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What Is the Best Method of Measuring the Physiology of Female Sexual Arousal?

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Abstract A number of instruments have been developed for the physiological measurement of female sexual response. While vaginal photoplethysmography (VPP) remains the most widely used instrument to date, a number of alternate technologies have been examined to address the limitations in the literature on female sexual arousal. In the past 10 years, VPP, ultrasonography, temperature measurement via thermistors and thermographic cameras, magnetic resonance imaging, laser Doppler imaging, and labial and clitoral photoplethysmography have all been used to assess sexual response. To establish which method is best, one must consider the output of each device; how the data generated relate to self-reported sexual arousal; quantitative strengths and limitations and practical issues that arise in using each instrument. Based on these criteria, it appears that ultrasonography is well suited for analysis of genital structures, while temperature measurement provides the strongest evidence for use in research as a methodology for assessing female sexual response.

Keywords Thermography · Photoplethysmography · Ultrasound · Laser Doppler imaging · Labial thermistor · Magnetic resonance imaging · MRI · Sexual psychophysiology · Physiology · Female sexual arousal · Measurement · Instrumentation · Review

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Introduction

The observation and calculated measurement of female sexual response dates back to the late nineteenth century; however, it is really in the past 40 years that a number of instruments have been created and evaluated for this purpose [1]. While all the most widely used instruments measure some aspect of genital vasocongestion, differing and contradictory research results between instruments suggest that some might be better suited for this task than others. Out of the instruments that are currently being used in research, there are differences in terms of the area of measurement (intra-vaginal, clitoral, labial), the degree of intrusiveness (genital contact or insertion vs. remote recording), and the output recorded, all of which can influence data analysis techniques and subsequent research results and conclusions.

The most widely used instrument, the vaginal photoplethysmograph (VPP), for example, measures changes within the vaginal walls during sexual arousal, and while vaginal blood flow is not equivalent to penile blood flow, direct comparisons of male and female sexual response are repeatedly made using this device [2, 3]. This has led to a body of literature that suggests that men have greater specificity in their sexual responses than women [4–6], that men are better able to estimate genital change than women [7, 8] and that men have a stronger concordance between physiological and self-report measures of sexual arousal than women [9•]. It has been argued, however, that clitoral blood flow would be a more appropriate comparison to penile blood flow as the clitoris and penis are homologous structures that are highly innervated and have erectile tissue that becomes engorged during sexual response [3, 10]. To date, there are no studies that directly compare clitoral blood flow to penile blood flow, although research using genital temperature as an indirect marker of blood flow has demonstrated similarities in the concordance between physiological and self-reported sexual response in men and women without sexual dysfunction [11, 12, 13•].

Quantitative limitations with vaginal photoplethysmography, such as relative output scales, high within-subject variability, the lack of standardized calibration protocols and standardized data reduction, has made it difficult to conduct between-groups comparisons of sexual arousal, as well limit the degree to which within-subject comparisons can be made [1, 2, 14, 15]. These particular limitations have had a significant effect on the study of female sexual dysfunction, where, to date, there are no definable physiological markers of impaired sexual arousal [16]. While a number of studies have been conducted to compare sexually healthy women to those complaining of arousal difficulties, physiological sexual responses as measured through VPP have not differentiated the groups [17–22].

While it is possible that these findings could accurately represent female sexual psychophysiology, the limitations with instrumentation suggest that these issues could be the result of a measurement artifact rather than true phenomena. As such, it is important to examine the different tools used to measure female physiological response in order to determine which might best capture the physiological construct of sexual response.

For the purposes of this article, instruments that have been used in the past 10 years are described and evaluated in an effort to determine which one might be best suited to measure female physiological sexual response.

To determine which instrument offers the most advantages in the measurement of female sexual response, one must first determine what research and/or clinical questions are being examined. Each of the outlined instruments has certain strengths and limitations that might make it more or less useful depending on the goal of the research. In evaluating each instrument, one must consider (1) its output, that is what each instrument is actually measuring in terms of physiological response and how that might relate to self-reported sexual arousal; (2) its quantitative parameters, which will determine what kinds of research designs and analyses can be conducted; (3) practical considerations with each instrument, such as ease of use, cost, and applicability to clinical and research settings.

The instruments evaluated here can be categorized into three groups: those using (1) photoplethysmography, (2) imaging, and (3) temperature measurement. Although extra-genital measures, such as skin conductance and heart rate variability, have also been assessed during sexual arousal, these responses are not unique to sexual response and thus have not been adopted as primary indicators of sexual arousal [1, 23].

Photoplethysmography

Vaginal Photoplethysmography Vaginal photoplethysmography is the most widely used methodology for the assessment of female sexual response. The vaginal photoplethysmograph (VPP) is a tampon-shaped instrument that is inserted into the vagina to emit and record light bounced off the vaginal walls [2]. The degree of backscattered light represents blood volume changes in the vagina and is measured as a relative change in mV from a baseline value [2]. The VPP provides two different measures: vaginal blood volume (VBV) and vaginal pulse amplitude (VPA). Of the two, research has demonstrated that VPA is more sensitive to sexual response and thus is the one most often used for data analysis [24].

In the nearly 40 years since its conception, VPP has been used extensively in female psychophysiological sex research. Increases in VPA have been shown to be specific to sexual arousal [6, 15, 24], although most studies have found weak to non-existent relationships between VPA and self-reported sexual response [9•, 25]. The VPP is often used to examine differences between groups; however, the relative nature of its output (e.g., a 10-mV change is not necessarily equivalent between two participants) and the lack of consensus on the physiological process underlying the changes in mV mean that results must be interpreted with caution [2]. Additionally, it has been suggested that for comparisons across sexes, the examination of clitoral blood flow would be more appropriate [3]. Other issues, such as a lack of within-subject stability in baseline VPA over multiple testing sessions and sensitivity to movement artifacts, limit the types of experimental designs that can be used with this device [2].

Despite these shortcomings, VPP requires minimal training to use as compared to some of the other instruments, is accessible to most researchers in terms of cost and equipment needs, is well tolerated by research participants, and allows for multiple short stimuli to be presented within one testing session. It is likely that these conveniences have contributed to its popularity as a research tool even though its lack of reliability and quantitative limitations put much of the research results in to question.

Clitoral and Labial Photoplethysmography To address the limitations of vaginal photoplethysmography, both clitoral and labial photoplethysmographies have been tested as methods of assessing sexual response. The clitoral photoplethysmograph is a device that cups the genital region from the urethral opening up to the clitoris [26]. This device provides a relative measure, clitoral blood volume (CBV), which theoretically corresponds better to measures of penile blood flow than intra-vaginal measures. An initial experiment with 32 women demonstrated that CBV significantly increased during the presentation of sexual stimuli [26]. The study did not, however, assess self-reported sexual arousal, and there have been no studies examining the reliability of this measure over time.

The labial photoplethysmograph is a pulse plethysmograph with a small plastic clip that is attached to the labia minora

[15]. The labial photoplethysmograph provides a relative measure of labial pulse amplitude (LPA). The labia have been shown to become engorged during sexual response, and in an initial study comparing VPP and labial photoplethysmography, it was found that LPA was specific to sexual response and correlated significantly with self-reported sexual arousal [15]. Additionally, LPA was a more robust measure against movement artifacts than VPP. Participants, however, found it harder to place than the VPP and reported more discomfort with the device than with the VPP [15].

Both the labial and clitoral photoplethysmographs are similar to the VPP in terms of researcher ease of use and accessibility. While they provide alternatives to VPP, both are relative measures and do require genital contact with participants, which can limit their use in between-subject research designs and with individuals who might be distracted by the genital contact.

Imaging

Ultrasound Ultrasound technology has been applied to the study of female sexual response for well over 10 years. Khalifé and colleagues first demonstrated that it was possible to image the clitoris using ultrasonography and also established that there was a significant concordance in measurements between two separate ultrasonographers [27]. For the measurement of sexual response, ultrasonography has focused on examining parameters in the clitoris. This technique requires the placement of an ultrasound probe on the clitoris and the probe must be manipulated and held in place by a trained ultrasonographer. Most studies have relied on measuring clitoral blood flow and size at baseline and following a stimulus; however, it is also possible to continuously use ultrasound throughout a testing session if the machine is hooked up to a computer or DVD recorder that can record and store the images [28].

Ultrasonography provides a number of different measurements including clitoral volume and blood flow parameters such as the peak systolic velocity (PSV), end diastolic velocity (EDV), resistance index (RI), and pulsatility index (PI). The absolute values provided by ultrasonography make it possible to conduct between-group comparisons.

Many studies have used this technology to examine and describe structural properties of the clitoris and pelvic region as well as to examine problems with genital vasculature in women [29–33]. For example, using ultrasound on five healthy premenopausal women, Foldes and Buisson were able to create 3D images of the clitoral complex and to visualize its movements during penetration [30].

Studies that have used ultrasound to assess genital blood flow have demonstrated significant increases in clitoral hemodynamics following application of a vasoactive agent, mechanical stimulation, or audiovisual stimulation [34–39]. Although there are increases in clitoral blood flow during sexual response, significant correlations with self-report have not been found [38]. Additionally, the one study that assessed the discriminant validity of ultrasound found no differences in blood flow between healthy participants in a sexual arousal condition versus those in a humor control condition [38].

Ultrasound machines are not readily available to most researchers. This technology is expensive and requires specialized training in order to accurately assess clitoral properties. While ultrasound does provide a direct measure of sexual response, the requirement of genital contact and the presence of a technician are not ideal for studies of sexual arousal as these variables can both enhance and inhibit participant sexual response. The ability to examine structural properties of female genitalia, however, is worth noting, particularly since ultrasound is less expensive and easier to use than MRI, the only other tool that can define and measure structural properties of the female genitalia.

Magnetic Resonance Imaging Dynamic magnetic resonance imaging allows for the direct examination of genital structures during sexual arousal [40]. For this type of measurement, the participant must lie in an MR magnet while stimuli are remotely projected into the magnet. There is no need for a researcher to be present in the room during testing as everything can be done remotely. No direct genital contact is required; however, participants must lie still in an enclosed space during testing. Additionally, while the MRI machine can capture images over the course of a testing session, data collection is dependent on how long it takes the machine to complete one scan (e.g., in one study, an image was completed once every 3 min) [41]. While there have been studies using MRI in conjunction with an injected contrast agent [42], Maravilla and colleagues demonstrated that dynamic MRI without the use of a contrast agent could reliably detect genital structures and significant changes during sexual response, which reduces the intrusiveness of the technique [41].

Researchers have demonstrated that visualization of different genital structures (labia majora and minora, clitoris, vestibular bulbs, vaginal canal, and urethra) is possible using MRI with change in clitoral volume (cc) being used as the most reliable marker of physiological sexual response [41].

One study has shown within-subject reliability in measuring clitoral volume at a 1-h and a 24-h interval in a small sample of participants, and significant increases in clitoral volume have been found during the presentation of audiovisual sexual stimuli [41, 43]. No significant relationship between self-reported sexual arousal and clitoral volume has been demonstrated, although the small sample sizes make it difficult to calculate correlations.

While research with larger sample sizes is needed, initial results suggest that clitoral volume is a stable construct within participants and that MRI can be used for both within- and between-subject designs. Additionally, the unit of measurement (cc) is on an absolute scale that can be easily interpreted. Due to the relatively slow scanning process (just under 3 min per scan), this method of measurement is better suited for longer experimental designs.

MRI machines are not readily available to most researchers and clinicians because of the cost and specialized nature of the equipment. Additionally, the use of an MRI scanner is costly, and subsequent data interpretation requires much specialized training. While the procedure does not require any genital contact, participants must lie very still during testing so as not to create movement artifacts in the scans [42]. Finally, there are weight and height restrictions for the scanning machines, and the procedure does require participants to be encased in a magnet, which can cause some anxiety or stress for individuals who feel claustrophobic [42].

Laser Doppler Imaging Laser Doppler imaging (LDI) is a technique that utilizes a Doppler imager to record superficial blood flow (2–3 mm under the skin) [44]. In LDI, the imaging machine is placed in close proximity to the genitals (within 20 cm) in order to scan the area of interest during sexual response [45]. This technique provides a direct measure of blood flow (in flux units) and does not require any kind of genital contact or manipulation. Participants must remain still during testing, and each scan of the genital area takes approximately 2 to 3 min to complete.

LDI provides a direct measure of superficial blood flow. The unit of measurement (Flux) is the product of blood volume and velocity of the area that is being scanned. For studies on physiological sexual response, analyses have been conducted on blood flow to the whole genital area as well as a region of interest consisting of the labia majora, labia minora, and clitoral hood [44–47]. Additionally, Styles and colleagues [45] examined blood flow to different genital structures including the labia minora, clitoral area, and fourchette. Results from these studies indicate that blood flow increases significantly during sexual response to all of the examined areas [44–47].

The first published study using LDI to measure sexual response examined 18 healthy premenopausal women over the course of two testing sessions and found that there were no significant differences in flux measurements between sessions, indicating that LDI has test-retest reliability [45]. Additionally, significant increases in Flux were noted when comparing baseline to erotic scans. While one question on self-reported sexual arousal was asked, no correlations were reported [45].

Subsequent research on LDI with audio-visual sexual stimuli has demonstrated a significant relationship between Flux measurement and self-reported sexual arousal in healthy premenopausal women [44, 46]. Furthermore, when comparing participants watching neutral, humorous, anxiety-provoking, or sexually explicit stimuli, only those in the sexual arousal condition demonstrated increases in genital blood flow [44].

The training required to use laser Doppler imaging is minimal; however, the imager is costly. The unit of measurement is absolute, which allows for group comparisons, and the lack of genital contact may help minimize perceived intrusiveness. As each scan takes between 2–3 min to complete, this technology may be better suited for longer experimental designs.

Temperature Measurement

Labial Thermistor The labial thermistor is a small pediatric thermistor disc that is attached to a metal clip [48]. This clip is affixed to the labia minora during testing and provides a measure of labial temperature during sexual arousal. Although temperature is an indirect measure of sexual arousal (temperature increases with increased blood flow to an area), it is on an absolute scale, which allows for between-group comparisons. Temperature measurement can also be recorded continuously in real time, which allows for an examination of patterns of temperature change. As the thermistor is affixed to the labia, it is fairly robust against movement artifacts [48].

The thermistor was first used in women over 30 years ago [49], and despite early studies demonstrating significant increases in genital temperature during sexual arousal that corresponded to self-report, this instrument remained largely unused because of the presumed slow return to baseline following a sexually arousing stimulus [49–52].

A revived interest in temperature measurement has found similar results to previous studies in that labial temperature increases were specific to sexual response and were significantly related to self-report [53, 54]. Additionally, Prause and Heiman noted that labial temperature returned to baseline during a 10-min neutral video between erotic stimuli, which suggests that the presentation of repeated within-session stimuli are possible [53, 55]. When simultaneously compared to VPP, there were no significant correlations between the two measures, and participants reported that the labial thermistor was significantly less comfortable than the VPP (though both instruments had mean scores of less than 2 on a scale of 1 to 7 with 1 being not uncomfortable at all) [53].

The labial thermistor is relatively easy to use and does not require much training. The absolute measurement scale allows for between-group comparisons, and the reasonable return to baseline allows for multiple stimuli to be presented within one session. Additionally, the ability to continuously record temperature across testing session allows for the examination of patterns in sexual response. The thermistor is robust against movement artifacts; however, it requires genital contact, and though it has been found to be relatively comfortable, it is still significantly less so than the VPP. Finally, as body temperature can fluctuate as a result of the environmental temperature, the thermistor does require the ambient room temperature to be stable during testing [48].

Thermographic Camera The thermal imaging camera is a device that can remotely record temperature through the assessment of infrared radiation. All objects emit infrared radiation that is directly proportional to their temperature, and the camera is able to detect this radiation and provide the temperature of the target in focus without requiring any kind of physical contact. Thermographic cameras were first used for the assessment of sexual response over 30 years ago [56–58]. The numerous quantitative limitations of the technology at the time, however, led to this line of research being abandoned until recently. Modern thermographic cameras can provide accurate, continuous temperature measurement and have been used to assess genital temperature in both men and women [12, 13•, 59•]. Similar to research using labial thermistors, genital temperature increases have been found to be specific to sexual response when compared to neutral, humorous, and anxiety-provoking stimuli, and they correlate with self-reported sexual arousal [12, 13•, 60]. Additionally, an examination of baseline genital temperature in 20 healthy women over three monthly testing sessions showed no significant differences over time, which suggests that genital temperature is a stable construct within individuals [61].

Thermographic cameras have come down in price considerably over the past 10 years. While still more expensive than thermistors, the price does not come close to other imagers such as LDI, ultrasonography, or MRI. The cameras are relatively easy to use, and the required training to master the software is minimal. As of yet, there is no way to map a region of interest (ROI) on to the thermographic image so that if a participant moves, the ROI will move with them. This means that a researcher must manually adjust the ROI if there is participant movement. The cameras provide continuous measurement and do not require any genital contact. The temperature output is an indirect measure of sexual response; however, it allows for between-group comparisons and is related to self-reported sexual arousal. Similar to labial thermistors, the thermographic cameras require ambient room temperature to be controlled.

Discussion and Conclusions

The measurement of female physiological sexual response has led to a number of controversies in our understanding of female sexual psychophysiology over the years, namely that there is a discordance between women's physiological and self-reported sexual arousal, that women are not as aware of their sexual arousal as men, and that there are no definable physiological criteria for arousal and desire disorders in women. Many of the conclusions drawn in the literature are based on the measurement of intra-vaginal changes, which may not be the most accurate representation of female physiological sexual response given that the clitoris is dedicated to sexual pleasure and is homologous to the penis. Additionally, the number of quantitative limitations with the most widely used instrument, the vaginal photoplethysmograph, raises the question of instrument artifacts in the interpretation of research results. While the VPP remains the instrument of choice for most researchers, a number of different tools have been developed to try and address the ongoing issues with measurement (see Table 1 for a summary). Each instrument has

Table 1 Summary of instruments used in the past 10 years for the measurement of physiological sexual arousal in women

Instrument	Remote measure	Output on an absolute scale	Capable of continuous recording	Correlated to self-report	Specific to sexual response	Relative ease of use●	Within participant stability of measure over time	Relative cost♦
Vaginal photoplethysmograph	No	No	Yes	Yes/no*	Yes	++++	No	$
Labial photoplethysmograph	No	No	Yes	Yes	Yes	++++	Not assessed	$
Clitoral photoplethysmograph	No	No	Yes	Not assessed	Not assessed	++++	Not assessed	$
Magnetic resonance imaging	Yes	Yes	No	No**	Not assessed	+	Yes	$$$$
Ultrasound	No	Yes	Yes***	No	No	++	Yes	$$$
Laser Doppler imaging	Yes	Yes	No	Yes	Yes	+++	Yes	$$$
Labial thermistor	No	Yes	Yes	Yes	Yes	++++	Yes	$
Thermographic camera	Yes	Yes	Yes	Yes	Yes	+++	Yes	$$

●Scale where + = the most difficult to use (i.e., requires extensive training, resources, specialized space), ++++ = easiest to use; ♦ scale where $ = relatively the cheapest to $$$$ = the most expensive; *there are mixed findings though most studies have low to no correlation; **small sample size could be to blame for lack of correlation; ***capable of continuous recording though all studies have used discrete measurements demonstrated a certain degree of reliability and construct validity in measuring genital response, though primarily through one or two studies. All would certainly benefit from additional testing of quantitative parameters to further validate research results. The determination of which instrument is best suited to measure female sexual response largely depends on the research questions and goals. If the goal is to directly examine anatomical structures during sexual response, then ultrasonography seems to offer a number of practical advantages over magnetic resonance imaging in that it is less susceptible to movement artifacts, is less expensive, and requires less training to use. While ultrasound has been shown to have inter-rater reliability and does provide a direct measure of sexual arousal, namely clitoral blood flow, the presence of a technician who must hold a probe on the clitoris has been shown to be intrusive to the process of sexual arousal (unpublished data from Kukkonen et al. [38], ultrasound study). A remote-controlled probe that requires minimal pressure would lessen this effect, but ultimately, clitoral contact is a requirement with ultrasonography, which makes it less suited for studies that might examine the effect of a particular stimulus or agent on sexual response. Although laser Doppler imaging addresses this issue by being a remote device, the laser can only record superficial blood flow and thus cannot provide structural information beneath the surface of the skin.

If the requirement of research, however, is to have a direct measure of sexual response without necessarily examining anatomical structures, then laser Doppler imaging shows much promise. The unit of measurement is absolute and can be compared across groups; the output significantly correlates with self-report and differentiates sexual arousal from control conditions. The laser Doppler imager has demonstrated within-subject reliability, and the lack of physical contact is an advantage for clinical populations, such as women with pain disorders. The laser Doppler imager is expensive and cannot, however, provide a continuous measure of sexual response as it is dependent on how long the imager takes to complete one scan, and participants must remain still during scanning so as not to distort the images. So while this technology can certainly examine participant blood flow prior to and following a stimulus, an examination of patterns of sexual responding over time is not feasible with the current technology. Additionally, it is not clear whether the laser Doppler can be used to record penile blood flow as the onset of erection changes the size and angle of the penis.

Finally, if the research goal does not require a direct physiological measure and/or requires continuous measurement, then genital temperature recording seems to have numerous advantages over other instruments. The output temperature is on a known, absolute scale, which allows for between-group comparisons, genital temperature has been shown to correlate with self-reported sexual arousal, and increases in temperature are specific to sexual response. Additionally, research has demonstrated reasonable return-to-baseline times and the stability of genital temperature over time. Thermographic cameras are advantageous over thermistors in that they require no physical contact—a point that might be particularly salient for research on clinical samples, such as women with genital pain disorders. Additionally, the remote nature of the cameras eliminates the need for disinfection of the apparatus between participants. The labial thermistor is, however, less expensive than thermographic cameras and is more robust against movement artifacts. Ultimately, both seem to address many of the existing limitations with plethysmography and have practical advantages over more expensive equipment such as the MRI, ultrasonography, and laser Doppler imaging. While the research on temperature measurement is still limited, initial results suggest that some of the issues in comparing male and female sexual response might be due to an instrument artifact and that future research should work on replicating previous findings with this technology.

Compliance with Ethics Guidelines

Conflict of Interest Tuuli M. Kukkonen declares that she has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with animal subjects performed by the author. With regard to the author's research cited in this paper, all procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

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