpensive, and quite flexible and have rigorously addressed complicated issues related to the precision of stimulus timing, it is typically not recommended to use a general programming language for stimulus control. Moreover, it is possible to substitute a stand-alone stimulus-control software package for the stimulus-controls software bundled within the integrated system if desired. In fact, with only moderate technical skills, most stimulus-control software packages can be integrated with any of the available physiology amplifiers and data acquisition packages. In the remainder of this section, we outline some of the more important criteria to consider when selecting between specific stand-alone or integrated stimulus-control software packages.

The first important criterion to consider when selecting a stimulus-control software package is its ease of use. The overall weight you assign to this dimension may depend on the programming expertise in your laboratory. For example, researchers who are familiar with software development in any general-purpose programming language will not find it difficult to master task development in any of the commercially available stimulus-control software packages. However, ease of use should still be considered if you intend to train graduate or undergraduate students with varied programming backgrounds to develop their own tasks without significant involvement from you. Software packages that support "visual" development procedures are often easier for nonprogrammers to learn to use. Visual development procedures typically involve arranging a set of objects or events (e.g., an image file, text on the screen, collection of a participant response) in a time line to represent the flow of the experiment across trials. The availability of precoded routines for common experimental tasks will also speed up and simplify development if your lab regularly relies on a small set of previously developed tasks. In some instances, software developers provide these "canned" routines themselves (e.g. Neuroscan's Stim) For other packages, sample tasks can be obtained from other users via a user listserv (e.g. DMDX) or Web-based archives (e.g., Presentation).

A second, but comparably important, criterion is the flexibility or power of the software with respect to creating diverse experimental tasks or paradigms. Unfortunately, this criterion is often inversely related to ease of use. Software that relies on canned routines or on only visual development procedures to construct tasks will be easy to use but not very flexible with respect to developing novel tasks. Of course, if your research typically involves only these well established paradigms (e.g., well-known cognitive tasks such as the Stroop test, common emotion elicitation tasks such as the slide viewing paradigm, etc.), flexibility may not be as important an issue. However, if you often develop your own tasks or paradigms, it is important that your choice of stimulus-control software does not limit your development options. In general, software packages that use a scripting language (i.e., writing code vs. visually constructing the task) will tend to allow more flexibility when developing tasks. For the most flexibility, the software's features should include various options for conditional branching, looping, and the definition of macros or other forms of subroutines. Such features will make programming easier and will increase the degree to which the stimuli presented can be tailored to specific needs; for example, adjusting the presentation of stimuli based on a participant's responses. In addition, the software should include variables that can be user defined and manipulated based on participant responding while the task executes.

Another important criterion to consider is user support. User support can take many forms, ranging from direct phone, e-mail, or onsite support from software providers to user listservs, detailed embedded or online help files. Of course, each type of support has advantages and disadvantages, and therefore preference should be given to software packages that provide the most comprehensive set of user support options. That said, user listservs are particularly helpful because of the "community building" nature of this type of support, which makes it possible to share scripts for common experimental tasks or paradigms among users. Moreover, open discussion among users may increase the probability of detecting and correcting "bugs" in the software package. The most helpful listervs are also moderated by the software developer (e.g., DMDX, Presentation). Another support factor to consider is the software developer's potential responsiveness to user requests for modifications. Regardless of how flexible or powerful the software package, occasionally the limits of a package will be reached when it is attempting to implement a novel task. In these instances, it is comforting to know that the developers will consider modifying their software to accommodate your need, often for an additional cost, of course. With respect to cost, it is also important to note that user support is not universally free for all software packages. Some packages charge yearly maintenance fees to provide users with continued support and access to software upgrades. Clearly, these maintenance fees must be considered when comparing overall cost across

Table 24.1
Commercially available hardware and software for psychophysiology applications

Vendor Name	*Address*	*Phone & Fax*	*Web Address*	*Description Instrument Types*
ANS Physiology Systems Vendors				
AD Instruments	2205 Executive Circle Colorado Springs, CO 80906	P: 719-576-3970 F: 719-576-3971	adinstruments.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG) and specialty amplifiers (EDA, impedance), analysis capabilities. ANS/CNS, Animal/Human.
Biopac Systems	42 Aero Camino Goleta, CA 93117	P: 805-685-0066 F: 805-685-0067	Biopac.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), telemetry, analysis capabilities. ANS/CNS, Animal/Human.
Bio Impedance Technology, Inc.	88 VilCom Campus Suite 165 Chapel Hill, NC 27514	P: 919-960-7799 F: 919-960-6864	Microtronics-nc.com/ BIT/Home.html	Data acquisition and analysis for cardiac function.
Contact Precision Instruments	P.O. Box 425605 Kendall Square Cambridge, MA 02142	P: 617-661-7220 F: 617-661-8224	Psylab.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), analysis capabilities. ANS/CNS, Animal/Human.
Coulborn Instruments	7462 Penn Drive Allentown, PA 18106	P: 610-395-3771 F: 610-391-1333	Coulbourn.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) specialty amplifiers (EDA, impedance), analysis capabilities. ANS/CNS, Animal/Human.
James Long Company	335 Kasson Drive Caroga Lake, NY 12032	P: 518-835-3734 F: 518-835-8436	Jameslong.net	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), analysis capabilities. ANS/CNS, Animal/Human.
Lafayette Instrument Company	3700 Sagamore Parkway North PO Box 5729 Lafayette, IN 47903	P: 800-428-7545 765-423-1505 F: 765-423-4111	lafayetteinstrument.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA), analysis capabilities. ANS/CNS, Animal/Human.
Mindware Technologies	1110 Beecher Crossing North, Suite D Gahanna, OH 43230	P: 888-765-9735 614-933-9735 F: 614-933-9736	Mindwaretech.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), telemetry, analysis capabilities. ANS/CNS, Animal/Human.

CNS Physiology Systems and Supplies Vendors

Biopac Systems	42 Aero Camino Santa Barbara, CA93117	P: 805-685-0066 F: 805-685-0067	Biopac.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), telemetry, analysis capabilities. ANS/CNS, Animal/Human.
Brain Products	Stockdorfer Strasse 54 Munich, D-81475 Germany	P: 49-89-744-244-50 F: 49-89-745-244-544	Brainproducts.com	CNS data acquisition and analysis. EEG, EMG, EOG (ECG, EEG, EMG), and analysis capabilities. CNS, Animal/Human.
Cortech Solutions	208 Princess Street Suite E Wilmington, NC 28401	P: 910-362-1143 F: 910-362-1147	Cortechsolutions.com	EEG data acquisition, analysis, and mapping
Electrical Geodesics, Inc.	1600 Millrace Dr. Suite 307 Eugene, OR 97403	P: 541-687-7962 F: 541-687-7963	Egi.com	EEG data acquisition, analysis, and mapping
Lafayette Instrument Company	3700 N. Sagamore Pkwy Lafayette, IN 47904 Spring Gardens	P: 800-428-7545 F: 765-423-4111	lafayetteinstrument.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG), and specialty amplifiers (EDA), analysis capabilities. ANS/CNS, Animal/Human.
Magstim Company Ltd.	Carmarthenshire, Whales, UK SA34 OHR	P: 44 (0)1994 240798 F: 44 (0)1994 240061	Magstim.com	Nerve Monitors, nerve stimulators, and mapping
MedCare, Inc.	55 Pineview Drive, # 100 Buffalo NY 14228-2101	P: 716-691-0718 888-662-7632 F: 716-691-1004	Medcare.com	Data acquisition and analysis. Bioamplifiers for sleep research.
Mindware Technologies	1110 Beecher Crossing N., Suite D Gahanna, OH 43230	P: 614-933-9735 F :614-933-9736	Mindwaretech.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG), and specialty amplifiers (EDA, impedance), telemetry, analysis capabilities. ANS/CNS, Animal/Human. Laboratory integration.
Neuroscan/ Compumedics	5700 Cromo Dr. Suite 100 El Paso, TX 79912	P: 915-845-5600 800-814-8890 F: 915- 845-2965	Neuro.com	EEG data acquisition, analysis, and mapping; recording supplies
SAM Technology, Inc.	425 Bush St, Fifth Floor San Francisco, CA 94108	P: 415-837-1600 F: 415-274-9575	Eeg.com	EEG data acquisition and integration with fMRI imaging.
Sensorium, Inc.	617 Dorset St. Charlotte, VT 05445	P: 802-425-2161 F: 802-425-2171	Sensoriuminc.com	EEG data acquisition
Thought Technology	8396 Route 9 West Chazy, NY 12992	P: 514-489-8251 800-361-3651 F: 514-489-8255	Thoughttechnology.com	General psychophysiological recording systems, biofeedback systems

(continued)

Table 24.1
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Vendor Name	*Address*	*Phone & Fax*	*Web Address*	*Description Instrument Types*
Ambulatory Vendors				
Ambulatory Monitoring	731 Saw Mill River Road Ardsley, NY 10502-0609	P: 800-341-0066 F: 914-693-6604	Ambulatory-monitoring.com	General purpose physiological data and activity/motion monitors.
Mindware Technologies	1110 Beecher Crossing N., Suite D Gahanna, OH 43230	P: 614-933-9735 F: 614-933-9736	Mindwaretech.com	Ambulatory impedance cardiograph, ANS/CNS data acquisition, wi-fi capable.
SunTech Medical	507 Airport Blvd., #117 Morrisville, NC 27560	P: 919-654-2300 800-421-8626 F: 919-654-2301	Suntechmed.com	Ambulatory blood pressure monitors
Mini Mitter / Respiroincs	20300 Empire Ave. Bldg. B-3 Bend, OR 97701	P: 541-598-3800 800-685-2999 F: 541-322-7277	Minimitter.com	ANS/CNS ambulatory monitoring and telemetry, animal and human, actigraphs
UFI	545 Main C-2 Morro Bay, CA 93442	P: 805-772-1203 F: 805-772-5056	Ufiservingscience.com	General purpose signal and data loggers.
Vivo Metrics	121 N. Fir St. Suite E Ventura, CA 93001	P: 805-667-2225 F: 805-667-6646	Vivometrics.com	Ambulatory biopotential monitors, including the lifeshirt
VU-Ambulatory Monitor	Prof. Dr. E. J. C. de Geus or Dr. G. Willemsen Vrije Universiteit Department of Biological Psychology Van der Boechorststaat 1 1081 BT Amsterdam The Netherlands	P: +31 (0)20 598 8787 F: +31-(0)20-598 8832	vu-ams@psy.vu.nl for sales	Ambulatory impedance cardiovascular monitor

Physiology Instruments Vendors

Beckman Coulter, Inc.	4300 N. Harbor Blvd P.O. Box 3100 Fullerton, CA 92834-3100	P: 714-993-5321 800-526-3821 F: 714-961-4165	Beckman.com	General purpose and medical instruments and supplies
Finapres Medical Systems	Paasheuvelweg 34a NL-1105 BJ Amsterdam ZO The Netherlands	P: +31 20 609 09 74 F: +31 20 609 06 77	Finapres.com	Blood pressure monitors
Grass Telefactor	Astro-Med Industrial Park 600 East Greenwich Ave. West Warwick, RI 02893	P: 401-828-4000 877-472-7779 F: 401-822-2430	Grass-telefactor.com	Measurement instruments, with focus on EEG and polysomnography systems and supplies
Keithley-Metrabyte, Inc.	28775 Aurora Rd. Cleavland, OH 44139	P: 440-248-0400 800-552-1115 F: 440-248-6168	Keithley.com	Measurement instruments, interface cards
National Instruments Corporation	11500 N Mopac Expwy Austin, TX 78759-3504	P: 800-531-5066 888-280-7645 F: 512-683-8411	Ni.com	Measurement instruments, interface cards, development software.
MedWave/ Vasotrac Inc.	435 Newbury St. Suite 206 Danvers, MA 01923-1065	P: 978-762-8999 F: 978-762-8908	Vasotrac.com	Blood pressure monitors
Nellcor Inc.	4280 Hacienda Dr. Pleasanton, CA 94588	P: 800-280-7645	Nellcor.com	Pulse oximetry
NIMS, Inc.	1666 Kennedy Causeway Suite 400 North Bay Village, FL 33141	P: 305-861-0075 F: 305-861-0669	http://www.ctech.net/nims/products.html	Noninvasive respiratory monitoring
Polar	1111 Marcus Ave., Suite M15 Lake Success, NY 11042-1034	P: 800-290-6330 ext. 3073 F: 516-364-5454	Polar.fi Polarusa.com	Heart rate monitors
Texas Instruments	13532 N. Central Expressway M/S 3807 Dallas, TX 75243-1108	P: 972-644-5580 F: 972-927-6377	ti.com	Amplifiers and signal processors

(continued)

Table 24.1
(continued)

Vendor Name	*Address*	*Phone & Fax*	*Web Address*	*Description Instrument Types*
ANS/CNS Recording Supplies Vendors				
Biopac Systems	42 Aero Camino Santa Barbara, CA 93117	P: 805-685-0066 F: 805-685-0067	Biopac.com	Data acquisition and analysis. General biopotential (ECG, EEG, EMG,) and specialty amplifiers (EDA, impedance), telemetry, analysis capabilities. ANS/CNS, animal/human.
ElectroCap International	1011 West Lexington Rd. P.O. Box 87 Eaton, OH 45320	P: 937-456-6099 800-527-2193 F: 937-456-7323	Electrocap.com	EEG caps, electrodes, gel, sterilant, general supplies
Easy Cap	Steingrabenstrasse 14 D-82211 Herrsching-Breitbrunn Germany	P: 49-0-8152- 3722-24 F: 49-0-8152- 3722-29	easycap.de/easycap/	EEG caps and electrodes
Discount Disposables	PO Box 111 St. Albans, Vermont 05478	P: 802-527-8331 F: 802-527-5095	discountdisposables.com	Disposable and reusable electrodes, gels, general supplies
Lafayette Instrument Company	3700 N. Sagamore Pkwy Lafayette, IN 47904	P: 800-428-7545 F: 765-423-4111	lafayetteinstrument.com	ANS/CNS, animal/human.
Mindware Technologies	1110 Beecher Crossing N., Suite D Gahanna, OH 43230	P: 614-933-9735 F :614-933-9736	Mindwaretech.com	ANS/CNS, animal/human.
Neuroscan/Compumedics	5700 Cromo Dr., Suite 100 El Paso, TX 79912	P: 915-845-5600 800-814-8890 F: 915-845-2965	Neuro.com	EEG data acquisition, analysis, and mapping; recording supplies
Animal Behavior and Monitoring Vendors				
Lafayette Instrument Company	3700 N. Sagamore Pkwy Lafayette, IN 47904	P: 800-428-7545 F: 765-423-4111	lafayetteinstrument.com	Animal behavior
Med Associates, Inc.	PO Box 319 St. Albans, VT 05478	P: 802-527-2343 F: 802-527-509	Med-associates.com	Animal behavior
Mini Mitter / Respiroincs	20300 Empire Ave. Bldg. B-3 Bend, OR 97701	P: 541-598-3800 800-685-2999 F: 541-322-7277	Minimitter.com	ANS/CNS ambulatory monitoring and telemetry, animal and human
Eye Tracking, Motion Measurement Vendors				
Applied Science Laboratories	175 Middlesex Turnpike Bedford, MA 01730	P: 781-275-4000 F: 781-275-3388	a-s-l.com	Eye tracking
Arrington Research	27237 N. 71st Place Scottsdale AZ 85262	P: 480-985-5810 866-222-3937 F: 425-984-6968	arringtonresearch.com	Eye tracking
Charnwood Dynamics	Unit 2, Victoria Mills, Fowke Street, Rothley, Leicestershire, LE7 7PJ, United Kingdom.	P: +44 0 116 230 1060 F: +44 0 116 230 1857	charndyn.com	Motion capture
Innovision Systems	3717 Peters Rd. Columbiaville, MI 48421	P: 810-793-5530 F: 810-793-1714	innovision-systems.com	Motion capture

Seeing Machines	Level 3, Innovations Building Corner Garran and Eggleston Rd Canberra ACT 2600 AUSTRALIA	P: + 61 2 6125 6501 F: + 61 2 6125 6504	Seeingmachines.com	Motion capture, gaze, head, and eye tracking
Tobii Technology	2050 Ardmore Boulevard, Suite 200 Pittsburgh, PA 15221-4610	P: 412-271-5040 F: 412-271-7077	Pstnet.com	Eye tracking
Software Vendors				
Biopac Systems	42 Aero Camino Santa Barbara, CA 93117	P: 805-685-0066 F: 805-685-0067	Biopac.com	ANS/CNS acquisition and analysis
CMET	University of Arizona		www.u.arizona.edu/~jallen	Freely available software for computing metrics of cardiac variability
DMDX Software	University of Arizona		www.u.arizona.edu/~kforster/dmdx/dmdx.htm	Freely available stimulus presentation and control
EEGLAB Software	University of California San Diego		www.sccn.ucsd.edu/eeglab	Open-source-based Matlab toolbox for CNS analysis
E-Prime; Psychology Software Tools	2050 Ardmore Boulevard, Suite 200 Pittsburgh, PA 15221-4610	P: 412-271-5040 F: 412-271-7077	Pstnet.com	Stimulus presentation and control
EMSE: Source Signal Imaging, Inc.	2323 Broadway Suite 102 San Diego, CA 92102	P: 619-234-9935 F: 619-234-9934	Sourcesignal.com	EMSE: an EEG/MEG/fMRI imaging analysis suite
ERTS Software: BeriSoft Corporation	Wildenbruchstr. 49 60431 Frankfurt Germany	P: +49 69 524248 F: +49 69 524218	www.erts.de	Stimulus presentation and control
INTERACT Software; Mangold Software & Consulting	Mangold Software & Consulting Graf von Deym Str. 5 94424 Arnstorf Germany	P: +49 0 8723 9 78 33 0 F: +49 0 8723 9 78 33 3	http://www.mangold.de/english/index.htm	Data processing of physiological signals, video recordings, and live observations
Labview Software; National Instruments	11500 N. Mopac Expwy Austin, TX 78759-3504	P: 800-531-5066 888-280-7645 F: 512-683-8411	Ni.com	Measurement instruments, interface cards, development software
MATLAB; The MathWorks, Inc.	3 Apple Hill Drive Natick, MA 01760-2098	P: 508-647-7000 F: 508-647-7001	www.mathworks.com	General purpose data analysis, with toolboxes for statistics and signal processing
MediaLab/Direct RT; Empirisoft Corporation	Empirisoft Corporation 28 W 27th St, Fl 5 New York, NY 10001	P: 212-686-8229 888-519-9758 F: 212-202-4536 877-474-1218	empirisoft.com	Stimulus presentation and control
Mindware Technologies	1110 Beecher Crossing N., Suite D Gahanna, OH 43230	P: 614-933-9735 F :614-933-9736	Mindwaretech.com	ANS/CNS acquisition and analysis, integrated stimulus presentation and control
Octave Software			Octave.org/	Free software for numerical computations
Pendragon Software	1580 S. Milwaukee Ave Suite 515 Libertyville, IL 60048	P: 847-816-9660 F: 847-816-9710	pendragon-software.com	PDA-based form sampling

(continued)

Table 24.1
(continued)

Vendor Name	*Address*	*Phone & Fax*	*Web Address*	*Description Instrument Types*
Presentation Software	Neurobehavioral Systems, Inc. 828 San Pablo Avenue Suite 216 Albany, CA 94706	P: 510-527-9231 F: 775-628-6773	nbs.neuro-bs.com/	Stimulus presentation and control
PsyLab: Contact Precision Instruments	P.O. Box 425605 Kendall Square Cambridge, MA 02142	P: 617-661-7220 F: 617-661-8224	www.psylab.com	ANS/CNS acquisition and analysis
SciLab Software		Scilab@inria.fr	www.scilab.org	Free development application for data acquisition and analysis
SuperLab: Cedrus Corporation	Cedrus Corporation P.O. Box 6309 San Pedro, CA 90734	P: 310-548-9595 800-233-7871 F: 310-548-9537	www.superlab.com	Stimulus presentation and control; experimental lab software and experiment generator
VivoLogic Software: Vivo Metrics	121 N. Fir St. Suite E Ventura, CA 93001	P: 805-667-2225 F: 805-667-6646	Vivometrics.com	ANS/CNS analysis
VPM Software	Ed Cook Campbell Hall/Suite 415 1300 University Blvd University of Alabama Birmingham, AL 35294		Ecook@uab.edu	DOS-based data collection and stimulus control program
Windaq Software: DataQ Instruments	241 Springside Drive Akron, OH 44333	P: 330-668-1444 F: 330-666-5434	www.dataq.com	ANS/CNS acquisition and analysis

the various software packages. In fact, total cost for stimulus-control software packages (initial purchase, license for additional work stations, maintenance fees) varies significantly, from totally free (DMDX) to well over $10,000 (Neuroscan's Stim).

Ease of setup is another criterion to consider when selecting among stimulus-control software packages. However, it may arguably be less important than the previously considered criteria because it applies primarily only when setting up your first lab (i.e., once you determine how to configure the software in one lab, setup of future labs is typically trivial). The primary challenge involves synchronization of the stimulus-control software with the software that acquires and records participants' physiology. Stimulus-control software included in turnkey systems obviously is easiest to set up, as these systems are typically preconfigured with the necessary cabling, I/O cards, and other hardware to facilitate synchronization "out of the box." However, as mentioned previously, almost any stimulus software package can be synchronized with physiology-recording software with proper information about the organization of the I/O ports on the stimulus-control and physiology-recording computers or amplifiers. Further information about I/O ports and commercially available terminal boards to facilitate setting up the physical connection between computers is described later, in the section on digital input and output.

Participant and Experimenter Displays

Many possible configurations must be considered when setting up stimulus-control computer displays for the participant and experimenter. However, the most common and important decisions include: (1) selection of type of participant display (cathode-ray tube [CRT], liquid crystal display [LCD] panel, data or slide projector with mechanical shutter); and (2) selection among two common display options for experimental control (simply mirroring the participant display or having independent yet simultaneous participant and experimenter views). Each of these two issues is considered briefly here. Wiens and Öhman (chapter 5, this volume) extensively review many of the issues related to participant displays in the context of research involving subliminal presentation of stimuli to investigate unconscious emotion processing, a research area that requires stringent control of stimulus presentation onset and duration. Rather than reproduce that material, we direct the reader to that chapter and simply provide a broad outline here.

Currently, the most common option for participant display is to attach a CRT monitor to the stimulus-control computer and place this monitor in the participant room. This provides the simplest, most cost-efficient method for participant display and is adequate for the vast majority of experimental tasks. However, this approach is not without limitations relative to other options. Perhaps the most critical issue results from limitations surrounding the refresh rate of the video card/CRT monitor combination. Display of an entire image on a CRT monitor does not occur instantaneously. Instead, the display is "drawn" by a CRT beam that moves rapidly across the screen (typically left to right within a line and line by line from top to bottom) and activates a thin phosphor layer on the screen. Changes in luminance as the CRT beam passes over a particular location on the screen occur quickly (typically less than a few milliseconds). However, the time required for the passage of this beam across the entire screen to change a display, referred to as the refresh cycle, is longer. Specifically, the duration of one refresh cycle is dependent on the current refresh rate, such that:

Refresh cycle duration (in ms) = 1000/Refresh rate (in Hz).

Given that currently available hardware (i.e., CRT monitors and video cards) supports refresh rates between 60 and 160 Hz, refresh cycles range from approximately 6.3 ms (at 160 Hz) up to 16.7 ms (at 60 Hz). The time required for one refresh cycle will dictate the time necessary to fully display an image that fills the entire screen. Moreover, both the duration of image presentation and the time between images must be multiples of the refresh cycle.

An obvious, but perhaps less critical, limitation of the CRT method relates to the size of the display. The largest widely available CRT displays do not currently exceed 20 viewable inches. Very expensive CRTs of up to 32 inches are available, but to achieve this size they are limited in both resolution and refresh rate (e.g., maximum resolution of 1024 × 768 at 60 Hz). In contrast, use of a data projector (or slide projector) allows presentation on vastly larger projection screens. Although we know of no systematic examination of the impact of image size on responding (e.g., whether image size affects emotional response intensity to IAPS images), subjectively we all know that we would prefer to see the latest blockbuster movie on the "big screen" in a movie theatre than on the largest CRT monitor we could fit in our laboratory. As the size of the CRT display is increased, the desk or table space required to support it (and the heat it puts outs) increases rapidly. In some instances, researchers have considered LCD panel displays to be attractive for use as a participant display in smaller participant chambers. However, operating characteristics of the LCD panels (e.g., pixel response times for dark to light, light to dark, etc.) are quite variable across manufacturers, and no standard indices for comparing these characteristics across LCD panels have been developed to date. Therefore, use of LCD panels for participant displays is not recommended for any experiment that requires timing precision for stimulus presentation.

For experiments that require the most rigorous control of stimulus onset/duration or very brief presentation times or interstimulus intervals for visual stimuli (e.g., visual stimuli followed immediately by masks), Wiens and Öhman recommend the use of data projectors with mechanical shutters (see figures 5.6 and 5.7, chapter 5, this volume). In their example, the setup includes two computers dedicated to stimulus presentation, each connected to a separate data projector. This setup provides for:

a. Instantaneous onset of the entire visual stimulus (vs. top-to-bottom drawing of the stimulus over the refresh cycle, as with CRT presentation).
b. Very brief (e.g., 1 ms) presentation duration (vs. minimum duration of approximately 6 ms with CRT, dependent on refresh cycle limitations).
c. Very brief interstimulus intervals between two different visual stimuli, as in tasks involving target followed by mask (vs. minimum times of approximately 6 ms with CRT, dependent again on refresh cycle).
d. Complete control over the choice of interstimulus interval times (vs. limitation to multiples of the refresh cycle).

Similar but simpler setups that involve only a single stimulus-control computer and a data projector with shutter are possible if experimental demands require instantaneous onset of full stimulus and/or very brief presentation duration (but not including c and d). In general, the shuttered-data-projector approach to stimulus presentation will cost more, will require more time to set up, and may lead to more complex experimental scripts to control stimulus presentation than with the use of a single CRT for participant display. However, as Wiens and Öhman review (chapter 5, this volume), these obstacles are not insurmountable if this level of precision is required for stimulus presentation.

After determining the method of stimulus presentation for the participant display, decisions must be made about the experimenter display. As described earlier, the experimenter is typically physically separated from the participant during the experiment. However, it is often advantageous for the experimenter to be able to observe the stimuli that are being presented to the participant to verify that the paradigm is executing correctly. To this end, commercially available dual-port video splitters are available (e.g., Belkin ExpandView) that can split output from the video card between the participant display (e.g., CRT or data projector in participant room) and a second monitor in the experimenter room. Some video cards also offer this dual-port option to create two identical displays. In addition, some stimulus-control software packages provide a second configuration option that includes two experimenter displays. With this configuration, one experimenter monitor duplicates the participant display, whereas the second experimenter monitor contains ongoing information about various aspects of the experiment, including participant responding (accuracy, response times), stimulus counts, and other task-related information. Typically, this will require the installation of either a dual-port video card or two independent video cards in the stimulus-control computer, but details vary across the stimulus-control software packages that support this two-display option. When available, this additional information is often useful and can save valuable data collection time. For example, providing ongoing information about participant responding can help to quickly identify participants' confusion about task instructions that could otherwise result in the loss of those participants' data if not detected until after the experiment is complete.

Sound Card

Not all psychophysiological experiments require that a sound card be available in the stimulus-control computer. However, if your stimulus-control software does support the presentation of digital sound (e.g., wav files or mp3 files), inclusion of a sound card can be advantageous with little additional cost (basic sound cards can be purchased for $15–30). Inclusion of a sound card allows you to digitize and present task instruction orally in a standardized fashion via the stimulus-control computer. Thus it is possible for participants to simultaneously read and hear instructions to facilitate training on the experimental task. The sound card can also be used by some stimulus-control software packages (e.g., DMDX) to record verbal responses and measure verbal response latency. Not all sound cards will work with every stimulus-control package, so it is worthwhile to check whether a given card is supported prior to purchase.

In some instances, presentation of auditory stimuli may be a critical component of the experimental task. For example, auditory oddball tasks require the presentation of tones or other, more complex sound stimuli. Measurement of the acoustic startle reflex requires the presentation of white noise probes to elicit the reflex. Other tasks make use of auditory stimuli to provide feedback to participants on task performance. In the past, presentation of auditory stimuli was typically accomplished by controlling peripheral hardware via an I/O port in the stimulus-control computer. Specifically, the stimulus-control computer directly controlled a gated audio mixer amplifier, with white noise or tone generators serving as inputs to the audio mixer amplifier. This setup allowed for precise control of the onset and offset of the audio signal. More recently, researchers have begun to digitize these task-related auditory stimuli and present them via the sound card within the stimulus-control computer. These sound files are created with third-party shareware (e.g., Audacity, Wavepad) or commercial (e.g., Adobe Audition) audio editing software. Control and timing of presentation of these digital sounds is then accomplished via the stimulus-control software, much like the presentation of digital images or other stimuli in the experiment. This approach facilitates the presentation of more complex sounds (e.g., International Affective Digitized Sounds; Bradley & Lang, 1999) and reduces the need to purchase somewhat costly additional audio hardware (e.g., audio mixer amplifier and various tone or noise signal generators). However, if precise timing of the presentation of sound stimuli is necessary, you must verify this for your hardware configuration. With all sound cards, there is a delay between the request from the stimulus-control software to present a digital sound file and the actual execution of that request. This delay can range from a few to 20 or more milliseconds. Perhaps more troublesome, this delay has been observed to be variable for some sound cards. This variability in the onset of the sound stimulus may be acceptable for some experiments and physiological measures (e.g., recording tone-elicited skin conductance response in a fear-conditioning task). However, such latency jitter would be unacceptable when measuring ERPs, latency of the startle reflex, or any other measure that requires a high degree of temporal precision. We have found that high-end "gamers" sound cards produce the shortest and most consistent delays (< 4 ms delay with no measurable variation). The performance of any particular sound card can be verified by recording the output of the sound card as an analog signal with your physiological amplifiers. Mark each sound presentation with an event marker and then treat the sound signal channel as you would any analog physiology signal that you can process and measure for response onset latency.

Calibrating the output of the sound card to a decibel level is sometimes required. The simplest way to do this is to contact a colleague who has a sound-level meter that fits like an ear in audiometric headphones and determine the settings that will yield the desired decibel output using a sound file typical of the stimulus you will use. Alternatively, one can find handheld sound-level meters to measure ambient decibel level, which would be used when headphones are not used, placing the meter where the participant's head will be. Once the desired decibel output is obtained, making notes about the settings on the computer software mixer is necessary, but not sufficient. One should measure the AC voltage output coming from the sound card using a standard volt-ohm meter and make note of the voltage that corresponds to the desired decibel level. One can then calibrate the decibel level on a regular or periodic basis simply by measuring the voltage output with the volt-ohm meter. Note also that sound intensity associated with a digital sound file may vary based on the application used to play it. Therefore, regardless of the calibration method, you should use the stimulus-control software package to present the sound during the calibration procedure.

Measuring Behavioral Response

In addition to measuring physiological signals, many psychophysiological experiments also involve collecting information on participants' behavioral responding. In some instances, information about simultaneous physiological and behavioral response is necessary for the reduction and processing of the physiological measure. For example, trials involving incorrect behavioral response are often excluded from the calculation of average stimulus-locked ERP waveforms. Similarly, information about trial-by-trial response time is necessary to calculate average response-locked ERPs such as the error-related negativity (Gehring, Goss, Coles, Meyer, & Donchin, 1993). In other instances, additional posttask information is collected from participants to aid interpretation of physiological responding. For example, in emotional picture viewing tasks, it is common to present the emotionally evocative pictures a second time to collect information about viewing time, interest value, and self-reported affective response (e.g., self-assessment manikin [SAM] ratings of valence and arousal). Finally, in some experiments, both physiological and behavioral response may be central dependent measures of interest.

A range of options are available for measuring participants' behavioral responding during an experiment. The most common options include the keyboard, a mouse, handheld buttons, or a fabricated response box. Some experiments may involve the use of a joystick (e.g., for SAM ratings), a voice-activated switch (e.g., for verbal response in Stroop tasks), or other, less common input options (e.g., touch screen). Several factors must be considered to determine which option is most appropriate for any specific experimental use. Obviously, the type of response required of the participant will dictate the selection among input options. In addition, as with many of the other issues related to the stimulus-control computer, the selection of stimulus-control software may narrow the range of behavioral input options available to you, or at least the ease with which these options can be readily configured. For example, DMDX supports input via the keyboard (when response-time precision is not critical), serial or USB mouse, joystick connected to a game port, or microswitches (e.g., response buttons) attached to an 8255 parallel digital I/O port. It does not support input via the LPT printer port, nor does it support other serial input devices.

The next issue to consider when selecting among options for behavioral response is the need for precision with respect to the timing of the behavioral response. Input devices can vary significantly in how reliably they measure response time. For example, Forster and Forster (2003) tested the precision of the array of input devices that are supported by DMDX. When test hardware was constructed to produce a series of events with known response times, the response buttons, or microswitches, connected to the parallel digital I/O port provided the most accurate timing, with all recorded responses within ±1 ms of the actual event. The joystick and specific Microsoft serial mouse tested proved to be reasonably accurate as well (range of errors: ±1.5 ms and ±3 ms, respectively). In contrast, large variation was seen in the measurement of response time across keyboards from various manufacturers, with the worst keyboard displaying timings errors of ±18 ms! This poor performance of the keyboard relative to the other input devices is the result of a standard keyboard polling effect that is part of all keyboard hardware, and therefore keyboards should be avoided as input devices if response-time precision is critical. Of course, in some instances information about the exact time of the response may not be necessary. For example, if the behavioral data is limited to self-reported ratings of valence and arousal (as in the picture-viewing task described earlier), information about response time is not recorded, and the keyboard may be more than adequate as an input device.

Various configurations of response buttons and multibutton response pads are available commercially from many of the same companies that have developed stimulus-control software. For example, Psychology Software Tools, Inc. (the developers of E-Prime stimulus-control software), provides a response pad that can be customized to support five to eight buttons. Cedrus (the developer of Superlab) provides standard response pads in various configurations. Cedrus also provides response pads that are constructed entirely of plastic with fiber-optic cable suitable for use in an fMRI environment. A range of fiber-optic behavioral input devices suitable for USB, serial, or TTL input (transistor-to-transistor logic; suitable for connection to a parallel digital I/O port) are also available from Current Designs (http://www.curdes.com).

If available, it is often easiest to purchase the response pad directly from the company that provides your stimulus-control software. This will guarantee that the response pad is compatible with the capabilities and requirements of the software. For instance, the Psychology Software Tools response pad connects to the stimulus-control computer via a serial port, as this is the preferred behavioral interface method for E-Prime stimulus-control software. However, this pad would not function for input if you were using DMDX software for stimulus control, as DMDX uses a commercially available parallel digital I/O port (e.g., PCI DI024 from Measurement Computing) instead of the serial port for input of participant responses. As a second example, the response pad from Cedrus includes a hardware timer within the box itself to provide millisecond resolution for response times. Superlab stimulus-control software appears to require this timer to provide accurate response timing, and therefore problems with response timing might occur if a different response pad were used with Superlab software. In addition, some features of the more complex response pads may be available only if you use the software for which it was designed. Again, the Cedrus response pad provides six additional digital I/O lines (with the purchase of an accessory cable), but only if used with Superlab software. Finally, it should be noted that, for the more technically inclined psychophysiologist who fully understands the requirements and capabilities of his or her stimulus-control software, construction of a simple input button or multibutton response pad is not difficult and can prove attractive both for cost considerations and for design flexibility (e.g., number and location of buttons, size of box, etc.). Appendix A and Figures 24.3 and 24.4 provide the necessary information to build an input button or response pad. If you're not one to relish the thought of constructing one yourself, often there are shops on university campuses where such devices can be easily constructed for you with the information provided in the figures and appendix.

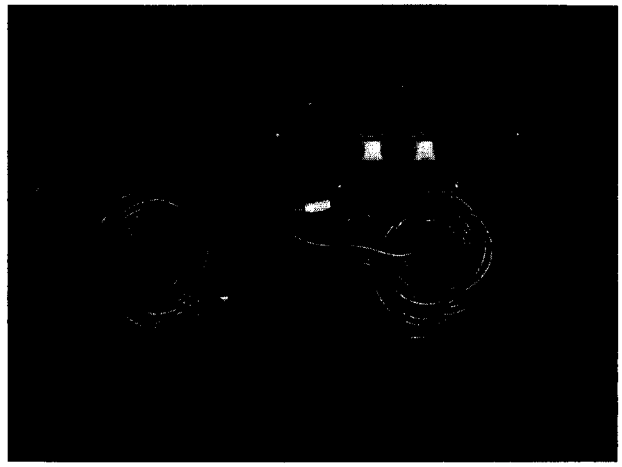

Figure 24.3. Custom response button and two-button response pad. Details on their construction are provided in appendix A. See color insert.

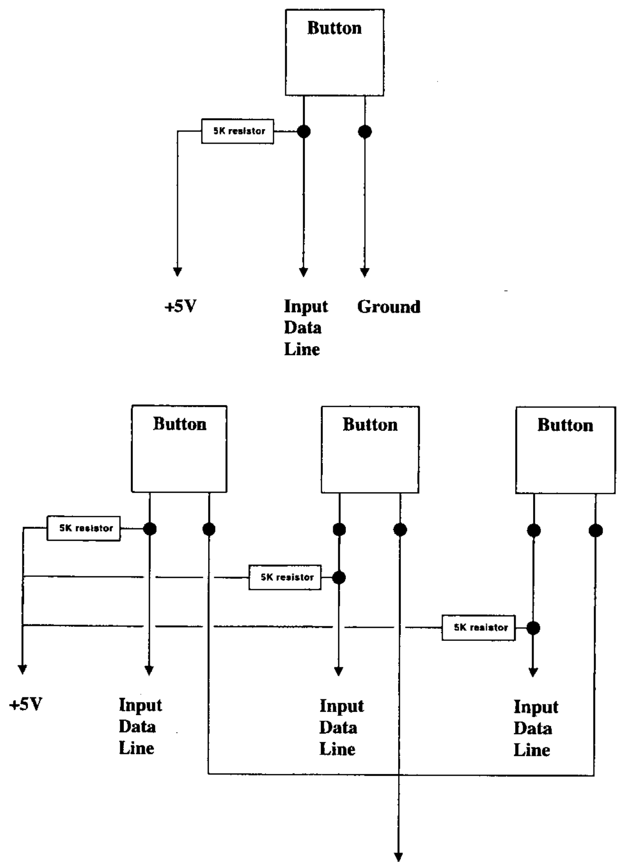

Figure 24.4. Wiring diagram for custom response button (*top*) and multibutton response pad (*bottom*). Details on their construction are provided in appendix A.

Digital Input and Output

Many stimulus-control software packages (e.g., DMDX, E-Prime, Mindware, Superlab, VPM) use parallel digital I/O ports to facilitate communication between the stimulus-control computer and the rest of the world. A parallel I/O port is an interface to the computer that allows data to be transferred in or out in parallel, that is, on more than one wire. A parallel port transfers one bit on each line, which provides for higher transfer rates than would be obtainable over a single cable (e.g., a serial port). There are also several extra lines on the port that are used for control and status signals and on some ports to provide access to the computer's power supply.

The most well-known parallel port is the standard IEEE printer port, which is used by many stimulus-control software packages (e.g., E-Prime, VPM) for digital I/O needs. However, on many modern computers, especially notebook computers, the parallel port is considered to be a "legacy port" and is omitted for cost savings. Therefore, if your software package requires this port, you should verify that the computer you purchase will include a printer port (also called an LPT port or a parallel port). The printer port has 25 independent lines (see Table 24.2 for printer port pin-out) and is accessed via a DB25 connector (a D-shaped connector on the back of the computer). In its most common configuration, 8 data lines are available for output (pins 2–9; although this can be increased to 12 lines if your software can configure the port appropriately) and 8 data lines for input (pins 10–17).

Parallel I/O ports of various configurations can also be purchased and installed. For example, one popular series of parallel digital I/O ports based on the 8255 standard is provided by Measurement Computing (http://www.measurementcomputing.com) and used for I/O by DMDX (and other) software packages. Specifically, DMDX uses the DI024 series, with options available for installation in the PCI bus (PCI-DI024) or PCMCIA type II/III slots (PC-CARD-D24/CTR3; ideal if using a notebook as the stimulus-control computer). These I/O cards provide 24 data lines, which are configurable in varying combinations for input or output. In addition, it provides access to +5V, +12V and ground from the computer's internal power supply to power external devices. These latter lines are convenient to provide power peripheral devices (e.g., response buttons).

The parallel I/O port is used by the stimulus-control software to accomplish three different categories of tasks:

1. *Measuring behavioral response.* Response pads/buttons are often connected to input data lines on a parallel port to precisely measure the participant's behavioral responding.
2. *Control of external devices.* The output data lines on the parallel port are often used to control external devices necessary for the experimental task. For instance, our laboratory has used the parallel port to control intensity and onset of administration of electric shocks (eight data lines are used to set the intensity of the shock, which provides 255 intensity settings; 2^8 minus 1 setting for "off") from a peripheral shock generator (Curtin et al., 2001) to control the onset and offset of light stimuli used as conditioned stimuli (Curtin et al., 1998), to control digital gates to present sound stimuli (e.g., startle probes for measuring acoustic startle response; Curtin et al., 2001), and to control a regulator to present noxious air blasts (an alternative to electric shock for fear-conditioning experiments; Verona & Curtin, in press).
3. *Output event markers to synchronize stimulus presentation with recording of psychophysiological response.* Each time the stimulus-control software presents a stimulus (text, bitmap image, etc), it will use the output data lines on the parallel port to send a digital event marker that is received by the data acquisition software (via a parallel port in the physiology-recording computer or associated physiology amplifier). These event markers denote both the onset time and the identity of the stimulus (typically, different event codes are used to

Table 24.2
Pin-out for standard LPT printer port

Pin	*Signal*
1	Strobe
2	Data Bit 0 (output)
3	Data Bit 1 (output)
4	Data Bit 2 (output)
5	Data Bit 3 (output)
6	Data Bit 4 (output)
7	Data Bit 5 (output)
8	Data Bit 6 (output)
9	Data Bit 7 (output)
10	Acknowledge (input)
11	Busy (input)
12	Paper end (input)
13	Select (input)
14	Auto Feed (input)
15	Error (input)
16	Init (input)
17	Select in (input)
18	Ground
19	Ground
20	Ground
21	Ground
22	Ground
23	Ground
24	Ground
25	Ground

indicate different stimuli; e.g., in a slide viewing task, event codes might be: 1 = onset of unpleasant image; 2 = onset of neutral image; 3 = onset of pleasant image). The number of output data lines dedicated to event code markers will dictate the number of discrete event types that can be recorded.

Regardless of the type of parallel port, it is often quite helpful to purchase or construct terminal boards for easy access to the data and other lines on these ports. For example, Measurement Computing sells a relatively inexpensive 37-pin screw terminal board (CIO-MINI37) that can be connected to their PCI or ISA bus parallel I/O port. Use of this terminal board simplifies the task of attaching and/or switching configurations of buttons, response pads, and other input devices that may be used in different experiments. Similarly, other peripheral devices (e.g., lights, stimulus generators, I/O cards in physiology-recording computers) can be easily connected to the output lines of the parallel port through this terminal board. Similar terminal boards are also available for 25-pin connectors used by printer ports (e.g., Measurement Computing's CIO-MINI25 terminal board). Custom terminal boards are also not that difficult to construct. For example, one of us (JJC) has built a dual-input terminal board for use in his lab. The left side of the board has 25 female banana plugs that are wired with ribbon cable to a 25-pin connector and attached to the parallel port in our physiology amplifiers. The right side of the board has 37 female banana plugs that are wired with ribbon cable to a 37-pin connector and attached to the parallel port in our stimulus-control computer (Measurement Computing's PCI-DI024 card).

Amplifiers and Data Collection System

One of the most important decisions when designing the laboratory is which hardware and software platform to use for collecting and analyzing your physiological data. There are numerous systems from which to choose, with a wide variety of topologies. Similar to deciding which computer to use, you want to make sure that you choose a system that fits your current needs yet offers growth in terms of channel density and signal type, as well as performance capabilities.

For example, you may be currently interested in measuring only EKG, respiration, and skin conductance, but you want to allow yourself to add additional amplifiers, such as EMG and EEG. An important consideration in this regard is not only having the ability to add the required amplifiers into your configuration but also ensuring that the performance is available to handle the increased channel count, data size, and sampling rates. Luckily, this is seldom an issue with the availability of Ethernet, USB, and PCI-based analog-to-digital (a/d) cards.

Most of the commercially available recording systems offer similar capabilities for acquiring the various physiological signals, but some may provide specific amplifiers with particular advantages for specific signals, whereas others use a more general approach in which a given amplifier can handle a wide variety of signals. Amplifiers can be classified into three general categories: biological, transducer, and specialty amplifiers.

Biological amplifiers, such as those designed to measure ECG, EMG, or EEG, can measure a voltage directly from the skin using surface electrodes. These amplifiers can increase the small electrical voltages from microvolt levels at the input to many volts. Provided that such amplifiers have the appropriate amplification and filter settings, a given amplifier may be used to record a variety of signals characterized by voltage oscillations over time (e.g., ECG, EMG, EEG). Transducer amplifiers, such as those used to measure respiration or pulse plythesmography, convert one type of energy, typically light or movement, to another. For instance, in the case of a piezoelectric respirometer belt, a small voltage is produced from the mechanical flexing on the crystal worn around the chest during inhalation and exhalation. This voltage is then magnified to a usable level by the amplifier. Photoplethysmographic devices similarly convert the amount of reflected infrared light to an electrical voltage.

Specialty amplifiers have features specifically required to measure physiological phenomena and will provide source energy, as well as measure voltages. Devices in this category would include a skin conductance amplifier or an impedance cardiograph. Both of these devices provide a small, constant current into the body and measure the amount of change to the return signal. These signals are modulated by autonomic activity, such as activation of the sweat glands or the amount of blood flow through the chest.

Just as there are basic differences between the amplifier types, there are also similarities. These would include programmable gain, input coupling, and filter settings. Gain(A), for a biological amplifier, is simply the amount an incoming signal is amplified before being output and is calculated as A = output/input. With respect to a transducer or specialty amplifier, these are typically scaled a bit differently to a voltage per unit of measure. For instance, when using a skin conductance amplifier, the gain setting is adjustable for a set amount of voltage per uSiemen of conductance. Similarly, an impedance cardiograph is adjustable for a defined voltage per every ohm of change.

Input coupling refers to how the signal is connected into the input of the internal instrumentation amplifier. There are two choices here: DC (direct current) or AC (alternating current) coupled. A DC-coupled amplifier connects the inputs directly to the instrumentation amplifier. Any DC level (essentially a baseline offset) present on the input is reflected on the output. You would use this setting when measuring skin conductance, as you are interested in the absolute level and in the slow-moving changes around that level. Conversely, an AC-coupled amplifier blocks DC by placing a capacitor at the input of the instrumentation amplifier. In AC-coupled mode, only the changes in the input signal are passed through the capacitor, and DC levels are blocked. This would be common in an amplifier configured to collect ECG, when you are primarily interested in the QRS complex, but not in the baseline level around which these features oscillate; in fact, in this example, a slow-moving DC shift can actually be problematic for detecting the R peak.

Lastly, filter selections vary among low-pass, high-pass, and notch filters. Low-pass filters, as the name illustrates, pass only frequencies present in the input signal that are lower than a specific settings. The low-pass filter is commonly used to remove higher frequency noise that lies outside of the range of interest and to make sure that you can adequately sample your signal in digital form without the problem of aliasing. Aliasing occurs when signals are sampled at a rate too slow for the highest frequencies that appear in the signal. Nyquist's (1928) theorem states that one must sample at a rate twice as fast as the highest signal frequency in order to adequately capture that signal; stated differently, the highest frequency that can be accurately represented is one-half of the sampling rate and has come to be known as the Nyquist frequency.

Conversely, high-pass filters pass frequencies that are higher than the stated setting. You might use these to remove any slow-moving component, such as the DC signal in ECG, or slow signals not of myogenic origin (e.g., movement, blinks) for the EMG. Filter settings must be chosen carefully, as incorrect settings may remove the signal of interest rather than the irrelevant noise, which could render an experiment useless.

Notch filters are different in that they stop or remove an unwanted specific frequency from the input signal. This can also be referred to as a band-stop filter. These are typically used as 60 Hz (or 50 Hz outside North America) notch filters when you want to remove noise generated from the AC power line or radiated in the ambient environment.

Another important consideration is the flexibility and features of the data-acquisition software that accompanies the hardware. Most software packages are designed to work specifically with their own hardware platform and generally will not work across systems. Generally, these software systems all have similar features, such as naming each channel, setting sampling rate (samples/second) and gain, selecting and programming digital filters, and defining the overall collection period, or epoch.

More advanced features might include the ability to synchronize data collection to an external trigger and enabling synchronous collection of digital input/output. These features are very important considerations when integrating data collection with stimulus presentation, as you are interested in physiological activity as it pertains to specific external stimuli. As discussed previously, you would likely link the parallel I/O port of your stimulus computer to your data collection system's trigger input or digital input port. The ability to send event markers via the parallel port is a common feature in most stimulus packages, such as DMDX, E-Prime, or MediaLab.

When integrating data collection and stimulus presentation systems, you must consider how best to keep timing synchronized. You may choose to collect your physiological data in a continuous fashion while storing the digital triggering information. This is often referred to as *continuous data collection*. This method is preferred when you are interested in the participant's physiological state immediately before and after a stimulus event or when timing is such that it cannot be predefined. As the data are continuous from start to end, you have a recording of all physiological activity throughout the experimental protocol, and most sophisticated analysis packages allow indexing through these data in a pre- or post-stimulus fashion. Recording in continuous mode will result in a larger data file, but it ultimately provides the greatest flexibility after data collection. Given that storage capacity has increased so rapidly, continuous mode has become the preferred method of data collection for most applications.

In cases in which you have an experimental protocol with clearly defined blocks, such as a 5-minute baseline task followed by 2-minute tasks and then a recovery period, you may prefer to collect in epoch mode. In epoch mode, you define tasks by set time periods and either randomize the order of the task or follow a sequential time line. This scenario may be better implemented by connecting the output port of the stimulus computer to the trigger input of the data collection system, allowing data collection to be controlled in start/stop fashion. The advantage of this scheme is smaller data files; however, you will have multiple files with varying names. You also need to keep a record of the order of the task, as this will likely be important. It is also possible to collect data in a single file with many different epochs, such as might occur in an ERP experiment, but one would need to carefully consider the timing of the epoch; continuous data formats may likely be preferred for such experimental designs.

Physiology Data Processing and Reduction Software

Once physiological data are collected, the raw binary signals must then be processed to accommodate the gain or scaling of the amplifiers, converted to physiological units (e.g., uSiemens/volt, ohms/volt), and then analyzed using accepted methodologies. Most physiological collection systems will have a basic means for physiological analysis (i.e., Biopac, Psylab), or these data can be analyzed using sophisticated third-party applications that can read various data formats (i.e., Mindware Technologies, Matlab)

Unfortunately, there is no universally accepted output data format used by equipment manufacturers, and each will define its own idiosyncratic format. Most manufacturers, however, will provide their file format specifications or will have a utility to output this data to a standard but space-consuming format such as ASCII.

There are standard references and textbooks that detail accepted methods for physiological data analysis. To go into this in detail is beyond the scope of this chapter; however, helpful texts and guideline articles are provided in table 24.3 as a starting point for instruction and recommendations on these topics.

Data Storage

Files created in psychophysiological research may range from rather small, in the case of a single channel of data sampled at a slow rate (e.g., skin conductance), to startlingly large, in the case of multichannel recordings sampled at a high rate. Small single-channel files may be unremarkable in size (e.g., 200 kilobytes), whereas high-density EEG arrays sampled at a high rate can easily consume over 20 megabytes per minute of recording. Digital video is similarly costly in terms of storage requirements. Thus the storage needs of the psychophysiologist may range from an ordinary system that includes simple data redundancy to a specialized system that handles gargantuan files.

Table 24.3
Guidelines articles appearing in *Psychophysiology*

Berntson, G. G., Bigger, J. T., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., et al. (1997). Heart rate variability: Origins, methods, and interpretive caveats. *Psychophysiology*, *34*, 623–648.
Blumenthal, T. D., Cuthbert, B. N., Filion, D. L., Hackley, S., Lipp, O. V., & van Boxtel, A. (2005). Committee report: Guidelines for human startle eyeblink electromyographic studies. *Psychophysiology*, *42*, 1–15.
Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W. W., Lykken, D. T., & Venables, P. H. (1981). Publication recommendations for electrodermal measurements. *Psychophysiology*, *18*, 232–239.
Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*, 567–589.
Jennings, J. R., Berg, W. K., Hutcheson, J. S., Obrist, P., Porges, S., & Turpin, G. (1981). Publication guidelines for heart rate studies in man. *Psychophysiology*, *18*, 226–231.
Picton, T. W, Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., et al. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, *37*, 127–152.
Pivik, R. T., Broughton, R. J. H., Coppola, R., Davidson, R. J., Fox, N., & Nuwer, M. R. (1993). Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. *Psychophysiology*, *30*, 547–558.
Putnam, L. E., Johnson, R., Jr., & Roth, W. T. (1992). Guidelines for reducing the risk of disease transmission in the psychophysiology laboratory. *Psychophysiology*, *29*(2), 127–141.
Ritz, T., Dahme, B., Dubois, A. B., Folgering, H., Fritz, G. K., Harver, A., et al. (2002). Guidelines for mechanical lung function measurements in psychophysiology. *Psychophysiology*, *39*, 546–567.
Shapiro, D., Jamner, L. D., Lane, J. D., Light, K. C., Myrtek, M., Sawada, Y., et al. (1996). Blood pressure publication guidelines. *Psychophysiology*, *33*, 1–12.
Sherwood, A., Alen, M. T., Fahrenberg, J., Kelsey, R. M., Lovallo, W. R., & van Doornen, L. J. P. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology*, 27, 1–23.

Note: All articles are available at http://www.sprweb.org/journal.html

Data Redundancy

No matter what the file size is, a wise practice is to protect data against several nemeses: (1) failure of the drive or disk on which it is stored; (2) failure or theft of the computer on which it is stored; (3) corruption during subsequent storage or processing. Good security against all three nemeses will involve: (1) fault-tolerant storage of original data, preferably beginning at the moment of recording; (2) regular off-site backup of the fault-tolerant storage media; and (3) off-site backup of original files. Table 24.4 provides an overview of the different methods of data storage and backup, with a brief list of advantages and disadvantages of each method. Reviewing the table and reading the ensuing sections may be insufficient to allow readers to set up their own data redundancy system, but this overview should provide the reader with a good grasp of the issues and options and provide a vocabulary that will prove helpful in decoding the acronym soup encountered when consulting with the local computer guru.

Primary Data Storage

Digitized data files can be stored on any conventional computer during the participant session or stored on a more elaborate medium that protects against media failure. Hard drives in desktop machines purchased in 2005 can exceed 400 gigabytes, more than adequate space to store files from multichannel psychophysiology sessions for hundreds of participants. Such storage is vulnerable to a single-drive failure, however, necessitating other protections against data loss. A simple solution is known as RAID, or a redundant array of inexpensive disks (Patterson, Gibson, & Katz, 1988). In its simplest form, this involves the installation of a second drive in the machine, with data redundantly and immediately and automatically written to this second drive, a process known as mirroring (or RAID-1, explained in appendix B). Mirroring can be handled by software in some operating systems (know as software RAID), but hardware devoted to the task is preferred in terms of speed and reliability. Many motherboards have onboard RAID controllers that allow for mirroring of drives, or a dedicated PCI card can be purchased and installed for this purpose (see table 24.4). Other options for primary storage that protect against drive failure include direct attached storage in the form of a RAID tower or network attached storage, both of which are described here.

RAID Systems for Handling Very Large Files or Very Many Very Large Files

By combining more than one drive, it is possible to create rather impressively large data storage arrays. A RAID provides this, with the additional benefit of allowing data re-

Table 24.4
Relative advantages and disadvantages of various data storage hardware solutions

Storage Method	*Uses*	*Sample Vendors*	*Advantages*	*Disadvantages*
Single hard drive	• Store primary data temporarily during or following collection • Store second copy of data at remote location	• Maxtor, Western Digital, Seagate, others	• Inexpensive • Already available in all computers • Easy to add another single drive to most computers	• No data redundancy
Mirrored hard drives (also termed RAID-1)	• Store primary data with protection against single-drive failure	• Built into motherboards such as AOpen, ASUS, Gigabyte, Shuttle, Tyan • Specialized cards such as those by Promise Techologies, Adaptec	• Small additional cost over single drive • Works under any OS • Used like a single drive so users have nothing new to learn	• Space limited by currently available drives • No external indicators that mirroring is functional; need to check software utility to ensure mirroring is working • Need to purchase one duplicate drive for every used drive
RAID tower (also termed direct attached storage)	• Store primary data with protection against single drive failure • Store second copy of data at remote location	• Promise technologies, IBM, HP, FantomDrives, StorCase, SnapAppliance, Sun, Mac (XServe)	• Only need to purchase one additional drive to ensure data redundancy for remaining drives (if using RAID-3 or RAID-5) • Hot-swappable spare drives possible • Will work with any OS (Windows, Unix, Mac) • Dual power supplies available to prevent downtime • Can be accessed over net if connected to a computer that shares this resource, often a server	• To share over a network, one must know how to share network resources and, ideally, use a server • Towers can be pricey
Network attached storage (NAS)	• Store primary data with protection against single-drive failure • Store second copy of data at remote location	• Buffalo, Adaptec, Dell, Iomega	• Usually works with multiple OS (Windows, Unix, Mac) • Remote management made simple • Accessed over net from virtually anywhere without need for a server	• Cost is higher than a RAID tower • Some do not have data redundancy (RAID) • Some less expensive models have small capacity
Digital tape	• Backup of data	• Dell, Iomega, Sony, HP, Quantum, Exabyte	• Inexpensive media • Incremental backups possible	• Slow access • For larger data sets, requires human intervention to switch tapes or investment in more expensive unit with autoloading capabilities • Backups must be scheduled; not immediate redundancy

(continued)

Table 24.4
(continued)

Storage Method	*Uses*	*Sample Vendors*	*Advantages*	*Disadvantages*
				• Technology changes fairly quickly, requiring one to retain old tape drives • Shelf life can be short if storage environment not well controlled or media accessed frequently
CD-R, CD-RW, DVD±R, DVD±RW	• Backup of data	• Sony, Teac, NEC, LG, Pioneer, myriad others	• Inexpensive hardware • Inexpensive media • Virtually universal format that is easily read by many machines and operating systems • Format not likely to become obsolete in near future • Shelf life of many decades likely	• "Burning" can be time-consuming • While "burning," machine may be unusable for many other purposes • May require many disks to back up data sets or large drives • Organizing and retrieving disks can be challenging, although carousels (e.g., that by Dacal Technology) can make this easy
USB-connected one-touch backup drive	• Backup of data	• Maxtor, Hitachi	• Ease of use—plug and press • Relatively inexpensive • Portable	• Only a single drive; if it fails, there is no protection against data loss
Remote storage on university or commercial server	• Store primary data with protection against single-drive failure • Store second copy of data at remote location	• Your university! • U.S. DataTrust, IBackup, LiveVault, myriad others	• Ease of use—mapped as a drive or automated and continuous backup • Your data are under an expert's control	• Can be prohibitively expensive for commercial vendors • Your data are under someone else's control
Distributed file system across servers	• Store primary data with protection against single-drive failure • Store second copy of data at remote location	• Most cost-effectively accomplished by building two servers with RAID towers	• Instantaneous or virtually real-time data backup to remote location	• Cost, as two duplicate systems required • Technical expertise required to set up server systems and manage them

dundancy to protect against a single-hard-drive failure. RAID towers thus house multiple same-sized drives (e.g., anywhere from 2 to 48 or more drives) that are then accessed as if there were one single very large drive by the user, connected to a computer by an interface card (e.g., SCSI card) or USB-2 cable or firewire cable. Different configurations of RAID, termed *levels*, control how those drives are combined and what strategy for data redundancy is employed. For the technophile, RAID has many levels that may hold technological appeal, but only the most commonly used and potentially pragmatic levels are reviewed in appendix B and depicted in Figure 24.5.

RAID Towers and Network Attached Storage

RAID towers provide hardware to house multiple drives that are then connected to a host computer, often a server but quite possibly a work station. Many commercially available RAID arrays can utilize the less expensive ATA drives or sometimes the newer and cost-effective serial ATA drives rather than the more expensive high-performance SCSI drives. These RAID towers are then connected via an interface cable, either a SCSI cable, a USB-2 cable, or a firewire cable, to the host computer. If the host computer lacks the particular interface port, a card must be purchased to create a SCSI, USB-2, or firewire connection as appropriate for that

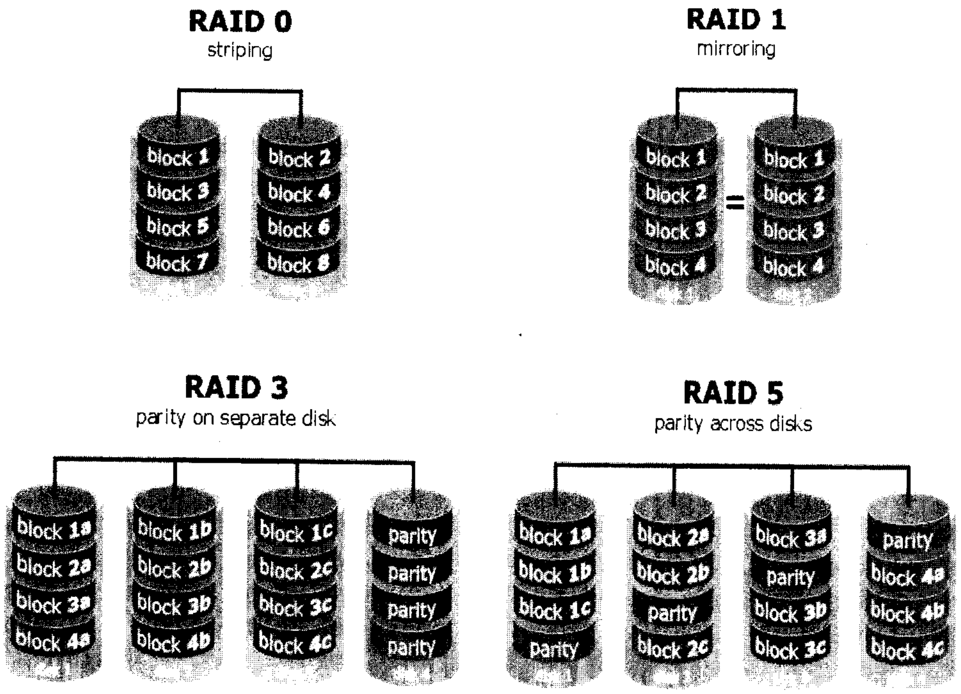

Figure 24.5. RAID configurations. Blocks with different numbers are entirely independent data. Blocks with identical numbers are identical data. For RAID-3, blocks with the same number but different letters are different pieces of data that are yoked together as part of a parity set, with their sum determining the parity bit for that set. For RAID-5, blocks within a "row" (e.g., 1a, 2a, and 3a) are different pieces of data yoked together as part of a parity set, with their sum determining the parity bit for that set. Adapted from the Promise Technology UltraTrak Series User Manual.

RAID tower. After installing the drives of the user's choosing, recalling that they must all be the same size, these RAID towers are easily configured to a RAID-0, 1, 3, 5 (appendix B) or other level configuration as desired. Many of these towers also allow the user to install an extra drive that is not configured as part of the array but rather is sitting there as a spare to be inserted into the array should one of the existing drives fail. When an existing drive fails, all data are safe with RAID-1, 3, or 5, but the data are then vulnerable should a second drive fail. By having such a "hot" spare, you can quickly return to having data redundancy while replacing what was previously the hot spare with a new drive.

RAID towers attached to work stations or servers can be accessed over a network from other computers, provided the host machine shares the drive for network access. An alternative is to purchase a network attached storage (NAS) device, which often is a RAID tower with its own operating system so that it need not be connected to any computer. NAS devices thus can offer all the advantages of a RAID tower but do not require the user to configure a server or work station to share files over a network. NAS devices have net-accessible interfaces that allow you to configure file access and security. Two considerations worth keeping in mind with respect to NAS devices are that (1) not all NAS devices have RAID arrays, as some are just a single drive without redundancy, and (2) NAS devices can be pricey, so it pays to shop around. NAS devices are especially helpful when data need to be accessed by machines that use different operating systems.

Archival Data Backup

In addition to a primary storage system, data backup can further protect against unforeseen catastrophe. As with primary data storage systems, these backup systems can range from very simple and inexpensive to rather expensive and sophisticated. The simplest technology is one with which most readers have experience, burning data to CD or DVD media and then storing them in cases or folders or storage carousels. CDs or the higher capacity DVDs make an excellent permanent archival copy of original data that ideally should be stored offsite at a location other than where the primary storage is housed. Because this system of archiving data is not automatic, researchers need to ensure that data backup to CD or DVD becomes a regular part of the participant-running and data-collection procedures.

Tape backup provides another option, although one that can be slow and frustrating unless you invest in a system that automatically loads tapes and conducts backups. Tape backups provide a good and inexpensive method for archiving data that one hopes to seldom have need to access (e.g., completed studies). Tape backup systems also can provide for incremental backups, backing files that have changed since a prior complete backup. In addition to backing up original participant data, such backup systems are useful for backing up operating systems and also for backing up drives that contain files that are created in the process of data scoring and data reduction. Retrieving data from tapes, however, is relatively slow and sometimes involves inserting multiple tapes to find the required file(s) to restore.

Newer USB-connected one-touch backup systems have become an appealing option. These relatively inexpensive systems will easily backup data to a single drive, and one that is easily ported to another machine or to offsite storage.

The most elaborate and expensive system of backup involves another large drive space in a separate location, whether that be another RAID tower, a NAS device, or a university or commercial server space and an automated routine that can back up data from the primary to the separate location (e.g., Cordes Development's "Backer" is very reasonable and powerful; http://www.cordes-dev.com). RAID towers and NAS devices provide another set of redundant storage that could immediately replace the main storage should a computer or device fail, thus allowing secure data storage with data redundancy. University or commercial storage provides a simple remote location for storing data, but commercial solutions are likely to be cost-prohibitive for large amounts of data. Many universities, however, provide large blocks of storage for faculty and students that could be used for backup storage.

Other Laboratory Paraphernalia

Electrodes, Caps, Gel, Wires, and More

Depending on the signals you will be recording, you will require specific electrodes, caps, transducers, conductive gels, and more. Most recording-system vendors also have catalogues of such supplies, and other vendors provide similar equipment (e.g., Discount Disposables provides disposable and reusable electrodes, gels and other accessories; www.discountdisposables.com). Some systems will have proprietary connectors (e.g., the Geodesic Sensor Net from EGI connects only to the amplifiers from the same company), whereas other connectors (e.g., those on single electrodes) are typically somewhat standard and easily utilized by a variety of systems. Appropriate gels also need to be utilized for the recording of some signals; not all gels are appropriate for all signals, although the reader is referred to the relevant articles in Table 24.3 for more details.

Most signals also require some degree of skin preparation, and for this purpose gauze pads, mildly abrasive exfoliating scrubs, and rubbing alcohol may be useful. For EEG recording, we have adopted a recommendation from Scott Smith (of Compumedics Neurscan) to use a hairbrush prior to electrode cap placement, as it will dramatically reduce the time required to obtain adequate impedance. We purchase a gross of brushes on line for less than a dollar a brush (e.g., Dollardays.com), give one to each participant, and ask them to spend a few minutes brushing their hair while ensuring that the plastic bristles brush over the scalp. (Note that we also ask bald or balding participants to do the same, as it reduces their scalp impedance as well!)

Finally, although many data acquisition systems can test impedance, having a stand-alone impedance checker can also be useful. Such devices pass a small alternating current through the electrodes and index the extent to which the signal is impeded. In contrast to a volt-ohm meter, which can check resistance using a DC signal, these impedance meters use signals that are quite similar in frequency characteristics to the signals you will be recording.

Essential Paraphernalia and Other Gadgetry

The psychophysiology laboratory may also benefit from a few additional items or conveniences. Although not essential, it can be very helpful to have a sink in the psychophysiological research space or a nearby sink dedicated for use by the psychophysiological researcher for cleaning and sanitizing electrodes and for storing electrodes and caps during the drying process. Disposable electrodes exist that are of fine quality, thus obviating the need for a cleaning and sanitizing method, although such electrodes may be more costly or may not be available for particular applications. If you need to clean electrodes, a water jet (e.g., the one by WaterPik) can be used for cleaning the gels from the electrodes.

Another essential tool is a volt-ohm meter, or at least a simple continuity tester. Volt-ohm meters are most often used to check whether there is a break in a wire, but they are also handy for checking whether batteries are charged, for calibrating sound decibel output, and for determining whether the proper voltage is being emitted by equipment.

Some additional tools may also be useful to have around the psychophysiological laboratory. A small set of screwdrivers, needle-nosed pliers, and an adjustable wrench can all be useful in attaching or wrestling with various pieces of equipment. And for simple wire fixes, a small soldering iron may be helpful.

Finally, it is worthwhile to invest in items to help keep the experimenter, the participant, and the lab clean and presentable. White lab coats are handy to keep gel off experimenters while lending a professional appearance. Wet wipes are useful for spontaneous cleanup of gel when exuberance or clumsiness results in recording gel ending up in unfortunate places on the participant or lab furniture.

Patient Safety and Comfort

Psychophysiological recording poses few risks to participants, and careful lab procedures can virtually eliminate any risk. A pragmatic overview of risks and how to drastically reduce or eliminate them is provided by Greene, Turetsky, and Kohler (2000). The main risks stem from the possibility of disease transmission and from unintentional electrical flow.

For detailed coverage of procedures to reduce the risk of disease transmission in the psychophysiological laboratory, the guidelines of the Society for Psychophysiological Research (Putnam, Johnson, & Roth, 1992; available from www.sprweb.org) are an excellent resource. These guidelines reiterate that psychophysiological recording is a very low-risk procedure in terms of the possibility of disease transmission but that, in cases in which skin must be abraded to obtain adequate signal quality (e.g., many EEG or EMG applications), a few key procedures can dramatically curtail the risk of disease transmission. Such procedures include wearing protective gloves during skin preparation, using single-use sterilized electrodes, or ensuring adequate high-level disinfection of reusable electrodes. Adequate disinfectants are available from many purveyors of electrodes and EEG caps.

Risk involving electrical flow stems primarily from the fact that during preparation for recording participants often have the top dead dry layer of skin removed and conductive gel applied in order to reduce the interference to the tiny electrical signals that originate from the participant. This reduced interference, however, not only allows signals within the participant to pass relatively unimpeded to the electrode but also allows electrical signals of external origin to pass quite easily to the participant. To appreciate this phenomenon, consider the rather common childhood antic of placing a 9-volt battery on one's tongue. When it is placed on skin, such as on the arm, one feels nothing, but when it is placed on the tongue, devoid of the protective layer and additionally coated in conductive saliva, one can feel the unmistakable and unpleasant sensation of electricity flowing across the tongue. Considering that such a sensation is produced with a mere 9-volt battery, one can appreciate the danger of the 110V or 220V electrical outlet. Procedures for minimizing the risk (see also Greene et al., 2000) of electrical current reaching the participant include: (1) proper grounding of all equipment; (2) using a ground fault interrupt circuit (such as those commonly found in bathrooms and kitchens); (3) keeping participants away from sources of electricity and ensuring that exposed electrodes are carefully wrapped in insulating material should a participant need to exit the laboratory (e.g. to use the lavatory); (4) using battery-powered equipment whenever possible; and (5) powering any equipment that must contact the participant (e.g., amplifiers, response buttons) with an isolation transformer.

Helpful Resources

Many resources exist to assist the investigator who wishes to undertake psychophysiological recording. Excellent basic handbooks that cover many aspects of psychophysiological research exist, including those by Cacioppo, Tassinary, and Berntson (2000), Andreassi (2000), Hugdahl (1996), and Stern, Ray, and Quigley (2000), as well as an older but useful compendium by Coles, Donchin, and Porges (1986). A basic primer in electricity can also help to demystify and unmuddle electrical concepts. Various primers are available on the Web or in self-paced readers such as that by Ryan (1986).

Articles that detail the guidelines for recording, analyzing, and reporting specific psychophysiological measures have been compiled by committees of the Society for Psychophysiological Research (SPR) and published in *Psychophysiology*. Table 24.3 lists these guideline articles, almost all of which are available for download from the SPR website (http://www.sprweb.org). SPR itself is a tremendous resource for nascent and experienced psychophysiologists alike, and attendance at an annual meeting (information available on the SPR website) is likely to be a tremendously helpful and stimulating experience. In addition to the opportunity to discuss psychophysiological research with other interested investigators, annual meetings often feature preconference workshops that provide pragmatic and didactic training on the recording and analysis of various psychophysiological signals. The SPR website has a variety of resources in addition to the standards articles, but especially helpful is the "teaching" page, with links to syllabi for courses in psychophysiology, as well as links to various software programs that may be of assistance.

To assist with your search for systems, software, hardware, and supplies, Table 24.1 provides a list of vendors and contact information, with a brief description of what items each vendor provides. Additionally, the instrumentation project undertaken by Dick Jennings and Pete Gianaros surveyed providers of psychophysiological systems to determine the capabilities of various systems. The results are available at http://www.pghmbc.org under Resources, Core E, Biological and Biomedical Measurement. The results of their project also greatly influenced the construction of Table 24.1.

Finally, other psychophysiologists are often excellent resources and can serve as consultants or collaborators for various projects. Phone consultations, site visits, and e-mail consultations are all potentially helpful, as is taking a semester's leave to sit in on a psychophysiology course taught by one of the many psychophysiologists listed on the teaching page of the SPR website.

Conclusion

Psychophysiology has become a mainstream research tool, one that is utilized increasingly in a wide variety of research domains. Whereas a half-century ago, choosing to embark on a program of research that utilized psychophysiological measures demanded custom fabrication of equipment and custom programming using specialized modules linked together with an impressively intimidating mass of wires, contemporary emotion researchers have at their disposal a wide variety of software and hardware that greatly simplifies the integration of psychophysiological measures into a research protocol. Although there remain many considerations in competently integrating psychophysiological measures into a program of research, it is indeed possible for such measures to be used by nonspecialists for whom psychophysiology is just one of many tools that can help in the effort to comprehensively address their research questions. This chapter is offered in the hopes of promoting this trend.

Appendix A. Building Response Buttons and Pads

A handheld response button (see Figure 24.3) can be constructed easily from PVC tubing and momentary input buttons available from Radio Shack or other similar electronics shops. Purchase an approximately 4-inch piece of PVC tubing (choose a diameter that fits comfortably in a participant's hand) and two PVC end caps from any hardware or plumbing store. Purchase a momentary push button or switch (e.g., Radio Shack catalog #275–609), a 4.7K resistor, and some 3-conductor wire (e.g., intercom wire from Radio Shack). Drill a hole in the first end cap to allow the wire to pass through. Drill a hole in the second end cap to fit the button. Strip the ends of the three wires and feed them through one end cap (from the outside in), then through the PVC tube, the hex nut for the button, and finally the other end cap (from the inside out). Next, solder the three wires to the two tabs on the push button, as depicted in the top panel of Figure 24.4. Finally, screw on the hex nut to secure the button in the end cap and secure the two end caps on the PVC tube. This simple button is now ready for use. The respective wires will be connected to an input data line, +5V, and ground on your I/O card as depicted in the figure. A multibutton response pad (see Figure 24.3) can be constructed similarly by wiring multiple push buttons into a box, as depicted in the bottom panel of Figure 24.4.

Appendix B: RAID Demystified

RAID-0 provides no data redundancy but merely increases performance as data are "striped" across multiple drives, allowing data to be stored and retrieved faster. Imagine that 24 blocks of data need to be written to save a file. One option is to write the 24 blocks to a single drive, but a speedier option would be to write 12 to one drive and simultaneously write 12 to another, potentially cutting in half the time required to save the file. Thus the file is now split intentionally across drives in order to decrease the time required to save (and read) the file. (Such a dramatic improvement in speed is seldom realized, because other factors also determine the write speed.) The biggest disadvantage to RAID-0 is that, if any drive fails, all data, including the data on the good drive, are useless. RAID-0 has gained some popularity among computer gaming enthusiasts, but for the psychophysiologist, such modest gains in performance are far outweighed by the risk of data loss.

RAID-1 is mirroring: Identical data packets are written to two separate drives, with one drive thus providing a "mirror" of the other. The mirror analogy is not entirely apt in that a reversed image is not created; instead, an identical copy is created every time data are written. Should one of the drives fail, the hardware will then access the good drive as a single drive, and all data will continue to be accessible provided the second drive does not fail. It is advisable to have a spare drive available should one fail so that the dead drive can be replaced and the mirror can be "rebuilt." RAID-1 systems are somewhat commonly found in desktop computers, or they can be found in external RAID towers.

RAID-5 provides data redundancy using striping that enhances performance (see the preceding RAID-0discussion) and a concept termed *parity* that allows redundancy, with fewer drives required to accomplish this redundancy. Perhaps the simplest way for behavioral scientists to understand parity is by way of analogy to degrees of freedom, a concept that refers to the number of values in the final calculation of a statistic that are free to vary. Imagine four hard drives, three of which contain blocks of data and the fourth containing a piece of data that is determined by a combination of those first three drives. Now, because computers write only 1s or 0s, a parity bit can be written based on the sum of the bits on the other drives (or the exclusive "or" function, XOR). If the sum is even, the parity is set to 0, and if the sum is odd, the parity is set to 1. Thus during normal operation, with all drives working, the degrees of freedom are $n - 1$, because data on all drives are free to vary, but the parity bit will then be determined given the data on those drives. If any one of the three data drives fails, however, there are no degrees of freedom; in other words, one can uniquely determine the value that must have existed on the failed data drive by examining the data on the other good drives in addition to the parity bit. When the parity bits are all located on a single drive, as in the preceding example, this is the seldom-used RAID-3 configuration; and when instead parity bits themselves are striped across drives, this is the more commonly used RAID-5 configuration. The biggest advantage to RAID-3 and RAID-5 systems are that they provide data redundancy without such a high overhead in terms of additional drives needed for the redundancy. With RAID-1, 50% of the drives are devoted to redundancy, whereas with a four-drive RAID-5 system, only 25% are devoted to redundancy. With larger arrays, the proportion devoted to redundancy is even smaller (e.g., 10% in a 10-drive RAID-5 array).

Finally, many drive arrays also allow for the "just a bunch of disks" (JBOD) option. Unlike the RAID options that require drives to be the same size, the JBOD option just combines any size drives you have, and the resultant single storage drive is the size of the sum of the drives you combine. This option provides no drive efficiency or data redundancy advantages, but it does use all available drive space. And a big disadvantage, like that of RAID-0, is that if any drive fails, all data, including the data on the remaining good drive(s), are useless.

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