

11 The Sexual Response

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1. PROLOGUE

Although physiological responses during sexual activity have been explored as early as in the 1800s (e.g., Mendelsohn, 1896, who described "pulse curves" (EKGs) during sexual intercourse), the first systematic attempts to understand the psychophysiology of sexual response should probably be dated in the first part of the twentieth century, originating with writings on sexual physiology (e.g., Van de Velde, 1926; Dickinson, 1933). These works predated the research of Kinsey and colleagues (Kinsey, Pomeroy, Martin, & Gebhard, 1953), who provided an extensive description of the physiological changes that accompany sexual arousal, and Masters and Johnson (1966), who observed sexual responses in over 650 individuals and summarized their work in a model that has been the stimulus for much psychophysiological research. Initially, researchers relied on direct observation and the use of extragenital measures such as heart rate, respiration, and sweat gland activity to index sexual arousal. Zuckerman (1971), after reviewing the then available literature, concluded that extragenital measures were not specific to sexual arousal. Zuckerman's review of the literature, coupled with Masters and Johnson's (1966) report that myotonia and genital vasocongestion were the most reliable indicators of sexual arousal, accounts for the trend in the field toward the development and use of genital response measures.

2. PHYSICAL CONTEXT

2.1. Anatomical substrate

2.1.1. Men

The principal focus of genital response measurement in men is the penis. The key structures mediating erection are the corpora cavernosa and spongiosum. The two corpora cavernosa are surrounded by a thick fibrous sheath, the tunica albuginea, and share a perforated septum that allows them to function as a single unit. The corpora contain a meshwork of small, interconnected compartments (lacunar spaces), which are lined by vascular endothe-

lium and separated by bonds of collagen and smooth muscle (trabeculae). The function of the corpora cavernosa is purely erectile. The corpus spongiosum, which expands to form the glans, also acts as a urinary conduit and an organ of ejaculation. On erection, the corpus spongiosum and the glans develop a modest turgidity.

With the exception of some minor branches from the scrotal and epigastric arteries, the blood supply to the penis is furnished by the two branches of the internal iliac artery, the internal pudendal arteries. After giving off the perineal arteries, they become the penile arteries, which branch off to become a complex of arteries that supplies the penis. Of particular interest are the paired dorsal and cavernous, or deep, arteries of the penis. The dorsal arteries give off circumflex branches and supply blood to the glans penis. The cavernosal arteries run along the middle of each corpus cavernosum, giving off helicine arteries, which open directly into the lacunar spaces (Kirby, 2004). Blood leaves the penis via a number of venous systems, including a network that lies between the smooth muscles and the tunica albuginea. The corpora cavernosa and spongiosum are surrounded by striated muscles. The most important ones, the bulbospongiosus and the ischio-cavernosus, support the erect penis and also contract during ejaculation.

2.1.2. Women

The external female genital area is known as the vulva. This area is rich in nerve endings and heavily vascularized. The labia majora, also known as the outer lips, surround the labia minora, or inner lips, which enclose an area called the vestibule. The labia minora fuse to form the clitoral prepuce and fuse under the vaginal opening to form the frenulum. During sexual arousal, the clitoris and the labia minora become engorged, and the latter can increase in diameter by two to three times during sexual excitement (Masters & Johnson, 1966).

The clitoris is composed of the clitoral shaft or corpus, the crura, and the clitoral head or glans. The clitoral body is formed from two corpora cavernosa and a single corpus spongiosum. The bulbs of the clitoris (formerly vestibular

bulbs) were only recently characterized (O'Connell, 1998) and are analogous to the corpus spongiosum in men. The clitoral shaft becomes engorged with blood during sexual arousal but women do not have a subalbugineal layer that would reduce venous outflow producing rigidity (Berman, Adhikari, and Goldstein, 2000).

The organ that has been the principal focus of psychophysiological measurement in women is the vagina. The vagina is an almost anaerobic collapsed canal (Levin, 2003) that is more a potential than a permanent space. The canal is formed by two layers. The innermost layer is a non-secretory, squamous epithelium made of many transverse folds or 'rugae' (Krantz, 1950). Rugae are more prominent in the lower third of the vagina and are thought to provide accordion-like distensibility (Droegemueller, 1992). The epithelium is lined by a lamina propria, which is thick, vascularized connective tissue composed of elastic fibers and a network of blood vessels. Transudate from these blood vessels contributes to vaginal lubrication when forced, by increased pressure in the vessels, through the epithelium to coalesce from sweat-like droplets forming a smooth, lubricative film on the vaginal wall. Small amounts of lubrication are also supplied by the paired greater vestibule, or Bartholin's glands. The two layers are surrounded by the muscularis, or circular smooth muscle (Levin, 1992), which is covered by longitudinal smooth muscle and a fibrous sheath allowing expansion.

Vaginal blood supply originates with the uterine artery, internal iliac artery, and the vaginal artery. The vaginal artery consists of multiple arteries on each side of the pelvis and branches to the anterior and posterior surfaces of the vagina. Vascular responding of the erectile tissues of the introitus and extending to the clitoris is, as with the penis, controlled by the nerves that pass through the nervi erigentes from the sacral plexus. In comparison to men, much less is known about the vascular mechanisms involved in the female genital response.

2.2. Neural/humoral control

2.2.1. Neurophysiology of erection

Erection is essentially a hydrodynamic manifestation, weighing arterial inflow against venous outflow. Cavertous smooth muscles, which are in a tonically contracted state when the penis is flaccid, relax during penile erection (Andersson and Wagner, 1995). This lowers the corporal vascular resistance and results in increased blood flow to the penis. Venous return is diminished by means of a passive occlusion of the subtunical veins pressed against the tunica albuginea.

The spinal cord contains all the necessary components for the coordination and initiation of penile erection (McKenna, 2000). The tone of the penile vasculature and smooth muscles is controlled by both contractant and relaxant factors, which themselves are modulated by local and central processes (Andersson, 2001, 2003). Although the cholinergic, parasympathetic nervous system is the pri-

mary proerectile system, normal erection also requires participation of the sympathetic and somatic nervous systems. Parasympathetic nerve endings are sparse in the corpora cavernosa and play primarily a role in the initiation of vasodilatation (Saenz de Tejada et al., 2004). Sympathetic pathways mediate anti-erectile as well as erectile effects. Erection requires inhibition of sympathetically controlled vasoconstriction in the penis, but also activation of sympathetic pathways in the pelvis to assist blood flow to the penis (McKenna, 2000). In addition, full rigidity is dependent on the contraction of striated perineal muscles.

Nonadrenergic noncholinergic (NANC) transmitters, found in both adrenergic and cholinergic nerves (Anderson, 2001), play a central role in penile erection. At present, nitric oxide (NO) is considered to be the principle mediator of corporeal smooth muscle relaxation (Burnett, 1997). NO stimulates the production of cGMP, the second messenger molecule responsible for smooth muscle relaxation. cGMP levels are regulated by the enzyme phosphodiesterase (PDE), of which several subtypes exist. Drugs like sildenafil (Viagra), vardenafil (Levitra), and tadalafil (Cialis) exert their effect by blocking the degradation of cGMP through the inhibition of phosphodiesterase-5, which is relatively specific to the penis (it is found in lower concentrations elsewhere, including lungs and aorta). This thus facilitates erection by increasing bioavailable cGMP in the penis (Gonzalez-Cadavid, Ignarro, & Rajfer, 1999; Wagner & Mulhall, 2001).

Our understanding of the supraspinal control of erection lags behind that of the local neurophysiological and biochemical processes (Bancroft, 2000; McKenna, 1998, 2000, 2001). The presence of descending tonic inhibition has been demonstrated in studies in animals and in humans with spinal cord transections or injury, and is believed to be under control of the nucleus paragigantocellularis, or nPGi, and mediated by serotonin (Giuliano and Rampin, 2000). Serotonin, however, can also have facilitatory effects, depending on receptor location and subtype, and this may be relevant to the sometimes conflicting findings on sexual effects of serotonin agonists and antagonists (Andersson, 2001). Other areas that are relevant to penile erection include the amygdala, hippocampus, locus coeruleus, periaqueductal gray, and hypothalamus (Bancroft, 2000), of which the medial preoptic area (MPOA) is believed to have a function in the processing of sensory stimuli and the paraventricular nucleus (PVN) in the integration of genital and nongenital autonomic processes (McKenna, 2001).

2.2.2. Neurophysiology of vaginal arousal

Considerably less is known about the neurophysiology of genital response in women than is known about the mechanisms of penile erection. The vaginal epithelium, blood vessels, and smooth muscle are innervated by the sympathetic and parasympathetic divisions of the autonomous nervous system. The striated muscles that surround the vagina are innervated by the somatic nervous system (Levin, 1992). The clitoris, which contains nerve endings

similar in number to those found in the male penis (Bancroft, 1989), is innervated by the pudendal nerve.

A number of peptides and neurotransmitters have been located in the female genital tissues. Among these are nitric oxide (NO) and vasoactive intestinal polypeptide (VIP; McKenna, 2002). Hoyle et al. (1996) failed to find NO synthase, the enzyme that manufactures nitric oxide, in approximately half of a group of pre- and postmenopausal women. According to Levin (1997), the available data point to VIP as the likely major neurotransmitter controlling vaginal blood flow and lubrication.

Central mechanisms of sexual arousal are becoming increasingly investigated in women, particularly as peripheral interventions appear relatively ineffective in improving women's self-reported sexual experiences (Basson, McInnes, Smith, Hodgson, & Koppiker, 2002; Laan et al., 2002). Research suggests that women, although reporting similar levels of arousal¹, display less amygdal activation to sexual stimuli than men (Hamann, Herman, Nolan, & Wallen, 2004). Although counterintuitive (if the amygdala are viewed primarily as an emotion center), the authors suggest that it may be more appropriate to view the amygdala as relevant to motivational processes. However, emotional responses to sexual stimuli appear more predictive of levels of sexual desire in men than in women (Prause, Janssen, & Hetrick, 2003). The use of stimuli that are equally effective in men and women is critical when exploring gender differences in neural activation to sexual stimuli, as otherwise findings may reflect simple differences in sexual arousal levels (cf. Janssen et al., 2003).

Recent research examining sexual functioning in women with spinal cord injuries has provided additional insight into the control of sexual response. Sipski et al. (2001) documented a relationship between sympathetic activation and level of genital vasocongestion in response to sexual stimulation, supporting the conclusion of studies in able-bodied women that sympathetic afferents are important in sexual arousal (Meston & Gorzalka, 1996; Meston & Heiman, 1998). Although Whipple and Komisaruk (2002) have suggested that the vagus nerve may be the primary afferent, the mechanism by which genital stimulation uses sympathetic pathways to reach the brain is still debated.

2.2.3. Hormonal control

A number of studies have examined the effects of anti-androgens and exogenous androgens in men. There is also literature on the effects of sexual activity or erotic stimuli on hormone levels. However, the most relevant evidence on the role of sex hormones in men comes from studies in hypogonadal men. These studies have shown that within weeks after androgen withdrawal a decline in sexual desire occurs. When considering erectile func-

tion, a more complex picture emerges. Erections during sleep (nocturnal penile tumescence or NPT) are reduced by androgen depletion and restored with androgen replacement. On the other hand, erections to visual erotic stimuli have been found to continue in spite of androgen withdrawal, although the degree and duration of response may be decreased, (Bancroft, 1995). These findings have led to the distinction between androgen dependent and independent erectile responsiveness (Bancroft, 1989). Variations in androgen levels are, however, not believed to lead to variations in sexual behavior and responsiveness, unless variations are significant, as found in hypogonadal men or in adolescents around the time of puberty (Bancroft, 1989; Halpern, Udry, & Suchindran, 1998).

Most studies on the relationship between reproductive hormones and sexual responsiveness in women have assessed these variables across the menstrual cycle (Meuwisen and Over, 1992). Several studies have found that the level of subjective sexual arousal evoked by fantasy, erotic film, and audiotaped stories and genital physiological response to visual sexual stimuli remains stable across phases of the menstrual cycle (Hoon, Bruce, & Kinchloe, 1982; Meuwissen & Over, 1993; Morrell, Dixon, Carter, & Davidson, 1984; Slob, Koster, Radder, & Van der Werff ten Bosch, 1990), whereas some have found higher subjective sexual arousal during periovulatory than during follicular phases (e.g., Graham, Janssen, & Sanders, 2000) and others found vaginal pulse amplitude changes to be higher in premenstrual than in periovulatory phases (Meuwissen & Over, 1993; Schreiner-Engel, Schiavi, Smith, & White, 1981). Among the factors that may explain this lack of consistency in findings, are differences in the method used for determining cycle phase, variations in experimental design, and differences in subject characteristics (Hedricks, 1994).

Increasingly, researchers are exploring the role of other hormones, such as estrogens, oxytocin, and prolactin in sexual response in men and (pre- and postmenopausal) women. Estrogens are necessary for normal vaginal lubrication, and vaginal dryness associated with menopause can be decreased using hormone replacement therapy. Levels of circulating oxytocin increase during sexual arousal and peak during orgasm in both women and men (e.g., Gimpl and Fahrenholz, 2001). Also, a role for orgasmic-released prolactin as an "off switch" of sexual arousal has been proposed (see Kruger et al., 2005) although the evidence is still inconclusive and other mechanisms may be involved, especially in women (Levin, 2003).

Recently, researchers using evoked response potentials (ERP) have found that P300 amplitudes to sexually (or reproductivity) relevant stimuli increase during ovulation (Krug, Plihal, Fehm, & Born, 2000). Changes in ERP responses to nonsexual stimuli, however, have not been found consistently, and when ERP differences were attributed to menstrual cycle phase, did not appear to affect performance in cognitive tasks (Johnston &

¹ However, the questionnaire used in this study asked about physical arousal (i.e., did not explicitly ask about sexual arousal: Hanann, 2004, personal communication).

Oliver-Rodriguez, 1997; O'Reilly, Cunningham, Lawlor, Walsh, & Rowan, 2004; Walpurger, Pietrowsky, Kirschbaum, & Wolf, 2004). Thus, although menstrual cycle phase may not consistently affect overt responses or behavior, it does appear to have an effect on attention to sexual stimuli. For these reasons, although the impact of menstrual cycle effects on laboratory findings remains to be established, controls for menstrual phase are advised.

3. SOCIAL CONTEXT

3.1. Measurement milieu

The following discussion of the measurement context in sexual psychophysiological research will only touch upon a few relevant issues. For a more extensive discussion, see Janssen (2002), Prause and Janssen (2006), and Rowland (1999). For the discussion of the political context of sex research in general and sexual psychophysiology in particular, see Bancroft (2005).

3.1.1. Ethical issues

Guidelines for the ethical treatment of research participants (e.g., American Psychological Association, 1992) apply "in spades" to research on sexuality. Due to the personal nature of the inquiry, researchers must be sensitive to the concerns of research participants to ensure both the confidentiality of the data and the comfort and well-being of participants. Particularly important is the clear and understandable description of the details concerning genital response measurement, presentation of sexual stimuli, and of any collection of information concerning sexual practices or attitudes. Thus, participants in sex research are told a great deal about the nature of the studies they take part in, and the effects of this approach are not clear. Amoroso and Brown (1973), in a study on demand characteristics in sex research, found that participants attached to electrical recording devices rated stimuli as more erotic than participants rating the same stimuli outside the laboratory. In another study, Hicks (1970) found that experimenter moods and behaviors influenced both physiological records and subjective reports.

To prevent disease transmission, genital devices should be cleaned using disinfectants such as glutaraldehyde (e.g., Cidex Plus) or ortho-phthalaldehyde (e.g., Cidex OPA). These disinfectants function, depending on how long the devices are immersed, as low- or high-level disinfectants or sterilants. Genital measurement devices require a minimum of high-level disinfection, which destroys all pathogenic microorganisms (bacteria, fungi, and viruses) except for endospores. High-level disinfection has been found to kill Herpes Simplex-II (Morokoff, Myers, Hay, & Flora, 1988), but it is unclear whether it also kills Human Papillomavirus (HPV). Until evidence documents the effectiveness of such cleaning agents in destroying HPV, we recommend a prewash with sodium dodecyl sulfate (SDS). SDS is a common component in shampoo (where it is often

listed as sodium lauryl sulfate) that has been shown to kill both HIV and HPV (Howett et al., 1999). Another goal of cleaning is to prevent tissue (e.g., vulvar) irritation. Tissue irritation can result from contact with disinfectants if they are not carefully rinsed off with sterile water.

3.1.2. Volunteer biases

A number of studies have explored differences between volunteers and nonvolunteers for sexuality studies. Differences have been found in sexual experience, frequencies of sexual activity, sex guilt, exposure to erotic materials, and sexual attitudes (e.g., Bogaert, 1996; Morokoff, 1986; Plaud et al., 1999; Strassberg & Lowe, 1995; Wiederman, 1999; Wolchik, Braver, & Jensen, 1985). Some of these studies found psychophysiological studies to be the most susceptible to volunteer biases. However, other studies have failed to find differences between volunteers and nonvolunteers for sex research on personality traits such as extraversion and neuroticism (Farkas et al., 1978), social desirability (Wolchik et al., 1983), and religiosity (Wiederman, 1999). Furthermore, in most cases, the differences that have been found are relatively small. Perhaps more important than differences in averages, however, is whether the *range* of relevant behaviors, attitudes, or experiences is represented in a volunteer sample. For example, Laan and Everaerd (1995), in a meta-analysis of psychophysiological studies involving approximately 300 women, found that 22% of participants had experienced some form of sexual abuse, a proportion similar to that found in the general population. Characteristics of volunteers may, even within a study, affect some variables but not others. Saunders et al. (1985), for example, found volunteer effects on negative affect in response to sexual films, but not on self-reported sexual arousal. Ultimately, the question is not whether differences exist between volunteers and nonvolunteers, but whether such differences influence the validity of our findings and conclusions. That is, the real question is whether the factors responsible for nonparticipation are related to the variables of interest (cf. Tourangeau, 2004).

3.2. Response agreement and within- vs. between-participant designs

A common finding in psychophysiological sex research is that correlations between subjective and genital responses are lower in women than in men (e.g., Laan & Everaerd, 1995). This has lead researchers to speculate about possible gender differences in the role of genital feedback in subjective sexual arousal (e.g., Laan and Janssen, in press). Although correlations tend to be higher in men than in women, discordant response *patterns* have been found as frequently in men. An increasing number of studies have shown that experimental manipulations may modify men's degree of erection although not affecting their subjective sexual arousal (Bach, Brown, and Barlow, 1999; Delizonna et al., 2001; Janssen & Everaerd, 1993; Lankveld and v. d. Hout, 2004). Such findings challenge the notion that

subjective sexual arousal in men is strongly influenced by feedback from (changes in) their genitals. Thus, although researchers are largely focusing on the possible explanation of gender differences in correlations between response levels, discordant response *patterns* occur in both men and women, and are not well understood.

Most commonly, correlations between genital and subjective measures of sexual arousal are evaluated in a between-participant design. In this approach, the data used for the computation of correlations are collected across a set of subjects. The resultant statistic reflects the degree to which the two measures covary to a single stimulus presentation. It tells us nothing about individual differences in the relationship between genital and subjective feeling states. In addition, this approach is especially problematic with VPA, a signal that has a relative scale and cannot be calibrated at present, complicating the interpretation of between-subject correlations. Using standardized scores may be an improvement, but this approach forces a normal distribution upon the data and implies linearity of changes that may or may not exist. Although within-participant approaches give us more information about covariance between physiological and subjective responses, they suffer from the problem that response levels will vary from person to person, leading to differences in the range covered by the data. Korff and Geer (1983) applied a within-participant approach that is less sensitive to this problem. Instead of calculating within-participant correlations using the data collected during one sexual stimulus, they computed correlations between stimulus intensity (photos varying in erotic value) and genital change in women. They found, using that methodology, very high within-participant correlations. Within-participant designs also permit the use of the relationship as a dependent variable, allowing researchers to explore how the relationship itself may vary across conditions or individuals.

3.3. Range of applications

Psychophysiological methods are being employed in the exploration of an increasingly broad array of basic and applied questions. The topics include the relationship between subjective and physiological sexual arousal; the interaction between sexual arousal and other emotional states; the activation and inhibition of sexual response; the habituation and conditioning of sexual arousal; the psychophysiology of sexual motivation, desire, and orgasm; the effects of drugs, hormones, and aging on sexual responsiveness; the association between sexual orientation and sexual arousal; and the effects of exposure to erotica or pornography on sexual attitudes and behavior. On a more applied level, sexual psychophysiology is used in studies focusing on the detection and diagnosis of sexual dysfunctions and problematic sexual preferences (e.g., pedophilia), and on the assessment of the effectiveness of pharmacological and psychological treatments. Rather

than attempt to review all research areas (for a collection of reviews, see Janssen, in press) we will briefly discuss two categories of clinical psychophysiological research.

3.3.1. Applications concerning arousal and response problems

One of the earliest applications of genital response measurement involves the diagnosis of erectile dysfunction. One of the central questions in the differential diagnosis of erectile dysfunction is to what degree the problem stems from peripheral (e.g., vascular, neurological) problems. Two types of psychophysiological paradigms have been used to evaluate men with erectile dysfunctions. The waking erectile assessment (WEA) approach involves the presentation of erotic stimuli and the determination of whether a normal penile response occurs. The other approach consists of recording erections during sleep to determine if normal nocturnal penile tumescence (NPT) occurs. Sakheim et al. (1985) reported 80% diagnostic accuracy in identifying functional versus organically impaired men using a waking assessment paradigm. Janssen et al. (1994a), found similarly high predictive values using a procedure in which patients were presented with combinations of visual, tactile, and cognitive stimuli.

Although early studies in men with premature ejaculation failed to find evidence for atypical response patterns, more recent studies have both confirmed and challenged some assumptions about the mechanisms involved in ejaculatory problems (see for review, Rowland, Tai, & Brummett, in press). For instance, rapid ejaculation in men with premature ejaculation occurs mainly in response to (vibro) tactile genital stimulation, not to erotic stimulation in general. Also, subjective sexual arousal levels are not higher in men with premature ejaculation than in sexually functional men, suggesting that the former are not "hyperaroused," although heart rate during sexual stimulation tends to accelerate in men with premature ejaculation, although it decelerates in sexually functional controls, suggesting that differences in autonomic control exist between men with and without premature ejaculation. Less is known about inhibited or retarded ejaculation.

Vaginal photoplethysmography (see section 4.1.2.3.) does not consistently differentiate women with and without sexual problems (Morokoff & Heiman, 1980), nor is it clear that it should because the measure is relative. However, some researchers have documented reduced VBV for women with arousal problems (Palace & Gorzalka, 1990; Wincze, Hoon, & Hoon, 1976), reported reduced VPA during penetration film clips for women with dyspareunia (Wouda et al., 1998), identified women with sildenafil-responsive arousal and orgasm problems (Basson & Brotto, 2003), predicted orgasm latency (Laan & van Lunsen, 2002), and identified radical hysterectomy patients with extensive vaginal deervation (Maas et al., 2004).

Individual differences in the relationship between genital and subjective sexual responses may increasingly become a focus in the development and evaluation of interventions for sexual problems in women. Drugs like sildenafil have been found to increase genital blood flow, although not necessarily affecting subjective sexual arousal in women. New pharmacological interventions are being developed that target central mechanisms, including dopamine agonists to increase sexual desire (Bechara, Bertolino, Casabe, & Fredotovich, 2004; Beharry, Hale, Wilson, Heaton, & Adams, 2003; Caruso et al., 2004; Everaerd & Laan, 2000, see also Rosen et al., in press). However, some of the effects of these agents resemble those of addictive substances and this warrants caution. More importantly, considering the variable relationship between subjective and genital sexual responses in women, the development of any type of treatment, ideally, should involve the evaluation of both genital and subjective responses.

3.3.2. Applications concerning specific object preferences

The second type of clinical application involves sexual object preferences. Psychophysiological methods have been used to both diagnose and track the progress of treatment of individuals whose sexual preferences involve adolescent or preadolescent children (e.g., Seto, 2001, in press). Although adult men with no pedophilic preferences can show sexual arousal to pedophilic stimuli (e.g., Hall, Hirschman, and Oliver, 1995), the use of psychophysiological methods within clinical samples has been found to have high predictive validity. Recent meta-analyses found that genital response to depictions of children was the single best predictor of sexual offense recidivism, exceeding all other indicators of sexual deviancy and any developmental, personality, or demographic variable (Hanson and Bussiere, 1998; cf. Kuban et al., 1999; Seto, 2001).

Similarly, sexual aggressive men and rapists have been studied using psychophysiological methods. Barbaree et al. (1979) reported significant correlations between a statistic obtained by dividing the percent of erection to rape cues by the percent of erection to cues of consenting heterosexual activity and the frequency of previously reported rapes as well as with the tendency to commit violent rapes. Lohr, Adams, and Davis (1997) reported that whereas men with sexually coercive histories showed greater penile responding to coercive cues, males with no history also yielded some arousal to those same cues. Similarly, Janssen et al. (2002) found that male college students with no history of offending who scored low on a measure of sexual inhibition proneness, showed erectile responses to depictions of rape that were indistinguishable from their responses to consensual sexual films. These findings make clear the fact that arousal to a particular stimulus category does not necessarily correspond with behavior. In women there are reports of rape victims responding with vaginal lubrication and even orgasm during a sexual assault (Levin and van Berlo, 2004). Laan et al. (1994) found that women

responded equally with genital arousal to male- versus female-oriented erotica even though the women reported that they found the female-oriented erotica more arousing. Again, care must be taken before one accepts genital responding as the "golden rule" of sexual arousal, and thus sexual object preference. Sexual arousal, as is true for other emotional states, is a complex phenomenon that expresses itself in multiple response systems that are not always closely tied together.

4. INFERENCEAL CONTEXT

4.1. Mensuration and quantification

The following discussion will not cover all possible measures but will only include those that are most widely used.

4.1.1. Male genital measurement devices

The first to measure genital response in men was a simple electromechanical transducer (Ohlmeyer, Brilmayer, & Hullstrung, 1944) that provided a binary signal of the presence or absence of erection. Current research in male sexual arousal relies primarily on continuous measures of penile volume, circumference, and rigidity.

4.1.1.1. Volume. Freund (1963) developed an air volumetric plethysmograph. Less widely used variants of this technique have been described by Fisher et al. (1965), who used water instead of air, and McConaghy (1976). The plethysmograph is positioned on the participant by the experimenter, who places a sponge-rubber ring and plastic ring with an inflatable cuff over the penis. A glass cylinder with a funnel at the top is fitted over the other components, and the cuff is inflated with air. Changes in the size of the penis result in displacement of air, which can be detected by a pressure transducer.

Volumetric devices can be calibrated in terms of absolute penile volume and have the advantage of offering high sensitivity. A limitation of this technique, however, is that it does not allow for the determination of the source of change (e.g., circumference or length). In addition, the apparatus is relatively complex, cumbersome, and sensitive to temperature and movement artifacts.

4.1.1.2. Circumference. Originally described by Fisher and colleagues (1965), the first circumferential measure, the mercury-in-rubber strain gauge, was adapted from a similar transducer used by Shapiro and Cohen (1965). The device consists of a hollow rubber tube filled with mercury and sealed at the ends with platinum electrodes. The operation of the mercury-in-rubber strain gauge depends upon penile circumference changes that cause the rubber tube to stretch or shorten, thus altering the cross-sectional area of the column of mercury within the tube. The resistance of the mercury inside the tube varies directly with its cross-sectional area, which in turn is reflective of changes in the circumference of the penis. Variations of the

mercury in rubber gauge have been described by Bancroft et al. (1966), Jovanovic (1967), and Karacan (1969).

Another type of penile strain gauge is the electromechanical strain gauge developed by Barlow and co-workers (1970). This device is made of two arcs of surgical spring material joined with two mechanical strain gauges. These gauges are flexed when the penis changes in circumference, producing changes in their resistance. The resistance changes are in turn coupled through a bridge circuit to a polygraph or computer. The electromechanical gauge does not fully enclose the penis. For this reason, it is more sensitive to movement artifacts and less suitable for studies on nocturnal penile tumescence (NPT) than the mercury-in-rubber gauge. However, mechanical strain gauges are quite sensitive and more rugged than their rubber counterparts. Both types of strain gauge are available from Behavioral Technology, Inc. (Salt Lake City, Utah) and the rubber strain gauge is also manufactured by Hokanson, Inc. (Bellevue, Washington).

4.1.1.3. Comparison studies on volume and circumference measures. Freund, Langevin, and Barlow (1974) compared the volumetric device with Barlow's electromechanical strain gauge. They presented a group of men slides of male and female nudes. Their results indicated that volumetric plethysmography is more sensitive to changes in penile tumescence. However, considering the type and number of stimuli used, and the absence of a check for habituation, their conclusion most likely pertains to relatively low response levels. McConaghy (1974) compared his adaptation of the volumetric device with a mercury strain gauge. He showed his subjects 10-second shots of male and female nudes that were inserted in a neutral film. In his paper he provides some example recordings, but no statistical analyses. In 1987, Wheeler and Rubin compared the mercury gauge and Freund's volumetric device, using erotic film excerpts, in 6 subjects. In contrast to Freund et al. (1974), they did not find any evidence for a higher sensitivity of the volumetric device. In addition, the authors reported that the volumetric device was more difficult to use and displayed more artifacts than the strain gauge (however, they did not use an inflatable cuff, Kuban et al., 1999). The absence of systematic differences in Wheeler and Rubin's (1987) study may be due to the possibility that their film stimuli induced higher response levels than the slides used by Freund and colleagues.

More recently, Kuban et al. (1999) compared the mercury gauge and volumetric device in 42 heterosexual men who were presented with sexual slides and audiotaped narratives. They found that the two devices were comparable at 'high' response levels (>2.5 mm circumference change), where correlations exceeded .80. In contrast, correlations were nonsignificant at lower response levels, where only the volumetric device differentiated responses to images of adult and pubescent females from other (prepubescent) stimuli. Unfortunately, Kuban et al.'s (1999) conclusions were based on between-participant comparisons of low

and high responders, instead of on low and high (i.e., within-participant) response levels. Undetermined differences between the two groups (e.g., in attitudes or experience) may have contributed to the findings, rendering as premature the authors' suggestion that lower circumferential responses may be less valid.

Due to the ease of their use, penile strain gauges have remained relatively popular in laboratory use (e.g., Bach et al., 1999; Delizonna et al., 2001; Hoffmann et al., 2004). A number of in vitro studies have shown that both the mercury-in-rubber and the electromechanical strain gauge demonstrate linear outputs, high test-retest reliability, high stability over time, and minor sensitivity to temperature (e.g., Karacan, 1969; Farkas et al., 1979; Earls and Jackson, 1981; Richards et al., 1985; Richards et al., 1990; Janssen et al., 1997). Nowadays, the mercury-in-rubber strain gauge is also available in versions filled with an indium-gallium alloy, which is considered to be even less sensitive to temperature than mercury (Richards et al., 1985).

A potential concern with the use of circumferential measures is the suggestion that penile circumference may show a slight decrease at the onset of sexual arousal (McConaghy, 1974; Abel et al., 1975; Laws and Bow, 1976; see also Kuban et al., 1999). A brief decrease in circumference may represent a problem in that it may be incorrectly interpreted as a decrease in sexual response. Further, it has also been noted that strain gauges may be unreliable at the upper end of the tumescence curve (Earls et al., 1983). This may represent a limitation if the measures are to be used for determining the full range of erectile capacity.

Laws (1977), who was the first to compare the two strain gauges in vivo, found discrepancies in measurement with the two devices. Unfortunately, he obtained data from only one participant. Janssen et al. (1997) compared the two penile strain gauges, using indium-gallium instead of mercury for the rubber gauge, in a group of 25 sexually functional men. In addition, they compared two different calibration methods, using a circular and an oval shaped device. The electromechanical gauge calibrated on the circular device reported greater circumference changes. Circumference changes were not different when the oval calibration device was used. In addition, the findings suggested that the electromechanical gauge is more sensitive to changes in penile circumference during initial stages of erection than the rubber gauge, a conclusion that is consistent with earlier in vitro findings (Earls and Jackson, 1981; Richards et al. 1985), and that should be taken into consideration when comparing the advantages and disadvantages of volumetric and circumferential measures (cf. Kuban et al., 1999 and Wheeler and Rubin, 1987, who compared volumetry with the mercury-in-rubber gauge).

4.1.1.4. Rigidity. One of the first attempts to measure penile rigidity was made by Karacan et al. (1978), who reported the use of "buckling pressure" as a dependent variable in penile responding. This method uses a device that measures the axial force required for the bending

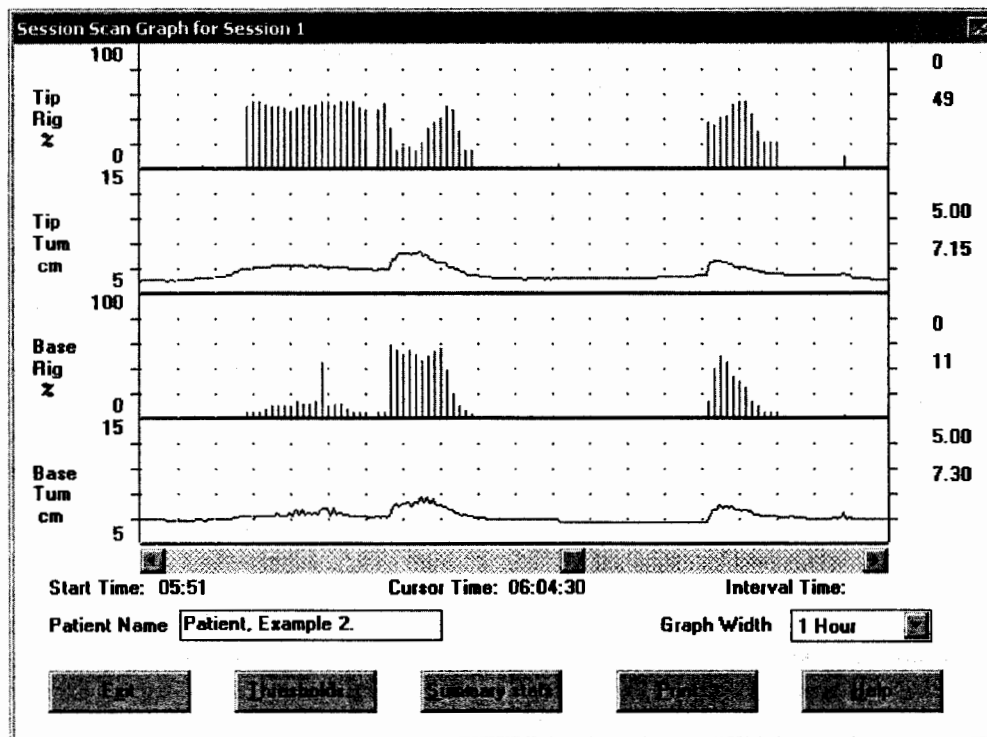


Figure 11.1. Example of output of the RigiScan. The vertical lines represent rigidity and the continuous ones penile circumference as measured at the base (bottom two signals) and the tip (top two signals) of the penis.

of the penis. Although it is mainly used in clinical studies (e.g., Goldstein et al., 2000), and has some predictive value, basic information on the validity and reliability of this method is still largely absent (Schiavi, 1992). Also, the rationale that is typically provided for preferring the measurement of axial over radial rigidity (i.e., intercourse involves mostly axial forces), though sensible, lacks an empirical basis. Other noncontinuous, discrete methods for indexing rigidity include stamp tests, the Snap Gauge, and the Erectiometer (Slob et al., 1998).

Bradley and Timm (1985) first described the RigiScan Plus monitor (Timm Medical Technologies, Eden Prairie, MN), an instrument designed to measure continuously both circumference and radial rigidity, and that can be used in real-time or ambulatory mode. The device consists of a recording unit, that can be strapped around the waist or thigh, and has two loops, one that can be placed around the base of the penis and the other just behind the corona. Each loop contains a cable that is tightened at discrete time intervals. Circumference is measured at 15-second intervals. The RigiScan takes its first rigidity measure when a 20% increase in circumference is detected. This is repeated every 30 seconds (see Figure 11.1). To measure rigidity, the loops tighten a second time after circumference is measured, with a force of 2.8 Newton.

The RigiScan represents the first practical measure of continuous rigidity, and has gained wide acceptance, particularly in clinical research. However, there are no published data on the test-retest reliability of the RigiScan

Information on the reliability of the device over longer periods of usage is pertinent because in contrast to strain gauges, where routine calibration allows for the test of linearity over time and where replacement is viable, a RigiScan is typically used for a number of years. The importance of developing a calibration method for the RigiScan is stressed by the finding of Munoz, Bancroft, and Marshall (1993) that different RigiScan devices can record different degrees of rigidity. In their study, Munoz et al. (1993) developed a system that provided a relatively constant circumference with variable rigidity. Using this system they found that the RigiScan underestimated circumference, in particular at lower levels of rigidity. This finding was confirmed by a comparison between the performance of the RigiScan and a mercury-in-rubber strain gauge in the measurement of NPT (Munoz et al., 1993).

The measurement procedure used by the RigiScan also raises questions about its potential reactivity. The extent to which the tightening of the loops may induce or modify sexual responses has not been assessed. Relevant to this, Munoz et al. (1993) found fewer NPT episodes in a group of men with erectile problems when a mercury-in-rubber strain gauge was used together with a RigiScan as compared to nights during which only a strain gauge was used.

The two main arguments in support of the development and usage of rigidity measures have face validity: (1) Penile circumference is not a reliable predictor of rigidity, and (2) rigidity is the ultimate, behaviorally relevant measure of erectile capacity. Regarding the first assertion,

two studies have been cited frequently. Wein and associates (1981) reported that significant changes in penile circumference occurred in 23% of normal control patients without sufficient increases in rigidity for vaginal penetration. Earls et al. (1988) reported finding discrepancies in circumference and participants' perception of erectile sufficiency for intromission. Wein et al. (1981), however, based their conclusions on the measurement of buckling force, which lacks proper validation (Schiavi, 1992). As for the second study, it is well established that the perception of erectile responses is biased in patient groups (Sakheim et al., 1987; Janssen and Everaerd, 1993). More importantly, however, with the availability of the Rigiscan, studies would be expected to test the relationship between circumference and rigidity. Remarkably, only one study to date has explored the relationship between the Rigiscan's base and tip circumference and rigidity measures (Levine and Carroll, 1994), and found correlations of $r = .87$ and $r = .88$, respectively.

Regarding the second issue, the key problem in erectile dysfunction is considered to involve a lack of rigidity (e.g., Giesbers et al., 1987). However, the question of what level of rigidity is sufficient has not yet been answered. Wabrek et al. (1986) and Wagner et al. (1986) gathered normative data on vaginal penetration pressure and found that it varied among positions (e.g., supine versus kneeling) and that it was lower during conditions of sexual stimulation. These studies indicate that, at present, any clinical criterion for deciding whether an erection is sufficiently rigid for penetration is a predictor, rather than an absolute measure, of erectile functionality in interactions with a partner.

4.1.1.5. Other measures of genital response in men. Less widely used measures involve the assessment of penile temperature, penile arterial pulse amplitude, and penile EMG. Thermistor devices have been designed to detect temperature changes that may accompany penile tumescence. Solnick and Berrin (1977) found a relatively high concordance between temperature changes and penile circumference. Webster and Hammer's results (1983) supported their findings.

Bancroft and Bell (1985) developed a reflectance photometer for the measurement of penile arterial pulse amplitude. The components of this device are similar to those used in the vaginal photometer, described later. It has been suggested that penile pulse amplitude may provide an index of arterial inflow related to generalizable penile tumescence (Rosen and Beck, 1988). However, the currently available data are insufficient to warrant a judgment on the usefulness of the penile photometer.

Wagner and Gerstenberg (1988) first described electrical activity in the cavernous tissues of the penis, using needle electrodes, and found that the perception of visual sexual stimuli resulted in decreased smooth muscle activity (Wagner & Gerstenberg, 1988; Gerstenberg et al., 1989; Wagner et al., 1989). Although one of the most sensitive measures of male genital response at present, the reliabil-

ity of the technique is still controversial. Various investigators have failed to reproduce the original findings. More problematic, however, is that the interpretation of the signal is hampered by the lack of information on its characteristic features and by the absence of standardized recording techniques. The recording of penile EMG is susceptible to sources of interference such as pelvic and penile muscle contractions, cross-talk due to cardiac action, and respiration (Jüneman et al., 1994). The non-invasive alternative, using surface electrodes, has been less well studied and also may be expected to be sensitive to interference. However, work on a consensus in measuring penile EMG is in progress and recommendations have been made for research that could increase our understanding of the electrophysiology of the corpora cavernosa (Sasso et al., 1997; Jiang et al., 2003).

4.1.2. Female measures

One of the first devices designed to measure female physiological sexual arousal recorded vaginal pH, as an indicator of lubrication (Shapiro et al., 1968). This method proved technically difficult and intrusive (Berman et al., 2001; Wagner & Levin, 1978) and researchers tended to document inconsistent and highly localized pH changes (Wagner & Levin, 1984). A second device, a mechanical strain gauge, was developed to measure clitoral enlargement in women with enlarged clitori from congenital adrenal hyperplasia (CAH), but the device has not been tested in nonclinical samples (Karacan, Rosenbloom, & Williams, 1970). A third, balloon-like device was developed to measure uterine contractions (Bardwick, 1967; Jovanovic, 1971), and another one for vaginal pressure (Berman et al., 2001), but the uterine device proved problematic because its placement could be painful and the device was occasionally extruded (Rosen and Beck, 1988). More recently, researchers are attempting to quantify clitoral blood flow and clitoral size changes using Doppler ultrasonography (Bechara et al., 2004; Khalifé & Binik, 2003; Munarriz, Maitland, Garcia, Talakoub, & Goldstein, 2003). Although the measurements appear to be reliable across analysts (Berman et al., 2001), currently the method requires a technician to hold the device in place during measurement (Khalife, Binik, Cohen, & Amsel, 2000). Finally, researchers are exploring the utility of electromyography, with concentric needle electrodes, in evaluating clitoral autonomic innervation and genital sensitivity (Yilmaz, 2002, 2004). However, further research is needed to further establish its validity and to determine the role of genital sensitivity in sexual arousal.

4.1.2.1. Oxygenation and thermal clearance. Levin and Wagner (1978) described a method in which a heated oxygen probe is used to detect changes in oxygen pressure (pO₂) in the vaginal wall. The device consists of an oxygen electrode and a suction cup that is held on the vaginal wall by a partial vacuum generated in the cup. It is assumed that the more blood present in the tissues, the greater

the amount of oxygen will be perfused across the vaginal epithelium. Using this device, it is possible to reliably determine the level of oxygen in the blood of the tissues located beneath the device. The actual dependent variable used is pO₂, which is expressed in millimeters mercury.

The same device can also measure heat dissipation into the tissues under the transducer. This approach measures the amount of energy (e.g., milliwatts) that is required to keep the temperature of a heated thermistor constant. The heated oxygen probe has contributed to our understanding of the mechanisms underlying genital response in women (Levin, 1992) and the technique has been replicated (Sommer, 2001). An advantage of the device is that it is relatively free of movement artifacts. Disadvantages are the intrusiveness of the procedure and the need to limit duration of measurement sessions to protect the vaginal mucosa from damage from heat and suction needed to hold the device in place (Levin, 1992).

4.1.2.2. Temperature. Fisher and Osofsky (1968) and Fisher (1973) used a thermistor to measure vaginal temperature and found that vaginal temperature reflects core temperature and is relatively insensitive to changes in sexual arousal. Fugl-Meyer, Sjogren, and Johansson (1984) described a radiotelemetric method for measuring vaginal temperature, using a battery-powered transducer mounted on a diaphragm ring. They reported decreases in vaginal temperature, measured during masturbation and intercourse, that were speculated to be the result of vaginal wall edema during sexual arousal (Wagner and Levin, 1978). Advantages of the device include its usability in natural settings. However, in view of the conflicting reports, replication is needed to establish the value of vaginal temperature as a measure of sexual arousal.

Henson et al. (1978) designed a transducer for measuring labial temperature. One thermistor monitors ambient room temperature, another monitors changes in skin temperature at an extragenital site, and a final thermistor is attached to the labia minora using a brass clip. Labial temperature of 9 of the 10 participants in Henson et al.'s study (1978) increased in response to an erotic film. Slob et al. (1990) and Slob et al. (1991) also found an increase in labial temperature in the majority of participants during the presentation of erotic stimuli. Slob et al. (1990) compared women with and without diabetes mellitus and found initial labial temperatures to be lower in the diabetic women. Differences between the two groups disappeared when participants were matched on initial labial temperature.

4.1.2.3. Vaginal and labial pulse amplitude/blood volume.

The most widely used method for monitoring genital responses in women is vaginal photoplethysmography. This technique uses a vaginal photometer, originally used by Palti and Bercovici (Palti & Bercovici, 1967) and refined by Sintchak and Geer (1975) and Hoon, Wincze, and Hoon (1976). The device, made by Behavioral Technology, Inc.

(Salt Lake City, Utah), is made of clear acrylic plastic and is shaped like a menstrual tampon. Embedded in the front end of the probe is a light source that illuminates the vaginal walls. Light is reflected and diffused through the tissues of the vaginal wall and reaches a photosensitive cell surface mounted within the body of the probe. Changes in the resistance of the cell correspond to changes in the amount of back-scattered light reaching the light-sensitive surface. It is assumed that a greater back-scattered signal reflects increased blood volume in the vaginal blood vessels (Levin, 1992). Hoon et al. (1976) introduced an improved model of the vaginal photometer that substituted an infrared LED (light-emitting diode) for the incandescent light source and a phototransistor for the photocell. These innovations reduced potential artifacts associated with blood oxygenation levels, problems of hysteresis, and light history effects. The vaginal photometer is designed so that it can be easily placed by the participant. A shield can be placed on the probe's cable so that depth of insertion and orientation of the photoreceptive surface is known and held constant (Geer, 1983; Laan, Everaerd, & Evers, 1995).

The photometer yields two analyzable signals. The first is the DC signal, which is thought to provide an index of the total amount of blood (Hatch, 1979), often abbreviated as VBV (vaginal blood volume). The second is the AC signal, often abbreviated as VPA (vaginal pulse amplitude), which is thought to reflect phasic changes in the vascular walls that result from pressure changes within the vessels (Jennings et al., 1980; see Figure 11.2). Although both signals have been found to reflect responses to erotic stimuli (e.g., Geer, Morokoff, & Greenwood, 1974; e.g., Hoon, Wincze, & Hoon, 1976), their exact nature and source is unknown. Heiman et al. (2004) compared, in 12 women, VPA and genital volume changes as measured using MRI, and found no significant correlations between the two. Heiman and Maravilla (in press) suggested it may be possible that at moderate levels of arousal the vaginal probe might detect changes to vaginal tissue that do not correspond with other genital blood volume changes. (Interestingly, however, the same study reported higher correlations with subjective sexual arousal for VPA than for MRI variables.) The interpretation of the relationship between the photometer's output and the underlying vascular mechanisms is hindered by the lack of a sound theoretical framework (Levin, 1992) and of a calibration method allowing transformation of its output in known physiological events. At present, most researchers describe their findings in relative measures, such as mm pen deflection or change in microVolts. Levin (1997) stated that one of the basic assumptions underlying use of the plethysmograph is that changes in VBV and VPA always reflect local vascular events. In his discussion of findings from studies on the effects of exercise and orgasm on VBV and VPA, however, he suggests that the signals are likely to reflect rather complex interactions between sympathetic and parasympathetic regulatory processes and between circulatory and vaginal blood pressure. However, Prause et al. (2005) found that, whereas VPA

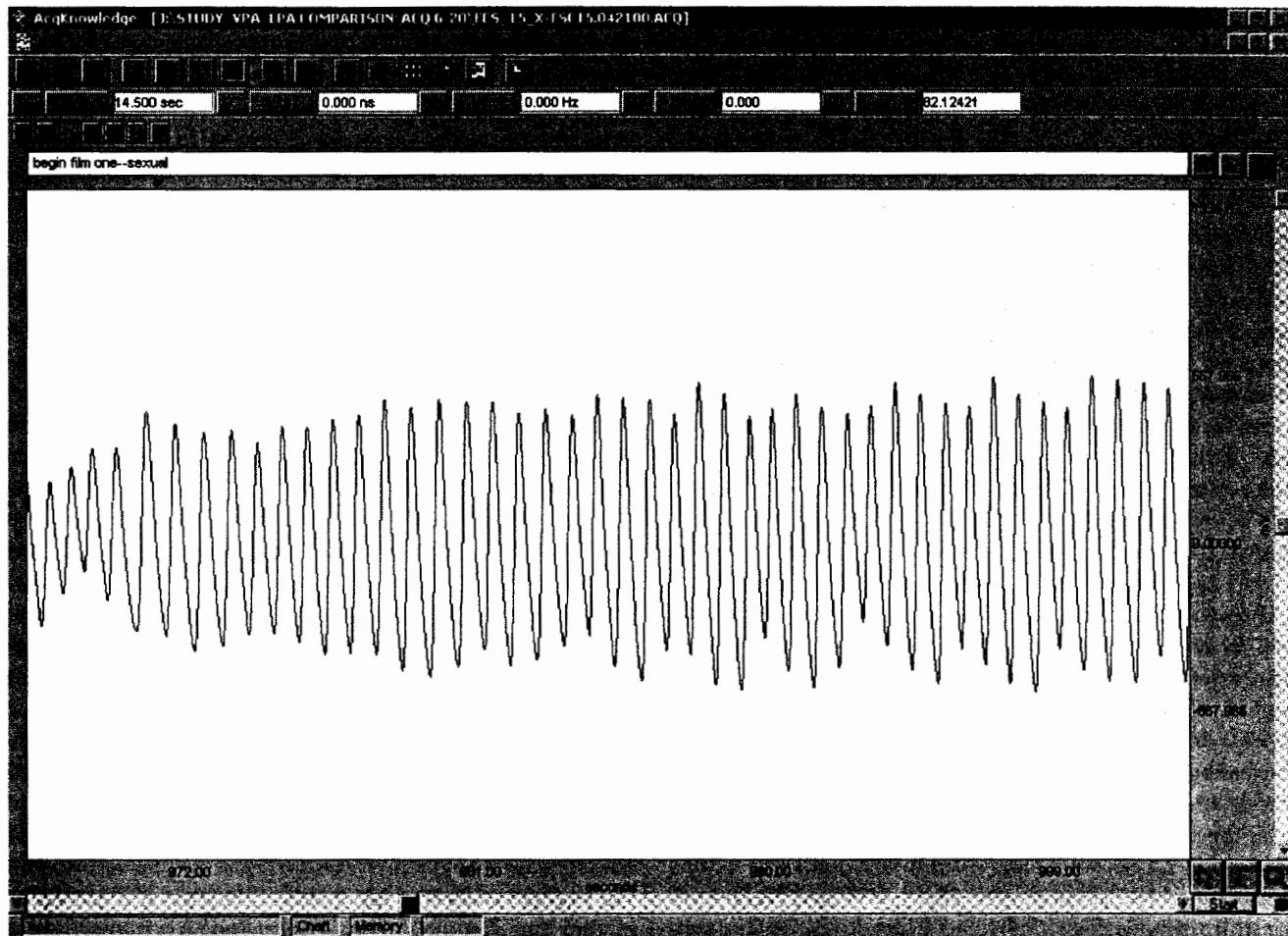


Figure 11.2. Example of a Vaginal Pulse Amplitude (VPA) signal obtained from the vaginal photoplethysmograph.

discriminated between sexual, sexually threatening, and threatening film stimuli, blood pressure (while increased during all three conditions) did not.

The construct validity of VPA is better established than that of VBV. Researchers have reported high correlations between VPA and VBV, particularly with stronger sexual stimuli, but others have found low or no concordance between the two signals (Heiman, 1976; Meston and Gorzalka, 1995). VPA appears to be more sensitive to changes in stimulus intensity than VBV (Geer et al., 1974; Osborn & Pollack, 1977). VPA also corresponds more closely with subjective reports of sexual arousal than VBV (Heiman, 1977). Finally, VBV changes in response to increases in *general* arousal, indicating that VBV is less specific to sexual arousal than VPA (Laan, Everaerd, & Evers, 1995). Two studies have directly assessed the sensitivity and specificity of VPA (Laan et al., 1995; Prause, Cerny, & Janssen, 2005). Both studies measured responses of sexually functional women to sexual, anxiety inducing, sexually threatening, and neutral film excerpts, and found maximal increases in VPA to the sexual stimulus and moderate increases to the sexually threatening film. (Participants also reported intermediate levels of sexual arousal to the sexual-threat stimulus.) On both studies, VPA did

not increase in response to anxiety-inducing stimuli. These results demonstrate response specificity of vaginal vasocongestion to sexual stimuli.

The study by Prause et al. (2005) included the comparison of VPA with a new measure of genital blood flow, the labial photoplethysmograph. Labial pulse amplitude (LPA), as measured by the labial photoplethysmograph, exhibited a degree of specificity to sexual stimuli that was similar to that found for VPA. Additionally, the labial photoplethysmograph demonstrated greater resistance to movement artifacts and a slightly higher correspondence with subjective measures of sexual arousal. Because it is worn externally, researchers can verify the placement of the device by visual inspection. The labial photoplethysmograph, though somewhat more difficult to place and less comfortable than its vaginal counterpart, warrants further development.

4.1.2.4. Comparison studies on temperature and pulse amplitude/blood volume. The literature comparing genital response measures in women is scant. Only one study has compared the measurement of vaginal temperature with vaginal blood flow (Gillan & Brindley, 1979).

However, that study used an atypical photometer (with more than one photocell). No studies have been published on the direct comparison of heat oxygenation and vaginal plethysmography. In contrast, various studies have been reported on the relationship between labial temperature and vaginal blood flow. Henson and Rubin (1978) and Henson, Rubin, and Henson (1982) compared changes in VBV and labial temperature in response to sexual films. Both measures were found to increase during stimulation, although there were large individual differences. Henson and Rubin (1978) found a low, nonsignificant correlation between VBV and labial temperature. Further, only correlations between labial temperature and subjective arousal were significant, leading to the suggestion that physiological changes in the labia might be more easily perceived than intravaginal changes. Although vaginal responses tended to decrease more quickly after stimulus presentations, neither instrument returned to pre-stimulus baseline levels.

In two other studies, C. Henson, Rubin, and Henson (1979) and D. Henson, Rubin, and Henson (1979) compared labial temperature with both the VPA and VBV signals of the vaginal plethysmograph. D. Henson et al. (1979) determined that, although there was considerable intrasubject consistency in response patterns and amplitudes across two recording sessions, labial temperature was the most consistent on both parameters. In the second study, C. Henson et al. (1979) found high correlations between subjective arousal and both VPA and labial temperature changes. VBV correlated less strongly with subjective arousal and returned to baseline more slowly than either VPA or labial temperature.

With respect to the advantages and disadvantages of each device. D. Henson et al. (1979) noted that ambient temperature control is a requirement for use with the labial clip but not with the vaginal transducer. In contrast, movement artifacts are more common with the vaginal probe, and reliable measurement with the thermistor is not precluded by the menses (there are, as yet, no published reports of vaginal photometer readings during menses). Levin (1997) asserted that the output of the vaginal measure, and in particular VBV, is readily invalidated because the photometer can slide over the lubricated epithelium, illuminating new areas of tissue.

Another important difference between the two devices is that the labial thermistor uses an absolute unit of measurement ($^{\circ}\text{C}$), whereas changes in vaginal blood flow are relative. Further, it is not yet known to what extent factors related to individual variations in anatomy and to physiological characteristics, such as resting levels of vaginal muscular tone and vaginal moistness, may affect the amplitude of the vaginal blood flow signal. Finally, although sensitivity of the probe to temperature appears to be minimal, it is in fact the temperature of the light source that is most often a concern. It is not implausible that vaginal temperature itself can alter the probe's output, thus confounding the data (Beck, Sakheim, & Barlow, 1983).

Rogers et al. (1985), in a study on genital responses during sleep, used a measure of integrated VPA and muscle-contraction pressure, which enabled the detection of movement and muscle contractions. It may prove valuable to extend the current design of the vaginal plethysmograph with additional measures of muscle-contraction pressure and temperature.

4.1.3. Cross-sex measurement devices

The desire to directly compare sexual responses in men and women has been the impetus for the development of several measurement devices. Unfortunately, the challenge reaches beyond the mere development of a measure that can be used in similar locations, and is complicated by differences in the innervation and vascularization of the male and female genitalia.

4.1.3.1. Anal blood flow and muscle activity. Bohlen and Held (1979) described a device to monitor intra-anal pressure changes and pulse waves. The design of the probe was based on the observation that genital changes associated with the experience of sexual arousal are a result of increased blood volume and muscle tension throughout the pelvic area (Masters and Johnson, 1966). The device consists of a photometer and pressure transducer encased in a silicone rubber body. An adaptation of this design was used by Carmichael et al. (1994) to measure anal electromyographic activity and blood flow during orgasm. They found that although men and women did not differ in anal muscle tone during baseline testing, higher initial levels of blood flow were measured in women. During both sexual arousal and orgasm, men demonstrated higher levels of anal blood flow and muscle activity.

4.1.3.2. Temperature. Thermistors have been used to measure genital temperature in both sexes but the measurements are obtained from different structures. In contrast, thermography can be used in cross-sex comparisons (Seeley et al., 1980). The methodology is not widely used because it is costly and intrusive. Seeley et al. (1980) compared thermographic images of a male participant engaging in masturbation and a female participant engaging in masturbation. Their results suggested that thermography indeed reflected the presence of sexual arousal. However, the relationship of temperature to physiological events in the genitalia, regardless of the methodology used, is unclear, as studies have not been done to relate thermographic data to vascular responses.

4.1.3.3. Brain and pelvic imaging. Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are fairly recent additions to the toolbox of psychophysicists and have enabled the investigation of blood flow (including size and position) changes of relevant structures and areas in the pelvis and genitalia as well as in the brain during sexual response. In women, the use of pelvic fMRI has shown that the anterior vaginal

wall is stretched and the uterus elevated during coitus, but that the uterus does not balloon as was previously thought (Faix, Lapray, Callede, Maubon, & Lanfrey, 2002; Weijmar-Schultz, van Andel, Sabelis, & Mooyaart, 1999). The finding that the anterior vaginal wall stretches is relevant because it is unknown how the signal of the vaginal photoplethysmograph may be affected by such changes. In men, it has been found that the penis during intercourse in "missionary position" obtains the shape of a boomerang, with approximately one third of its length consisting of the internal root (Weijmar-Shultz et al., 1999). In women, researchers have isolated the clitoris as a target organ, as it exhibits the most sizeable genital changes during sexual arousal (Suh et al., 2004) and clitoral measurements appear reliable (Maravilla et al., 2003). Investigators are still debating, however, whether MRI can document vaginal atrophy in post-menopausal women, and it also remains to be established exactly what physiological changes contribute to the output (Deliganis et al., 2002).

Brain-imaging studies make a unique contribution to the literature because they, in contrast to research in animal models and neurological patients, can be used to study brain mechanisms in nonclinical human populations. Studies using PET and fMRI have found activation during the processing of visual sexual stimuli of the occipitotemporal cortex, orbitofrontal cortex, parietal lobules, putamen, amygdala, insula, claustrum, hypothalamus, as well as the deactivation of several areas of the lateral temporal cortex (Stoleru and Mouras, in press, Canli and Gabrieli, 2004).

Future research will, through the comparison of different populations and types of stimuli, undoubtedly refine our understanding of the role of specific brain areas and systems in sexual response and behavior. For example, imaging techniques can be applied to the study of gender differences in brain activation to different stimulus modes (e.g., visual, tactile, auditory, imaginary) as well as stimulus characteristics (e.g., heterosexual/homosexual, explicit/romantic, aggressive). Similarly, brain-imaging techniques can be used in research on sexual dysfunction (e.g., Stoleru et al., 2003) and its treatment (e.g., Montorsi et al., 2003). Stoleru and colleagues (2003) found that men with low sexual desire exhibited less activation of parietal regions (involved in emotional and motor imagery) and decreased *deactivation* of the medial orbitofrontal cortex (involved in the inhibition of motivated behavior) as compared to a control sample. When it comes to treatment, Montorsi and colleagues (2003a, 2003b) evaluated, also using fMRI, the effects of the first officially approved centrally acting drug for the treatment of erectile dysfunction, apomorphine, in men with psychogenic problems. Apomorphine was associated with increased activation of parietal areas and, consistent with Stoleru and colleagues' (2003) findings, greater deactivation of the medial OFC.

These examples merely serve to illustrate the potential for brain-imaging methods to lead to new insights and hypotheses in the study of sexual response. Yet, researchers

in this area face a number of challenges. For instance, the study of central processes using imaging techniques would benefit from the inclusion of measures of peripheral (genital and spinal) mechanisms. Unfortunately, the use of genital measures in MRI scanners is at present problematic (cf. Montorsi et al., 2003a). Also, it is unclear to what degree other autonomic (e.g., cardiovascular, respiratory) processes may be a confound, and thus threaten internal validity, in imaging studies of sexual arousal, which further emphasizes the need for including additional physiological measures. For example, Arnow and colleagues (2002) found correlations in the range of .3 and .5 between changes in respiration and changes in penile tumescence, introducing the possibility that the relationship between brain activation and sexual response in their study was mediated by (or reflected) changes in respiration. Another matter that requires attention involves the reliance on relatively large numbers of (often discrete) sexual stimuli. In contrast to traditional psychophysiological sex studies, imaging approaches have relatively specific requirements for the averaging of responses over time and across stimuli, making it more challenging to control for the effects of habituation, sensitization, or boredom. This may be especially problematic if differences in brain activation between groups of patients and controls or men and women really reflect differences in, for example, the speed of or propensity for habituation.

Although research in this area is increasingly guided by theoretical models (e.g., Redoute et al., 2000), most imaging studies still rely on "emotionally neutral" control stimuli. Progress in this area will depend on the use of designs and reference conditions that will allow the assessment of the specificity of changes (increases or decreases) to *sexual* systems by comparing sexual with other emotional stimuli. Although brain-imaging techniques represent a promising approach to the study of neural structures and processes, they are, like any other emergent technique, subject to methodological (e.g., the reliance on subtraction methods) and conceptual (e.g., the presence or absence of differential brain activation does not necessarily prove or rule out a role for a specific region) challenges, and researchers should be critical of the assumptions underlying the collection and interpretation of brain-imaging data (Cacioppo et al., 2003).

4.1.4. Measurement of subjective sexual arousal

The construct of sexual arousal, its necessary and sufficient conditions, its phenomenology, and its distinction from other components of sexual response (e.g., sexual desire), is receiving renewed and growing interest from researchers (e.g., Everaerd, Laan, & Both, 2003; Graham et al., 2004; Rowland, 1999). Although the physiological measurement of sexual arousal is a maturing science, the operationalization and assessment of subjective sexual arousal is still relatively undeveloped and poses challenges of its own. According to Mosher's (1980) involvement theory, subjective sexual arousal consists of awareness of

physiological sexual arousal, sexual affects, and affect-cognition blends. Mosher, Barton-Henry, and Green (1988) developed a scale that measures these three dimensions but, while one of the few self-report measures with known psychometric properties (see Mosher, 1998), is rarely used in its original form. Most researchers use adaptations of this measure or comparable questions derived from the work of others (e.g., Heiman & Rowland, 1983; Henson et al., 1979).

Some researchers also use continuous measures of sexual arousal. Wincze, Hoon, and Hoon (1977) first reported on a lever capable of swinging through a 90° arc that participants could operate to indicate their degree of sexual arousal. Other researchers (e.g., Janssen et al., 1997; Laan et al., 1995) have employed a variant of this technique using horizontally placed sliders with lights providing subjects with feedback. Although rating scales and continuous measures have been found to yield roughly equivalent results (Steinman et al., 1981), both approaches have their disadvantages. One disadvantage of discrete measures of subjective sexual arousal is that they are retrospective in nature. The use of a continuous measure requires participants to monitor their response continuously, and thus may yield distractions or lead to "spectatoring" (Masters & Johnson, 1970). Thus, the reactivity of this measure may depend on participant characteristics (e.g., clinical versus nonclinical), a possibility that warrants more research. An obvious advantage of the continuous measure is that it allows for the evaluation of subjective responses throughout an entire stimulus episode. Peak levels of sexual arousal may be comparable with continuous and discrete measures, but *when* the peak occurs can be determined only with continuous measures. In addition, continuous measures allow for the calculation of within-participant correlations. With physiological measures where calibration of the signal is not possible (e.g., VPA), within-participant correlations are more reliable and informative than between-participant correlations.

4.2. Signal recording and processing

In contrast to many other areas of psychophysiological research, no guidelines exist for the measurement of sexual arousal, and the current lack of standardization of signal recording, processing, and analysis, complicates the evaluation and comparison of research findings². Signal processing and data reduction appear to be the most significant sources of error variability. Although the more commonly used measurement systems (Contact Precision Instruments, Boston, MA; BIOPAC Systems, Inc., Goleta, CA) come with software containing basic signal processing tools, procedures for artifact detection and removal,

² In 1998, SexLab, a listserv with companion website (www.indiana.edu/~sexlab) was established to facilitate standardization and stimulate discussion of methodological issues among sexual psychophysiologicalists.

especially relevant in the analysis of VPA, are not standardized in these programs and often are not described in sufficient detail in publications. Automated algorithms exist in related fields for correcting artifacts similar to those seen in VPA (Kaiser & Findeis, 1999; Linden & Estrin, 1988) and could vastly decrease VPA processing time and increase standardization. Others have attempted to use Fourier analysis to select relevant VPA components (Polan, 2003; Wouda et al., 1998), but this approach is still confounded by movement artifacts that may cross into the desired frequency band (Prause & Janssen, 2004).

Another source of error in sexual response measurement is related to variations in device placement. Although measurement devices are usually put in place by participants, visual inspection of placement could increase measurement accuracy and reliability. However, with measures such as penile strain gauges, "improper" device selection or placement cannot always be prevented. For example, a gauge that fits well on a flaccid penis may prove too small for an erect penis. Placement of the vaginal plethysmograph can be standardized by using a shield (Geer, 1983; Laan et al. 1995) and this practice is recommended. A placement shield, however, will not prevent inaccurate readings due to (phasic or tonic) muscle contractions. As for the labial thermistor, little is known about the effects of placement and how changes in size or volume of the labia affect the output of the device. In view of this, we emphasize the importance of carefully checking all genital response data for outliers before performing statistical analyses.

Meuwissen and Over (1993) and Julien and Over (1981) examined whether the Law of Initial Values (LIV) applies to the measurement of genital responses and reported inconsistent findings. Not uncommonly, positive instead of negative correlations are found between baseline and response levels (e.g., Heiman et al., 2004, reported baseline-response level correlations of $r = 0.89$ for VPA and $r = 0.84$ for clitoral volume in women). Recent reconceptualizations of LIV (e.g., Jin, 1992) propose that within the middle range of initial states, higher initial values are expected to be related to greater (not smaller) reactivity. Only when an initial value reaches its upper limit, a tendency to reversed responses may occur. Although LIV may account for a portion of the variance, more research is needed to determine how it relates to constitutional (e.g., anatomical differences) and physiological factors in psychophysiological sex studies.

4.3. Models of sexual response

One of the first models of sexual response was introduced by Havelock Ellis in 1906. His two-stage model differentiates between a stage of "building up" (tumescence) and climactic release (detumescence). This model was extended by Moll (1908/1912) who described a *curve of voluptuousness* which consisted of four phases: the build-up of sexual excitement (the ascending limb), a high, stable level

of sexual excitement (the equable voluptuous sensation), orgasm (the acme), and the cessation of the sexual impulse (the decline).

4.3.1. The sexual response cycle

Although initially introduced as little more than a frame of reference, Masters and Johnson's (1966) four-stage model is probably the best-known model of sexual response to date. The model, reminiscent of Moll's curve of voluptuousness, describes the genital and extragenital responses that occur in humans during sexual behavior. The phases are (1) excitement phase, (2) plateau phase, (3) orgasmic phase, and (4) resolution phase. Although few would dispute the impact of Masters and Johnson's model on subsequent research and the development of sex therapy, it has been subjected to serious criticism. For example, the separation of sexual response into four discrete stages has been challenged (Robinson, 1976). The distinction between excitement and plateau phases is especially problematic, as there is no empirical support for an identifiable plateau phase. Similarly, the universality of the model has been questioned (Tiefer, 1991). Also, Masters and Johnson did not describe adequately their methods and their data were not quantified nor presented in a form that permits evaluation by others. Finally, the studies were restricted to the observation of physiological changes; psychological factors were not measured.

Kaplan (1977, 1979) presented a modification of Masters and Johnson's model in which she replaced their first stage by a "desire" phase. Her second and third phase, the excitement and orgasm phase, are similar to Masters and Johnson's first and third phases. Kaplan's model has been influential in the formulation of the American Psychiatric Association's diagnostic manuals since the *Diagnostic and Statistical Manual III* (APA, 1980).

4.3.2. Cognitive-affective models

Models of sexual response such as Masters and Johnson's suggest that some preprogrammed mechanism exists that is activated by adequate sexual stimulation (Janssen & Everaerd, 1993). They fail, however, to describe what exactly constitutes effective stimulation. In fact, Masters and Johnson's definition of the term is circular: Effective stimulation produces a response, and a response is evidence for effective stimulation. Another problem with models such as Masters and Johnson's is that they do not provide an explanation for the many regulatory processes related to sexual response, nor do they account for the many variations in subjective experience of sexual response and the complicated variation in stimulus and response parameters from such models.

Although a number of other sexual response models have been proposed over the years (e.g., Bancroft, 1989; Byrne, 1977), only a few originated from or are based on psychophysiological research. One such model was proposed by Barlow (1986). In a series of studies, he found support for a number of factors differentiating men

with erectile problems from men without sexual problems. Together, these findings provided the basis for his model, which emphasizes the interaction between autonomic activation and cognitive processes. Sexual response patterns are conceptualized as forming either a positive or a negative feedback system, both starting with the perception of an explicit or implicit demand for sexual performance. This results in either positive or negative affective evaluations, both triggering autonomic arousal. The increase in autonomic arousal enhances attention for those features of the sexual situation that are most salient. Continued processing of erotic cues produces genital response, and ultimately leads to sexual approach behavior. Continued processing of nonerotic issues (e.g., consequences of not responding) interferes with sexual arousal and ultimately leads to avoidance behavior. By combining cognitive-affective and physiological features of sexual response, this type of conceptual approach holds genuine promise of yielding substantial theoretical progress.

Barlow's original model was based on studies of men. Palace (1995a) presented a similar model, based on studies in sexually functional and dysfunctional women, in which the summation of autonomic arousal and perceived and expected levels of genital response leads to an optimal sexual response. The model is based on studies showing that increased autonomic arousal and positive false feedback can enhance sexual responses in women (Palace, 1995b; Palace & Gorzalka, 1990). Thus, Palace emphasizes the relevance of expectations, as does Barlow (see also Wiegel et al., 2005), and both models emphasize the interaction between autonomic and cognitive processes and highlight the importance of feedback.

In constructing their models, Barlow and Palace both recognize the complexity of the interrelationships among response components, yet they essentially treat sexual arousal as a unified construct. Instances of discordance, however, suggest that genital and subjective sexual responses are, at least to a certain degree, under the control of different mechanisms (Bancroft, 1989). Janssen, Everaerd, Spiering, and Janssen (2000) presented a model that highlights the interaction between automatic (unconscious) and controlled (conscious) cognitive processes and proposes that different levels of processing can differentially affect subjective and physiological sexual arousal. The model states that unconscious processes are relevant to explaining the automaticity of the genital response, whereas subjective feelings of sexual arousal are believed to be under control of higher-level, conscious cognitive processing (see also Janssen and Everaerd, 1993; Laan and Everaerd, 1995; Laan and Janssen, in press). Support for the model is provided by studies exploring the role of unconscious processes in the activation of genital responses and sexual meaning (e.g., Janssen et al., 2000; Spiering et al., 2003; Spiering et al., 2004). A basic assumption of the model is that sexual stimuli may convey more than one meaning. Thus automatic and controlled cognitive processes may help explain differences in outcome in

situations that convey sexual meaning while simultaneously activating negative meanings. Janssen et al. (2000) proposed that in these situations, automatic processing of sexual meaning initiates genital response, whereas controlled processing of negative meaning may result in decreased or nonsexual subjective experience.

5. EPILOGUE

Psychophysiology has matured into an important approach in studies on human sexuality. In addition to a growing number of studies on basic mechanisms of sexual response, an impressive body of practical information has accumulated, particularly related to the study of dysfunctions and to methods for the assessment of sex offenders. Progress in the laboratory study of human sexuality, however, is contingent upon methodological advancements. More than 15 years ago, Rosen and Beck (1988) noted that methods in sexual psychophysiology are based more on the availability and ease of use of particular transducers than upon a sound understanding of the underlying processes of sexual arousal. These concerns are still relevant today. For example, Rosen and Beck questioned the reliance on the vaginal photometer, pointing out that basic physiological studies (e.g., Wagner & Ottesen, 1980) "highlighted serious limitations in the vaginal photoplethysmograph as an adequate measure of genital engorgement" (p. 340). The development of new measures, especially of genital response in women, would indeed be a welcome contribution to the field of sexual psychophysiology.

Although the variable relationship between genital responses and subjective reports of sexual arousal in women has been documented extensively, and while experiential and laboratory differences have been found to influence this relationship (for review see Prause & Janssen 2006), the mechanisms involved are not well-understood. More generally, our understanding of the role of feedback from the genitals, and how it interacts with other processes that affect behavior, is still limited. Harking back to the early views of James-Lange, there is a continuing interest in peripheral feedback. Lang's (1994) discussion of the importance of that view and the more contemporary perspectives in emotion theory (e.g., Damasio, 1994) reemphasize the importance of the question of the role of feedback, and possible gender differences therein.

The role of individual differences has, as yet, not received much attention in sexual psychophysiology. Bancroft and Janssen (2000, 2001) proposed a model that postulates that sexual response depends on the balance between sexual excitation and inhibition, and that individual differences exist in the propensity for both. Just as future sexual response models should, at least ideally, attempt to incorporate predictions about the interrelationships between physiological and subjective responses, sexual psychophysiology could benefit from the development of conceptual approaches that contribute to our understanding of individual differences in sexual response and

behavior. This would be especially relevant in respect to questions about the development of problematic or unusual response (e.g., sexual dysfunction, paraphilic interests) and behavioral (e.g., sexual "compulsivity," sexual risk taking) patterns. Although such approaches could include the exploration of both general and more specific, sexuality-related (e.g., sexual inhibition proneness or erotophilia/phobia) aspects of personality, they also should include the consideration of interindividual variability in response patterning as reflected by, for example, individual differences in conditionability (Hoffmann, 2005).

Another unanswered question alluded to earlier is how to conceptualize and deal with the fact that sexuality is often surrounded with both positively and negatively valenced emotions. Some research suggests that sexual arousal may simply be a case of a highly arousing positive emotional state (Carrette, Hinojosa, & Mercado, 2003), whereas other studies have shown that sexual stimuli are processed differently from other emotional stimuli and are processed differently by the two genders (Geer & Manguno-Mire, 1997). Although it has been argued (Everaerd, 1988) that sexual arousal should be considered to be among the emotions, it is not clear whether its study would benefit most from a discrete or dimensional (e.g., circumplex) theoretical approach. What's more, some may contend that sexual arousal is not a prototypical emotion exactly *because* it often involves the co-activation of positive and negative affect, where other emotions are assumed to show stability in valence. However, findings of studies combining within- and between-subjects approaches increasingly challenge the notion that negative and positive emotions are mutually exclusive (e.g., Larsen, McGraw, & Cacioppo, 2001; Scollon, Diener, Oishi, & Biswas-Diener, 2005). Also, imaging studies (e.g., Canli, 2004; Cunningham, Raye, & Johnson, 2004) suggest "that positive and negative do not subtract from one another in our brains in the way that circumplex models tell us they should" (Zautra & Davis, 2004, p. 1099; cf. Cacioppo & Berntson, 1994). Either way, the advantage that the study of the sexual emotions holds is the specificity of the genital response. Although there is some independence of genital responding and subjective or cognitive events, there is also amazing specificity. Certainly there is no other domain in emotion and psychophysiology in which the physiological response system is as closely tied to the feeling state and stimuli under study.

Albertus Magnus noted, in the 1200s, that "pleasure is attached to intercourse so that it will be more desired, and thus generation will continue" (Book IX, Ch 3, Kitchell & Resnick, 1999). This is the premise that suggests that living animals are "prewired" to respond to relevant stimuli and engage in behaviors that will insure perpetuation of the species. Evolutionary psychology with its emphasis on natural selection is directly related to such a conceptualization. Three areas have been the principal focus in evolutionary approaches to sexuality: mate selection, jealousy, and attractiveness (Allgeier & Wiederman, 1994).

Psychophysiology provides a useful tool for the study and advancement of these research areas.

The future lies, we believe, in the amalgamation of interdisciplinary efforts. Specifically, the explosion of methodologies for assessing brain function will have a powerful impact. As methodologies become increasingly available to study the individual's brain functioning in naturalistic settings, our theories and conceptualizations may be altered dramatically. This does not mean that the measurement of peripheral processes and genital responses will become lost in the shuffle. It appears that peripheral feedback is important and information only from central events will not have the full picture available. In a similar vein, increasing attention to cognitive psychology and the neurosciences with the availability of sophisticated experimental paradigms will play an increasingly important role in the study of sexuality. The combination of studying brain function, cognitive and affective processes, and peripheral mechanisms can be expected to provide researchers with novel, powerful, multi-method approaches that will advance our understanding of the psychophysiology of sexual response and behavior.

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