International Journal of Psychophysiology 133 (2018) 28–40

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Review

A review of infrared thermography as applied to human sexual psychophysiology

Inês M. Tavares[a,*], Ricardo Vardasca[a,b,c], Nicoletta Cera[a], Raquel Pereira[a], Filippo M. Nimbi[d], Dominika Lisy[e], Erick Janssen[f,g], Pedro J. Nobre[a]

[a] SexLab, Center of Psychology of the University of Porto, Porto, Portugal
[b] LABIOMEP, INEGI-LAETA, Faculty of Engineering, University of Porto, Portugal
[c] Medical Imaging Research Unit, Faculty of Computing, Engineering and Science, University of South Wales, United Kingdom
[d] Department of Dynamic and Clinical Psychology, Sapienza University of Rome, Rome, Italy
[e] Faculty of Behavioural and Social Sciences, University of Groningen, the Netherlands
[f] Institute for Family and Sexuality Studies, Department of Neurosciences, University of Leuven, Leuven, Belgium
[g] Kinsey Institute for Research in Sex, Gender, and Reproduction, Indiana University, Bloomington, IN, USA

ARTICLE INFO

Keywords:
Infrared thermography
Instrumentation
Psychophysiology
Review
Sexual arousal

ABSTRACT

Infrared thermography (IRT) is a non-contact technique that permits mapping and analysis of the temperature of the body's skin surface. This method has been applied to sexual psychophysiology since the 1980s and its use has been expanding ever since, mainly because it provides several advantages over existing genital response measures. This article presents a review of experimental studies employing IRT to investigate human sexual arousal, with the aim of summarizing the available procedures and evidence so far and to identify important caveats in the literature. The studies reviewed support the feasibility and validity of IRT as a real-time physiological measure of sexual arousal but varied substantially regarding methodology and procedures. The results of this review underscore the value and validity of IRT in sexual psychophysiology and point at the critical need for the standardization of IRT protocols to accommodate the specific needs of applying this methodology to sexual physiology.

1. Introduction

The study of the psychophysiology of human sexual response continues to be a developing field. Over the decades, our understanding of sexual response has expanded and a wide array of measures has been developed to assess the physiological markers of sexual arousal in men and women. However, current instruments used to investigate the physiology of sexual response demonstrate a number of limitations and challenges to its interpretation and usage in different populations. The availability of valid and reliable psychophysiological instruments that can be used in both sexes, across different populations, and with the potential of establishing diagnostic criteria is of crucial importance for both scientific and clinical purposes.

Infrared Thermography (IRT) is a method to measure temperature that is based on the infrared radiation emitted from objects' surface. It provides a map of the distribution of temperatures on the surface of the imaged object and is not related to morphology, like methods such as those relying on the use of X-Rays or MRI (Ammer and Ring, 2012). Infrared thermography has been applied to the study of sexual psychophysiology since the 1980s and provides a number of advantages over alternative measures of genital response.

Studies have shown evidence of the feasibility, reliability, and validity of thermography as a physiological measure of sexual arousal (e.g., Huberman and Chivers, 2015; Huberman et al., 2017; Kukkonen et al., 2007, 2010). Notwithstanding the relevance of these promising results, the heterogeneity of the studies in terms of methodology and measurement procedure warrants a critical interpretation of their findings. The goal of this review is to synthesize and critically discuss the literature on IRT as it has been applied to sexual psychophysiology. Remaining questions and suggestions for future research are also presented.

1.1. Measuring human sexual response throughout time: various measures and inherent limitations

Sexual arousal is a multi-dimensional state that encompasses

* Corresponding author at: SexLab, Faculty of Psychology and Educational Sciences, University of Porto, Rua Alfredo Allen, 4200-135 Porto, Portugal.
E-mail address: inesmmtavares@gmail.com (I.M. Tavares).

https://doi.org/10.1016/j.ijpsycho.2018.09.001
Received 3 May 2018; Received in revised form 5 September 2018; Accepted 7 September 2018
Available online 09 September 2018

physiological changes dependent on activation of the central nervous system, the perception of these changes, subjective experience of arousal, and motivated behavior (Geer et al., 1993; Rosen and Beck, 1988). Physiological responses specific to sexual arousal include genital responses (erection in men and vaginal lubrication, clitoral, and vulvar congestion in women), with the congestion leading to an increase in pelvic vascular blood flow and resultant pelvic vasocongestion (Levin, 1998, 2003; Levin and Riley, 2007). Genital vasocongestion is also associated with increases in genital skin temperature (Henson et al., 1977; Webster and Hammer, 1983). The different components of sexual arousal are integrated through positive feedback, such that initial genital responses to a sexual stimulus direct attention to sexual cues, inducing subjective arousal and increased genital responses if stimulation is maintained (Barlow, 1986; Geer et al., 1993; Janssen et al., 2000; Rosen and Beck, 1988).

Throughout time, an important focus of sexual psychophysiology has been on the direct measurement of changes in the genitals that are associated with sexual arousal. Extragenital peripheral measures such as skin conductance and heart rate variability have also been studied, but have been found to be indicators of general autonomic arousal and not to be specific to sexual arousal (Zuckerman, 1971).

For men, the most commonly used genital measures include penile volumetric plethysmography (Freund, 1963), mercury and Barlow strain gauges (Bancroft et al., 1966; Barlow et al., 1970), rigiscan monitoring (Bradley et al., 1985; Levine and Carroll, 1994), and penile ultrasonography (Meuleman et al., 1992). For women, vaginal photoplethysmography has become the most widely used measure, with other measures including pelvic magnetic resonance imaging (Maravilla and Yang, 2008; Maravilla et al., 2005), labial thermistors (Henson et al., 1977; Prause and Heiman, 2009), labial and clitoral photoplethysmography (Gerritsen et al., 2009; Prause and Heiman, 2009; Prause et al., 2005), laser Doppler imaging (Styles et al., 2006; Waxman and Pukall, 2009), clitoral ultrasonography (Buisson et al., 2008; Foldes and Buisson, 2009), and heated oxygen electrodes (Beck and Baldwin, 1994; Levin, 2006) also being used. For review of measures of female sexual response see Kukkonen, 2015; for review of both male and female sexual response measures see Janssen, 2001 and Zuckerman, 1971.

Although offering important contributions to the physiological study of human sexual response, each of the above-mentioned instruments is associated with a number of problems that limit or hinder its use and that could constrain our understanding of human sexual arousal. One important limitation concerns the fact that most current instruments cannot be used in both men and women, which impedes the comparison between male and female sexual response. Although an anal probe suitable for measuring vascular and muscular activity during sexual arousal for both genders does exist, it has rarely been used in research (Bohlen and Held, 1979; Bohlen et al., 1980; Bohlen et al., 1982) and only one study used a variation of this instrument to compare male and female sexual response (Carmichael et al., 1994). Additionally, the use of these instruments requires direct genital contact or insertion, either by the participant or the experimenter. This constitutes another limitation of these technologies, since their potential intrusiveness may interfere with the activation and experience of sexual arousal and thus influence the outcome measurement (Kukkonen et al., 2006; Prause et al., 2005).

Standardization and between-subjects comparisons are also difficult to establish using the currently available instruments. The absence of an absolute measurement scale or calibration method in the case of techniques such as vaginal and labial photoplethysmography makes it difficult to interpret and compare data between subjects (Janssen, 2001; Prause et al., 2005; Prause and Janssen, 2006). Also, in the case of penile plethysmography and rigiscan monitoring, it is still unclear how strongly the output measures associate with clinically relevant levels of penile rigidity. For these reasons, the task of establishing diagnostic criteria using the current measures has been a challenge, since this requires between-subject comparability and standardization. This holds true in spades for women, since none of the existent measures of physiological sexual arousal have been used to establish diagnostic criteria for female sexual arousal difficulties.

Finally, most existing measures of physiological sexual response do not adequately account for variations in anatomy and physiology, in particular in women. Normal variations in the length of the vagina can lead to positioning differences for the vaginal probes used in plethysmography. Other individual differences in female anatomy and physiological response such as resting levels of vaginal muscular tone and vaginal moistness may also affect the photoplethysmograph signal (Geer and Janssen, 2000). Moreover, participants' movements, including muscle contractions, can easily alter the output of vaginal photoplethysmography. This artifact is even likely to be intensified by the experience of sexual arousal (Janssen, 2001), since muscular activity in and around the vagina increases during sexual arousal (e.g., Bohlen et al., 1982).

1.2. Principles and advantages of infrared thermography as applied to sex research

Infrared thermography (IRT) presents several advantages over existing measures of sexual response, including: (1) the same instrumentation can be used for both men and women, allowing for between-gender comparisons; (2) thermography does not require any genital manipulation or contact; and (3) thermographic output, temperature, is measured on a known absolute scale. The fact that IRT is a remote sensing technique is a particularly important advantage, as the measurement can be carried out without requiring – and thus potentially being affected by – any physical contact.

The use of IRT as a means of assessing sexual arousal relies on three basic principles: (1) that all objects with a temperature above absolute zero constantly emit electromagnetic energy such as infrared radiation at a level proportional to its temperature; (2) that it is possible to detect infrared emission from membranes such as the skin by remote sensing; and (3) that changes in genital temperature are an indirect marker of sexual arousal, by indicating increased genital peripheral blood flow (Bacon, 1976; Kukkonen et al., 2010).

Modern infrared cameras are able to measure the temperature of a body by remotely detecting the infrared radiation emitted as well as to provide a continuous reading of the object in focus through a visual representation (Jones, 1998). These visual representations, called thermograms or temperature "maps", can be qualitatively and quantitatively analysed, thus making it possible to detect subtle increases or decreases in temperature (Seeley et al., 1980). The current infrared thermographic equipment is able to determine average temperature changes in an area of less than 1 mm of skin with a maximum precision of 50mK in a very short period of time.

Due to all of its advantages, IRT has been established as an effective tool in many different applications (Meola, 2012). In the field of sex research, IRT has been utilized to measure sexual response in both men and women since the 1980s (Abramson and Pearsall, 1983; Abramson et al., 1981a; Abramson et al., 1981b; Beck et al., 1983; Seeley et al., 1980). These initial studies used a technologically limited thermographic equipment and were vastly heterogeneous in study design, populations investigated, and evaluation criteria applied. Still, the results of these studies provided early evidence of feasibility and discriminant validity of IRT as a reliable measure of sexual arousal. These initial studies were followed by a period during which IRT was not used often, but about two decades later this technique gained renewed attention within the field of sex research.

Considering the outlined research, the aim of the present review is to address the gaps in the literature concerning the application of IRT to the assessment of human sexual response, by providing a comprehensive analysis of the empirical data published to date.

2. Methods

A literature search was conducted combining the search terms "thermography" and "sexual" using the PubMed, Web of Science, and EBSCOhost databases (Academic Search Complete, PsycARTICLES, Medline, Psychology and Behavioural Sciences Collection). The search was restricted to titles, abstracts, and keywords of papers published in English until June 2018. One article was added following a reference list check. This approach yielded a total of 26 relevant studies. After a first screening based on the titles and abstracts, studies were only included if:

(1) the paper reported results of experimental or quasi-experimental studies (i.e., reviews, theoretical papers, or commentaries were excluded);
(2) the study had included the use of IRT as a physiological measure of human sexual response (papers using other instruments such as surface thermistors were excluded).

Six studies were excluded following criterion 1 and one by following criterion 2. The remaining 19 studies included in our review are summarized in Table 1.

3. Results

The studies that used IRT as a physiological measure of sexual arousal were assessed and discussed with regard to two main dimensions: methodological procedures (e.g., laboratory setting, participant management protocol, data collection procedures) and study findings relevant to the validity and feasibility of thermography as a measure of sexual arousal. A summary of these results is presented in Tables 1 and 2.

3.1. Methodological procedures

3.1.1. Laboratory setting

To ensure image quality control, the design and environmental conditions of the room where thermographic assessment takes place should conform to a number of principles and criteria (Ammer and Ring, 2012; Ring and Ammer, 2015). The acquisition room should be carefully designed as to control for important variables that influence thermographic reading, namely: ambient room temperature, relative humidity, airflow, and incident lightning (Di Carlo, 1994; Ishigaki et al., 1989; Issing and Hensel, 1982; Jones and Plassmann, 2002; Mabuchi et al., 1997). Of all the nineteen studies analysed, most studies do not report details regarding temperature, and none of them included information about humidity or lightning of the experimental setting.

Regarding room average temperature, thirteen studies (68%) do not include information about possible temperature variation in the experimental room over the course of the study. Of the six studies (32%) that do report details on ambient temperature, the information provided generally conforms to the quality standards for the use of thermal imaging, such that temperature range was held constant between sessions with a variation of ± 1 °C (see Table 2 for details).

None of the studies reported the relative humidity of the room over the course of the thermographic sessions. This also applies to air-flow and incident lightning, since no information was provided regarding air-conditioning systems, or lightning conditions. When it comes to the latter, the only exception is the study by Seeley et al. (1980), which made use of a darkened room.

3.1.2. Participant management protocol

Studies were heterogeneous in sample size and participant demographics. Two papers have reported case studies (Obayashi et al., 2000; Seeley et al., 1980). The remaining studies used sample sizes between $N = 3$ (Abramson and Pearsall, 1983) and $N = 84$ (Sarin et al., 2016). Regarding age, studies included men and women ranging from 18 to 50 years.

Fourteen (74%) of the included studies used IRT to examine sexual response in healthy participants while five studies (26%) focused on clinical populations (see Table 1 for details). Of these five studies, three investigated men with a diagnostic of erectile dysfunction (Ng et al., 2009; Obayashi et al., 2000; Sarin et al., 2014), hypoactive sexual desire disorder (Sarin et al., 2014), or the combination of erectile dysfunction and hypoactive sexual desire disorder (Sarin et al., 2014). The two studies that used female clinical samples focused on women with vaginismus, dyspareunia (Cherner and Reissing, 2013), female sexual arousal disorder, hypoactive sexual desire disorder, or the combination of the latter (Sarin et al., 2016).

With respect to experimental procedures relevant to participants' preparation, both participant preparation guidelines and acclimation times varied considerably across studies. Only three (16%) of the reviewed studies described the procedure used to prepare participants for the thermographic assessment (Goldstein et al., 2016a; Huberman and Chivers, 2015; Huberman et al., 2017). The protocol used in these studies asked participants to refrain from: sexual activity for 24 h before testing (Huberman and Chivers, 2015; Huberman et al., 2017); physical exercise for 1 h before testing (Huberman and Chivers, 2015; Huberman et al., 2017); using substances on the day of examination that may influence arousal (e.g., alcohol, tobacco, caffeine; Goldstein et al., 2016a; Huberman and Chivers, 2015; Huberman et al., 2017); and using any vaginal cream or lubricant within 24 h of the thermographic procedure (Goldstein et al., 2016a).

With regard to acclimation time, five (26%) of the nineteen studies did not include any information on the use of an adaptation period. Acclimation time in the remaining studies varied between 1 and 15 min (see Table 2).

3.1.3. Data collection procedures

Imaging protocols applied in the included studies were reviewed on the following variables: sampling intervals (i.e., time interval between capture of each thermographic image), participant/camera positioning (i.e., views), and selected regions of interest (ROIs). Sampling intervals ranged between 0.028 s and 5 min across studies (see Table 2).

Thermographic views of relevant anatomic areas depend on the relative positioning of participant and instrumentation, and should be defined in order to provide adequate imaging of the regions of interest. Views were standardized in the majority of the studies, with the exception of Abramson and Pearsall (1983), who had couples capture thermograms of each other. Three other studies did not provide information about camera and participant positioning (Goldstein et al., 2016b; Ng et al., 2009; Payne et al., 2007). In the initial studies conducted in the 1980s, views were defined the same way for men and women, i.e., frontal views angled at 30° at a 0.91 m distance from the participant. In more recent studies views have been defined in a slightly different manner for male and female participants in order to adjust to anatomical and physiological differences. The typical parameters of the captured views in the reviewed studies are presented in Table 3.

Concerning the selected ROIs of each study, the most commonly used ROIs for the analysis of thermal variation associated with sexual arousal were the shaft of the penis in the case of men ($n = 9$; 47% of studies investigating male samples), and the left labium majus in the case of women ($n = 8$; 42% of studies investigating female samples). A description of the ROIs utilized in the included studies is provided in Table 4.

3.2. Empirical evidence on validity and feasibility of infrared thermography

3.2.1. Discriminant validity

3.2.1.1. Sexual arousal versus other psychophysiological states. Early studies utilizing thermography found that genital temperature increases in both men and women were specific to sexual arousal

Table 1
Summary of selected studies on thermography and sexual response (sorted by year of publication).

Reference	Sample	Age	Study focus	Main findings
Seeley et al. (1980)	1 man, 1 woman	Man 28 Woman 21	Detecting heat patterns of sexual arousal consistent with Masters and Johnson's four stages of sexual response	Thermography data corroborated the expected physiological patterns across stages of sexual response
Abramson et al. (1981a)	32 men, 37 women	19–45	Assessing pelvic vasocongestion as a function of attitudes toward masturbation	Increases in genital temperature were specific to sexual stimuli, comparing to emotional stimuli and standing controls GT ≈ SSA (r = 0.71, P < .001)
Abramson et al. (1981b)	32 men, 37 women	19–45	Establishing discriminant validity of thermography measurement of sexual arousal	Increases in genital temperature were specific to sexual stimuli, compared to emotional stimuli and waiting controls GT ≈ SSA (r_{males} = 0.73, P < .001; $r_{females}$ = 0.70, P < .001)
Abramson and Pearsall (1983)	3 married men and women	Men 27–40 Women 22–35	Examining pectoral temperature over the course of the sexual response cycle	Asymmetrical increases in pectoral temperature were observed in response to sexual stimulation (i.e., masturbation to orgasm sequence) compared to a control behavior sequence
Obayashi et al. (2000)	1 man with erectile dysfunction due to organic impairment of the autonomic nervous system	34	Using thermography to assess the effect of sildenafil citrate (Viagra) to treat erectile dysfunction	Penile erection and pelvic temperature increases were detected after the administration of sildenafil citrate
Kukkonen et al. (2007)	28 men, 30 women	18–28	Assessing feasibility of current thermal imaging technology to measure sexual arousal in healthy men and women	Patterns of increased genital temperature were specific to sexual stimuli, comparing to humor and neutral stimuli Men and women did not differ in time to peak genital temperature GT ≈ SSA (r = 0.51–0.68, P < .001)
Payne et al. (2007)	20 uncircumcised and 20 age-matched circumcised men	18–45	Comparing genital and non-genital sensation as a function of sexual arousal between circumcised and uncircumcised men	Both groups showed increased penile temperature in response to sexual stimuli comparing to baseline and neutral stimuli Uncircumcised men showed lower penile temperature and larger increases in penile temperature with sexual arousal than circumcised men GT ≈ SSA ($r_{uncircumcised}$ = 0.77, P < .001; $r_{circumcised}$ = 0.82, P < .001)
Ng et al. (2009)	14 men with erectile dysfunction	NA	Examining thermography as a tool to differentiate sexual response from men with organic or psychogenic ED	Psychogenic ED subjects showed higher genital temperatures than organic ED subjects in both flaccid and erected states
Kukkonen et al. (2010)	40 men, 39 women	30–45	Extending previous findings of thermographic assessment of sexual arousal by investigating an older sample, including an anxiety control condition, and using a continuous measure of subjective sexual arousal	Temperature change was specific to the genitals and to sexual arousal condition; control conditions were neutral, humor, and anxiety Men and women did not differ in time to peak genital temperature GT ~ continuous SSA for all time periods of erotic condition ($r_{first\ 5\ min}$ = 0.26, P < .05; $r_{mid\ 5\ min}$ = 0.41, P < .001; $r_{last\ 5\ min}$ = 0.46, P < .001) GT ~ discrete SSA for two time periods of erotic condition ($r_{mid\ 5\ min}$ = 0.38, P < .001; $r_{last\ 5\ min}$ = 0.46, P < .001)
Cherner and Reissing (2013)	45 women (15 vaginismus, 15 dyspareunia, 15 healthy controls)	18–44	Comparing genital and subjective responses to sexual stimuli between women with lifelong vaginismus, lifelong dyspareunia, and healthy controls	All groups showed increased vulvar temperature in response to sexual stimuli comparing to neutral stimuli For all women GT ~ SSA (r = 0.31, P < .05)[a] For controls GT ~ SSA (r = 0.55–0.59, P < .05)[a] In women with lifelong vaginismus or dyspareunia GT and SSA were not correlated for any sexual stimuli
Sarin et al. (2014)	71 men (13 HSDD, 19 ED, 20 ED/HSDD, 19 healthy controls)	18–50	Comparing subjective and genital arousal between men with HSDD, ED, both HSDD and ED, and healthy controls	All groups showed increased genital temperature in response to sexual stimuli comparing to neutral stimuli. ED and ED/HSDD subjects showed lower temperatures than controls For controls, GT ≈ SSA for two time periods of erotic condition ($r_{first\ 5\ min}$ = 0.56, P < .05; $r_{mid\ 5\ min}$ = 0.47, P < .05) For clinical groups, GT ~ SSA (HSDD group, r's = 0.22, 0.44, 0.13, all *ns*; ED/HSDD group, r's = 0.37, 0.21, 0.20, all *ns*; ED group, r's = −0.09, −0.10, −0.04, all *ns*)
Huberman and Chivers (2015)	27 men, 28 women	Men 18–38 Women 18–49	Assessing gender specificity of sexual response in men and women with concurrent thermography and plethysmography	Temperature increase was specific to genital regions and to sexual stimuli Results of thermography, vaginal photoplethysmography, and penile plethysmography congruently indicated that men's sexual responses were gender-specific and women's responses were gender-nonspecific GT ~ PPG ($rho_{male\text{-}stimulus}$ = 0.47, P < .05; $r_{female\text{-}stimulus}$ = 0.18, *ns*) GT ≈ VPP ($rho_{male\text{-}stimulus}$ = 0.62, P < .05; $r_{female\text{-}stimulus}$ = 0.69, P = .001)
Goldstein et al. (2016b)	14 women	M = 37 ± 9	Evaluating the effect of Fiera™, a women's sexual health consumer product, on female sexual arousal	Fiera™ produced significant increases in vulvar temperatures comparing to baseline levels

(*continued on next page*)

Table 1 (*continued*)

Reference	Sample	Age	Study focus	Main findings
				GT ≈ subjective sexual desire (93% of women reported sexual desire after product use)
Goldstein et al. (2016a)	10 women	27–43	Comparing the effect of topical alprostadil (vasodilator) with over-the-counter lubricant (placebo) on female genital arousal in the absence of visual sexual stimuli	Topical alprostadil induced significant and sustained increases in genital temperatures of the vestibule, clitoris, and vulva comparing to placebo GT ≈ SSA (60% of women reported awareness of vaginal sensations after topical application)
Hodgson et al. (2016)	18 men, 15 women	$M = 28 \pm 9$	Investigating whether the interaction between mood and sexual excitation/inhibition proneness predicted subjective and genital arousal	Mood interacted with sexual excitation and inhibition to significantly predict both subjective and genital arousal in men and women; specific gender differences were reported GT ≈ SSA ($r_{men} = 0.65$; $r_{women} = 0.56$), no differences between genders
Landry et al. (2016)	20 men, 20 women	18–45	Assessing sexual response to male- and female- oriented sexually explicit films in heterosexual men and women	Both men and women demonstrated increased genital temperatures in response to sexual stimuli comparing to neutral stimuli. No significant effect of film orientation on physiologic sexual response For men GT ≈ SSA (mean r range for all sexual films = 0.61–0.81) For women GT ≈ SSA (mean r range for all sexual films = 0.55–0.65)
Sarin et al. (2016)	84 women (18 FSAD, 22 HSDD, 25 FSAD/HSDD, 19 healthy controls)	$M = 27 \pm 7$	Comparing psychosocial-physiological patterns between women with FSAD, HSDD, both FSAD and HSDD, and healthy controls	All groups showed increased GT in response to sexual stimuli comparing to neutral stimuli. Women with HSDD and FSAD/HSDD reported less SSA than controls or FSAD women For controls, GT ≈ SSA ($r = 0.66$) was significantly higher than for FSAD/HSDD group, GT ~ SSA ($r = 0.41$). For the other clinical groups, GT ~ SSA (HSDD group, $r = 0.44$; FSAD group, $r = 0.57$), no significant differences
Huberman et al. (2017)	27 men, 28 women	Men 18–38 Women 18–49	Examining the time course of genital and subjective sexual response in men and women with concurrent thermography and plethysmography	Temperature increase was specific to genital regions and to sexual stimuli Time course of changes in subjective arousal was most similar to changes in genital temperature GT ≈ SSA ($r_{men} = 0.63$; $r_{women} = 0.53$), no differences between genders PPG ≈ SSA ($r = 0.64$) significantly greater than VPP ~ SSA ($r = -0.13$) GT ~ PPG ($r = 0.48$) GT ~ VPP ($r = 0.45$)
Parada et al. (2018)	20 men, 20 women	Men 18–31 Women 19–30	Investigating the neural correlates of peripheral physiologic sexual arousal in men and women using thermography	Temperature increase was specific to genital regions and to sexual stimuli Women had significantly smaller changes in temperature than men ($M_{women} = 0.006$, $SD = 0.309$; $M_{men} = 0.271$, $SD = 1.027$, $P < .001$) An activation of a broader range of neural regions in women was found compared with men during sexual arousal

Note. ≈ = strongly correlated; ~ = correlated; ED = erectile dysfunction; FSAD = female sexual arousal disorder; GT = genital temperature; HSDD = hypoactive sexual desire disorder; min = minutes; NA = information not available/not applicable; PPG = penile plethysmography; SSA = subjective sexual arousal; VPP = vaginal photoplethysmography.

[a] In Cherner and Reissing (2013) sexual stimuli with and without depiction of penetration were used. Genital skin temperature was concordant with subjective sexual arousal only in response to sexual stimuli without penetration.

Table 2
Methodological details of the included studies on thermography and human sexual response.

Reference	Acclimation time	Environmental controls			Views and selected ROIs	Sampling interval	Return-to-baseline procedures	Technology
		Room temperature	Relative humidity	Lighting				
Seeley et al. (1980)	NA	NA	NA	Darkened room	View: frontal at 30° angle for men and women ROIs: base of the penis for men; vaginal entrance for women	1–3 min	2 resting minutes post sexual stimulation and orgasm	UTI-Spectrotherm LWIR
Abramson et al. (1981a)	1 min	NA	NA	NA	View: frontal at 30° angle and 0.91 m distance for men and women ROIs: base of the penis for men; pubic bone for women	2 min	NA	UTI-Spectrotherm LWIR
Abramson et al. (1981b)	NA	NA	NA	NA	View: frontal at 30° angle for men and women ROIs: base of the penis for men; vaginal entrance for women	NA	NA	UTI-Spectrotherm LWIRea
Abramson and Pearsall (1983)	NA	NA	NA	NA	View: not standardized[a] ROIs: pectoral region for men and women	1–5 min	2 resting minutes post sexual stimulation and orgasm	UTI-Spectrotherm LWIR
Obayashi et al. (2000)	NA	NA	NA	NA	View: frontal and lateral for men ROIs: scrotum, glans penis, and base of the penis for men	NA	NA	NA
Kukkonen et al. (2007)	15 min	Held constant between sessions (± 1 °C)	NA	NA	View: for men 30° diagonally left, 1.0 m distance, 1.09 m height; for women 20° frontal, 0.5 m distance, 1.09 m height ROIs: shaft of the penis for men; left labium majus for women; control ROI at inner right thigh for both	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)
Payne et al. (2007)	10 min	NA	NA	NA	View: NA ROIs: right side of penile shaft below the glans penis for men	0.063 s	NA	TSA ImagIR system (Seahorse Bioscience)
Ng et al. (2009)	NA	NA	NA	NA	NA	NA	NA	NA
Kukkonen et al. (2010)	15 min	Held constant between sessions (± 1 °C; $M = 22.51$)	NA	NA	View: for men 30° diagonally left, 1.0 m distance, 1.09 m height; for women 20° frontal, 0.5 m distance, 1.09 m height ROIs: shaft of the penis for men; left labium majus for women; control ROI at inner right thigh for both	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)
Cherner and Reissing (2013)	15 min	Held constant between sessions (92% of sessions ± 1 °C; $M = 24.61$)	NA	NA	View: frontal at 0.43 m distance for women ROI: left labium minus for women	1 s	NA	VarioCAM HD (InfraTec)
Sarin et al. (2014)	15 min	Held constant between sessions (± 1.5 °C; $M = 24.35$)	NA	NA	View: for men 30° diagonally left, 1.0 m distance, 1.09 m height ROIs: shaft of the penis for men; control ROI at inner right thigh	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)
Huberman and Chivers (2015)	10–15 min	Held constant between sessions ($M = 24.94$ °C)	NA	NA	View: for men 30° diagonally left, 0.55 m distance, 0.67 m height; for women 20° frontal, 0.61 m distance, 0.61 m height ROIs: shaft of the penis and glans for men; left labium majus and clitoris for women; control ROI at inner thigh for both	1 s	5–12 min film after the sexual film	Thermo Tracer TS9230 (Nippon Avionics Co.)
Goldstein et al. (2016b)	NA	NA	NA	NA	View: NA ROIs: clitoris, labia, and vestibule for women	NA	NA	Camera details NA (FLIR Systems, Inc.)
Goldstein et al. (2016a)	5 min	NA	NA	NA	View: for women diagonally above[b] ROIs: vestibule, clitoris, and vulva for women	2 min	NA	Thermos-Vision A-Series (FLIR Systems, Inc.)
Hodgson et al. (2016)	15 min	NA	NA	NA	View: for men 30° diagonally left, 1.0 m distance, 1.09 m height; for women frontal, 0.5 m distance, 1.09 m height	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)

(*continued on next page*)

Table 2 (*continued*)

Reference	Acclimation time	Environmental controls			Views and selected ROIs	Sampling interval	Return-to-baseline procedures	Technology
		Room temperature	Relative humidity	Lighting				
					ROIs: shaft of the penis for men; left labium majus for women			
Landry et al. (2016)	15 min	NA	NA	NA	View: for men 30° diagonally left, 1.0 m distance, 1.09 m height; for women 20° frontal, 0.5 m distance, 1.09 m height ROIs: shaft of the penis for men; left labium majus for women	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)
Sarin et al. (2016)	15 min	Held constant between sessions (± 1.5 °C; $M_{baseline}$ = 24.37, M_{erotic} = 24.49)	NA	NA	View: for women 20° frontal, 0.5 m distance, 1.09 m height ROIs: left labium majus (midway between the clitoris and the vaginal entrance) for women; control ROI at inner right thigh	0.125 s	NA	TSA ImagIR system (Seahorse Bioscience)
Huberman et al. (2017)	10–15 min	NA	NA	NA	View: for men 30° diagonally left, 0.55 m distance, 0.67 m height; for women 20° frontal, 0.61 m distance, 0.61 m height ROIs: shaft of the penis and glans for men; left labium majus and clitoris for women	1 s	5–12 min nonsexual film after the sexual film, with a 2 min interval between them	Thermo Tracer TS9230 (Nippon Avionics Co.)
Parada et al. (2018)	10 min	NA	NA	NA	View: for men 45° downward, ± 5.5 m distance from the MRI magnet, 3.0 m height; for women frontal, ± 5.5 m distance from the MRI magnet, 1.0 m height ROIs: midway along the shaft and tip of the penis for men; midway on the right labium majus and external clitoral glans for women; control ROI at inner right thigh	0.028 s	NA	Flir T450sc Camera (FLIR Systems, Inc.)

Note. °C = degrees Celsius; m = meters; NA = information not available/not applicable; ROI = region of interest.

[a] Distance, height, and angle parameters of views not standardized in this study since thermograms were captured by participants themselves.

[b] Distance, height, and angle parameters of captured views not available in the manuscript. For visualization of the camera positioning please see accompanying image in Goldstein et al. (2016a).

Table 3
Parameters used for thermographic views in male and female samples.

View parameters	Men	Women
Distance	0.55 m – 5.5 m	0.43 m – 5.5 m
Height	0.67 m – 3.0 m	0.61 m – 1.09 m
Angle	30° diagonally left	20° frontal

Table 4
Regions of interest (ROIs) used for the assessment of sexual response using infrared thermography.

ROIs	Men		ROIs	Women	
	# of studies	% of studies		# of studies	% of studies
Shaft of the penis	9	47	Left labium majus	8	42
Inner right thigh[a]	6	32	Clitoris	4	21
Base of the penis	4	21	Inner right thigh[a]	5	26
Glans of the penis	3	16	Vaginal entrance	2	11
Scrotum	1	5	Vestibule	2	11
			Labia (non-specified)	1	5
			Pubic bone	1	5
			Right labium majus	1	5
			Vulva	1	5

Notes. ROIs arranged according to frequency of use. Relative values calculated according to the total number of studies investigating male ($N = 13$) or female samples ($N = 14$). Excluded from the analysis were Ng et al. (2009) due to absence of information regarding ROIs, and Abramson and Pearsall (1983) due to using an extra-genital ROI, i.e. pectoral region, only.
[a] Control ROI.

(e.g., Abramson et al., 1981a; Seeley et al., 1980). Almost three decades later, recent studies applying more current-day thermographic technology to the measurement of sexual response provided additional support for the discriminant validity of thermography as a measurement of sexual arousal. The skin temperature increase recorded by thermography was again found to be specific to genital regions since there were no significant changes in the non-genital control areas, i.e., the thigh (e.g., Huberman and Chivers, 2015; Kukkonen et al., 2007, 2010). Thermal imaging has also demonstrated to clearly differentiate between sexual arousal and control conditions (neutral, humor, and anxiety control conditions; e.g., Huberman and Chivers, 2015; Landry et al., 2016). Studies using both positive (humor) and anxiety control groups (e.g., Kukkonen et al., 2010) provided additional discriminant validity for genital temperature as a measure of sexual arousal and were in line with previous research using such control groups while using other psychophysiological measures (Both et al., 2003; Kukkonen et al., 2007; Laan et al., 1995; Prause et al., 2005).

3.2.1.2. Clinical versus sexually healthy groups. Genital thermography has also been used to compare sexually healthy participants with men and women with sexual difficulties. Cherner and Reissing (2013) found that women with lifelong vaginismus exhibited physiological sexual responses similar to comparison groups of women with lifelong dyspareunia and women who reported pain-free intercourse, also during the presentation of erotic films that depicted penile-vaginal penetration. For women with lifelong vaginismus or dyspareunia, genital temperature and subjective sexual arousal were not significantly correlated, whereas for women with pain-free intercourse these two measures were highly and positively correlated ($r = 0.55–0.59$, $P < .05$). In a different study, Sarin et al. (2016) compared the psychophysiological patterns of women with female sexual arousal disorder (FSAD), with hypoactive sexual desire disorder (HSDD), with both FSDA/HSDD, and healthy controls. An increase in genital temperature in response to sexual stimulus for all groups of women was reported, with no significant differences between groups. However, the association between genital temperature and subjective sexual arousal was significantly different across groups, in such a way that it was significantly stronger in healthy controls compared to women with FSAD/HSDD (see Table 1).

In men, Sarin et al. (2014) used IRT to assess sexual response in subjects with hypoactive sexual desire disorder (HSDD), erectile dysfunction (ED), or a combination of both ED and HSDD, and they compared them to a group of men without sexual problems. Genital temperature increased for all groups during erotic stimuli, but men with ED and combined ED/HSDD showed a smaller change in genital temperature than men in the control group. Pairing thermal data with subjective ratings of arousal revealed that physiological and subjective arousal were highly correlated for controls but less strongly so for clinical groups; among the clinical groups, men with ED showed the lowest agreement between subjective and genital arousal. Two other studies investigated sexual response patterns in men with ED using IRT and both replicated the previous finding of increased genital temperature associated with erectile response (Ng et al., 2009; Obayashi et al., 2000; see Table 1).

3.2.2. Convergent validity

The association between IRT and other sexual response instruments has been investigated. Studies conducted by Huberman and Chivers (2015) and Huberman et al. (2017) used concurrent thermography and plethysmography measures and provided support for the convergent validity of IRT. In both studies, the association between the different measures, i.e., IRT and vaginal photoplethysmography (VPP)/penile plethysmography (PPG), was evaluated and results indicated a significant and positive association between them. Huberman and Chivers (2015) found stronger associations between IRT and VPP ($rho_{male\text{-}stimulus} = 0.62$, $P < .05$; $r_{female\text{-}stimulus} = 0.69$, $P = .001$) than between IRT and PPG ($rho_{male\text{-}stimulus} = 0.47$, $P < .05$; $r_{female\text{-}stimulus} = 0.18$, *ns*).[1] Using the same sample from Huberman and Chivers' (2015), Huberman et al. (2017) also found an association between measures, in such a way that IRT was positively correlated with both PPG ($r = 0.48$) and VPP ($r = 0.45$). In both studies, time to peak response was significantly shorter when genital responses were assessed with VPP ($M = 22.5$ s, $SD = 21.2$, Huberman and Chivers, 2015; $M = 20.8$ s, $SD = 20.0$, Huberman et al., 2017) as compared to IRT ($M = 441.6$ s, $SD = 149.8$, Huberman and Chivers, 2015; $M = 440.9$ s, $SD = 121.6$, Huberman et al., 2017), and with PPG ($M = 222.1$ s, $SD = 196.7$, Huberman and Chivers, 2015; $M = 228.7$ s, $SD = 198.1$, Huberman et al., 2017) as compared to IRT ($M = 350.2$ s, $SD = 169.8$, Huberman and Chivers, 2015; $M = 379.0$ s, $SD = 173.2$, Huberman et al., 2017).

3.2.3. Concurrent validity

Early studies utilizing thermography found that genital temperature increases in both men and women highly correlate with self-reports (e.g., Abramson et al., 1981b). In recent studies, discrete and continuous ratings of subjective sexual arousal have also been shown to increase during the erotic condition and to be significantly and positively correlated with genital temperature for both male and female participants, providing further support for the convergent validity of

[1] In Huberman and Chivers (2015), Pearson correlations (*r*) were used for analyses including normally distributed variables while Spearman correlations (*rho*) were used for analyses including at least one skewed variable. Of note that, for the female sexual stimulus, men's peak responses (not relative to baseline) with IRT and PPG were strongly, significantly correlated, $r = 0.57$, $p = .003$.

genital temperature as a measure of sexual arousal (e.g., Hodgson et al., 2016; Kukkonen et al., 2007, 2010[2]; Sarin et al., 2014, 2016). Furthermore, it has been demonstrated that the time course of changes in subjective arousal follows more closely the time course of changes in genital temperature than that of changes in penile circumference/VPA (Huberman et al., 2017).

3.2.4. Other considerations

3.2.4.1. Gender differences. Differences between men and women have been found regarding the patterns of genital temperature change in response to erotic stimuli. Men's baseline genital temperatures were found to be lower than women's and to show greater increases than women's during the erotic film (Kukkonen et al., 2010; Landry et al., 2016; Parada et al., 2018). Some studies reported similar patterns of temperature change during the erotic clips between men and women, with no significant differences in the time necessary to reach peak temperature (men took approximately 11 min and women took approximately 12 min), suggesting similarity in the pattern of sexual response between the sexes (Kukkonen et al., 2007, 2010). However, other studies demonstrated that men reached peak genital temperature more quickly (after approximately 6 min) than women (after approximately 7 min; Huberman and Chivers, 2015; Huberman et al., 2017). Possible explanatory factors for these differences are considered in the discussion. Huberman and Chivers (2015) also found that the gender difference in gender specificity of arousal seems robust to methodology, since data from IRT, VPP, PPG, and self-report measures all congruently indicated that men's sexual responses were gender-specific and women's responses were gender-nonspecific. Additional gender differences reported in the reviewed studies include genital temperature and subjective sexual arousal being significant and positive time-varying covariates for men but not women (i.e., in the case of men only, changes in genital temperature significantly and positively predicted changes in subjective sexual arousal and vice-versa; Hodgson et al., 2016).

3.2.4.2. Return-to-baseline. Another topic that is yet not sufficiently established is the return-to-baseline (RTB) of sexual response assessed through IRT. Of all the reviewed papers, only four (21%) used procedures to assess RTB of IRT within the context of their studies (Abramson and Pearsall, 1983; Huberman and Chivers, 2015; Huberman et al., 2017; Seeley et al., 1980). Across these studies, a variable period of either no stimulation (2 min in Abramson and Pearsall, 1983 and Seeley et al., 1980) or nonsexual stimulation (5–12 min in Huberman and Chivers, 2015 and Huberman et al., 2017)[3] was utilized to assess decreases in the physiological pattern of sexual response after the sexual stimulus is withdrawn. It has been found that all or almost all participants returned to approximately their baseline level of sexual arousal with IRT (i.e., during the RTB period they were within 5% of their baseline genital temperature; Huberman and Chivers, 2015; Huberman et al., 2017). No differences were found in time to return to baseline across measures (VPA/PPG and self-reported sexual arousal) or genders (Huberman and Chivers, 2015; Huberman et al., 2017). However, Huberman et al. (2017) noted that most participants did not reach a 5% increase in genital temperature during the sexual stimuli, indicating that this criterion may not capture a true return to baseline; instead, their findings suggest that baseline plus 2% in women and 2.5% in men may be more appropriate criteria.

3.2.4.3. Menstrual cycle variability. Of the included studies assessing women, eight of them (53%) controlled for menstrual cycle effects and only included women who reported regular menstrual cycles (Cherner and Reissing, 2013; Goldstein et al., 2016a; Hodgson et al., 2016; Huberman and Chivers, 2015; Kukkonen et al., 2007, 2010; Parada et al., 2018; Sarin et al., 2016), and seven of these tested naturally cycling women in their follicular phase (within the first 12 days of their menstrual cycle), whereas participants using oral hormonal contraception were tested any day that they were taking hormone pills (Cherner and Reissing, 2013[4]; Hodgson et al., 2016; Huberman and Chivers, 2015; Kukkonen et al., 2007, 2010; Parada et al., 2018; Sarin et al., 2016).

3.2.4.4. Penile circumcision. To date, only one study has investigated the effect of penile circumcision on penile temperature. In this study, genital and nongenital sensations were compared between circumcised and uncircumcised men, while assessing sexual arousal via thermal imaging of the penis (Payne et al., 2007). In response to erotic stimuli, both groups evidenced a significant increase in penile temperature, which correlated highly with subjective reports of sexual arousal ($r_{uncircumcised} = 0.77$, $P < .001$; $r_{circumcised} = 0.82$, $P < .001$). Uncircumcised men had significantly lower baseline penile temperature than circumcised men and evidenced a larger increase in penile temperature with sexual arousal. No differences in genital sensitivity were found between the uncircumcised and circumcised groups.

4. Discussion and future directions

Infrared Thermography is a remote and safe technique that permits the acquisition and analysis of the temperature of large areas of the body's skin surface. Although the application of IRT to the field of sex research has been expanding since the 1980s, a number of important questions about its use still remain to be answered. The critical assessment of the included studies represents an attempt to comprehensively summarize the procedures and evidence available so far, as well as to identify important caveats in the literature.

Studies utilizing IRT as a physiological measure of sexual arousal have provided us with promising results regarding the feasibility and validity of this technique. Our review has shown that IRT is able to detect patterns of temperature increase in men and women that are specific to sexual stimuli and to genital (versus nongenital) regions, indicating a strong discriminant validity. IRT successfully identified and differentiated between patterns of physiological sexual arousal resulting from neutral, anxiety, and positive affect (humor) stimuli in both men and women (e.g., Kukkonen et al., 2007, 2010).

The use of IRT allows for the comparison of sexual arousal patterns in men and women on the same, absolute scale (temperature), but the findings of studies directly comparing men and women have been complex and, at times, contradictory. Some studies have found patterns of skin temperature change in response to sexual stimuli that were the same for men and women, with no significant differences in the time it took them to reach peak genital temperature (Kukkonen et al., 2007, 2010). In contrast, other studies found differences in the physiological pattern of sexual arousal between men and women, in that men reached peak genital temperatures more quickly than women (Huberman and Chivers, 2015; Huberman et al., 2017). It should be of note that, across studies, men demonstrated greater changes in genital temperature during the erotic condition than women (Huberman and Chivers, 2015;

[2] For men and women, a significant association between genital temperature and the continuous report of subjective sexual arousal was found for all time periods of the sexual clip. However, the association between genital temperature and the discrete report of subjective sexual arousal was only significant for the mid and last 5 min of the erotic clip (Kukkonen et al., 2010).

[3] In these studies, the duration of RTB audiovisual stimuli for each participant varied according to the amount of time required for genital temperature to return to baseline; this duration did not significantly differ between men and women ($M = 7.05$, $SD = 2.08$).

[4] In Cherner and Reissing (2013)'s study, all women were tested within the follicular phase, with the exception of women who used continuous hormonal contraception who were tested any day.

Kukkonen et al., 2007, 2010; Landry et al., 2016; Parada et al., 2018). It may be argued that this difference may be accounted for by the anatomical differences in genital structure rather than by higher levels of arousal, since previous studies have mainly used dissimilar anatomical ROIs across sexes (i.e., penile shaft and labia majora). The dorsal artery of the penis, which runs through the penile shaft, is likely to experience greater blood flow changes than the smaller capillaries located throughout the labia, which could explain the greater increase in temperature observed in men (Tortora and Derrickson, 2012). Another possible explanation for the reported gender differences may be related to the erotic stimuli used in these studies. Whereas Kukkonen et al. (2007, 2010) used 15-min clips depicting diverse coupled sexual activities, Huberman and Chivers (2015) used 10-min sequences of five 2-min excerpts of men or women masturbating. Futures studies should explore the impact of stimulus intensity and duration on various aspects (including latency to maximum) of genital temperature in more depth.

Regarding the age span of participants, studies conducted until now have examined relatively young, and when it comes to women premenopausal, samples, with a maximum age of 50 years. When examining samples of older healthy participants (ranging from 30 to 45 years-old), the magnitude of temperature changes associated with sexual arousal was lower than in younger samples (Kukkonen et al., 2010). Although other factors may have played a role, this points at the possibility that age differences could have contributed to the observed changes in physiological functioning, especially considering the finding that subjective sexual arousal reported by both age groups did not differ (Kukkonen et al., 2007, 2010).

IRT has demonstrated strong concurrent validity as a measurement of sexual arousal. Across studies, IRT data have consistently shown strong correlations with subjective sexual arousal, both as measured continuously and discretely (e.g., Abramson et al., 1981b; Kukkonen et al., 2010; Payne et al., 2007; Sarin et al., 2014). Also, the time course of changes in subjective arousal has been found to be more similar to the time course of changes in genital temperature than to that of changes in VPA and penile circumference (Huberman et al., 2017), although possible explanations for this effect are still to be explored.

With respect to convergent validity, studies indicate that genital temperature changes consistently correlate with other sexual psychophysiological measures of genital response, such as VPA and penile circumference (Huberman and Chivers, 2015; Huberman et al., 2017). However, in one study IRT and PPG were weakly correlated for men's preferred sexual stimuli (Huberman and Chivers, 2015). Considering that penile circumference is one of the most well-established measures used in sex research in respect to validity and underlying physiology, reasons for such a low correlation between PPG and IRT still need to be identified. One such reason may relate to the indicator used to compare measures across studies. It is worth noting that, in Huberman and Chivers' (2015) study, the relationship between IRT and PPG was weak when maximal responses in the two measures were computed relative to baseline, but when men's peak responses (i.e., maximal responding) were examined alone, a stronger correlation between IRT and PPG was found for men's preferred sexual stimuli. Thus, an important factor to consider when assessing convergent validity of IRT should be the dependent variable used for such comparisons. Since genital temperature changes relatively slowly (Henson and Rubin, 1978; Payne and Binik, 2006), mean temperature may be a less sensitive measure and less optimal for comparison with VPP/PPG, which change more quickly. Maximal responding, on the other hand, may be particularly relevant for this purpose, although the consideration of underlying physiological mechanisms is still scarce and should prove relevant to inform this discussion. Even though findings support a high convergent validity of IRT, the correlations between IRT and the most traditional sexual psychophysiological measures, while high in many cases, do indicate that a substantial part of the variance is not shared. This raises important questions about the role and importance of ROI selection, of potential variations in the association among ROIs, of differences between intra-vaginal and surface skin-related changes in blood flow, and of a possible, relative disconnection between changes in volume and temperature (e.g., of the penis, of the labia/glans clitoris).

Authors have also suggested that the different genital measures may assess different aspects or phases of sexual response (i.e., earlier versus later responses) based on the finding that time to peak response was shorter with VPP/PPG than with IRT (Huberman and Chivers, 2015). However, whether and how these differences reflect underlying functional physiological changes is still unknown. As in other parts of the body, it is possible that time delays exist in changes in vascular processes and genital temperature (Caton et al., 1988; Johnson et al., 2014; Johnson et al., 1974). Regarding changes in temperature of genital skin, we are still lacking a gold standard to define what represents *early* versus *later* phases of sexual response. If it is the case that VPA assesses initial changes in blood flow before genital skin temperature changes occur, then it could be argued that VPA captures a fuller range of genital response, but includes changes a participant may not yet perceive, which could partly explain the stronger connection between changes in genital temperature and subjective arousal. At the same time, some studies using the labial thermistor have shown that temperature may be slower to return to baseline than other genital measures, although this result is not consistent across studies (Payne and Binik, 2006; Prause and Heiman, 2009). With IRT specifically, no differences in time to return to baseline across measures or genders have been found (Huberman and Chivers, 2015; Huberman et al., 2017), although only a minority of studies has examined this. At the time being, we are still lacking definite answers to questions such as whether similar numeric changes in temperature are equivalent in men and women or even in different age groups, how long genital temperature takes to return to baseline after the cessation of a sexual stimulus, or how reliable it is between different testing sessions. The examination of these questions is recommended as they would enhance the feasibility of multimethod approaches to understanding human sexual arousal. Overall, sufficient evidence exists to propose that genital skin temperature oscillations coexist with genital blood flow oscillations, and that there is a consistent correlation between them. Yet, the reasons for the delay between genital blood flow/vascular diameter and temperature oscillations are, still, far from being fully understood and warrant further research.

When it comes to its use in clinical populations, thermography has been found to successfully differentiate between men with low sexual desire and men with sexual arousal disorders (Sarin et al., 2014). IRT has also shown the potential to differentiate between organic and psychogenic ED (Ng et al., 2009). This is consistent with findings in men using other measures, including penile circumference (e.g., Abrahamson et al., 1985; Sakheim et al., 1987). When assessing female samples, an increased vulvar temperature of the clinical groups was found with IRT in response to the erotic films, which is consistent with the majority of studies on the physiological response of women with dyspareunia (Brauer et al., 2006; Brauer et al., 2009; Brauer et al., 2007; Payne et al., 2007). Additionally, physiological (i.e., thermal) and subjective arousal have shown to be less strongly correlated in clinical groups than in controls (Cherner and Reissing, 2013; Sarin et al., 2014). These findings are also in line with studies using other measures of sexual response in clinical groups (e.g., Abrahamson et al., 1985; Brauer et al., 2007; McCall and Meston, 2007).

Regarding the criteria used for the inclusion or exclusion of participants, a discrepancy is noted across the reviewed studies. In earlier studies, selection criteria were not described and information about participants was limited to age, gender, and, in one study, parity. The more recent studies, however, do describe inclusion and exclusion criteria, the most frequently used being common to other sexual psychophysiology studies (e.g., current use of medication that interferes with sexual response, major medical or psychiatric illnesses, no previous intercourse experience, irregular menstrual cycles in case of women). However, specific criteria with the potential to interfere with the thermographic measurement are largely disregarded in most reviewed studies.

The experimental procedures, including those relevant to the preparation of participants, have also developed and become more rigorous over the years. This includes instructions given to the participant, both before and during the examination, as well as the incorporation of an acclimation period, which precedes the actual thermal assessment (Ring, 1976; Roberts and Goodman, 1987; Mabuchi et al., 1995). Participant acclimation is a critical step, as enough time must be allowed for the subject's body to adjust to the ambient conditions of the laboratory and to reach a physiologic state of thermodynamic equilibrium (Ammer, 2008; Ammer and Ring, 2012; Ring and Ammer, 2015; Schwartz et al., 2006).

A marked heterogeneity was found in methodological detail and approach across studies. The standard procedures for thermographic imaging recommend that a stable ambient temperature must be maintained across sessions; that the humidity should be controlled to avoid air moisture build up on the skin, perspiration, or vapor levels that can interact with radiant infrared energy; that the impact of air conditioning systems is minimized, and that standard fluorescent, instead of incandescent, lighting is used (Jones and Plassmann, 2002; Ring et al., 2009). Since the majority of studies failed to provide a description of important environmental controls, more detail and greater clarity in the presentation and description of important environmental controls is advised for future research. More specifically, it is advised that incident lightning to the thermographed area should be avoided in future studies to prevent undesired thermal radiation and consequent measurement errors. This is justified by the implications of any source of lightning (such as solar radiation of an incident light) including undesired thermal reflections. Since the human body is not a flat surface, it is more susceptible of having thermal reflections, which would generate wrong measurements (Vardasca et al., 2017; Vollmer and Klaus-Peter, 2017; Ring and Ammer, 2015). Therefore, it is better to avoid the lighting effect than to keep it constant, since there is no assurance of constant lightning, the power source is based in phase and it has oscillations, and in the case the experimental room is exposed to solar light, outside natural solar light is also variable from time to time.

The guidelines established (Ammer, 2008; Ammer and Ring, 2012; Ring and Ammer, 2015) also recommend a detailed preparation of the participant prior to thermal examination as to decrease the possibility of artifacts and to increase the accuracy of the results. Only three (16%) of the reviewed studies described the procedures used to prepare participants for thermographic assessment; for the remaining studies, it is unknown whether these principles were taken into account and not described, or whether they were not taken into consideration to begin with. In addition, the duration of the adaptation or acclimation period varied considerably across studies (between 1 and 15 min), while a minimum equilibration period of 15 min is advised (Mabuchi et al., 1995; Ring, 1976; Roberts and Goodman, 1987).

Beyond the importance and potential impact of subject preparation and acclimation, more research is needed on variables that might potentially interfere with accurate genital thermographic assessments. For example, whereas there is initial evidence on the impact of circumcision on thermographic measurement in men, it is as yet unknown what the influence is, in both men and women, of the presence of pubic hair. Also, temperature patterns and response levels may be affected by the menstrual cycle in women. Menstrual cycle effects have been reported for labial temperature change recorded during the follicular and luteal phases of the menstrual cycle (Slob et al., 1991; Slob et al., 1996). The effect of cycle variability on temperature responses and on concordance of thermal and subjective measures among female participants is, however, largely ignored across studies. Genital jewelry is another factor that has been absent from the discussions. Further research assessing its possible effects on thermographic measurement would be beneficial for determining whether this should be an exclusion criterion (cf. Ammer, 2008; Ammer and Ring, 2012; Ring and Ammer, 2015).

The studies included in this review differed in the selected regions of interest. Most commonly used ROIs were the shaft of the penis in the case of men (47% of studies) and the left labium majus in the case of women (42% of studies). Still, even in studies using the same ROI, heterogeneity existed in the level of anatomical specificity. For instance, in one study the selected ROI was the shaft of the penis, near the base (Huberman and Chivers, 2015). In another study, however, thermal variation was measured midway along the shaft (Sarin et al., 2014). It is recommended that future studies select ROIs that take into consideration specific anatomical and physiological variables, which may influence temperature (e.g., vascularization, dermatomes, angiosomes), and that use and compare a larger number of ROIs. Also, more detailed information on ROIs could be presented. For example, none of the reviewed studies included a graphical depiction or example picture of the selected ROIs.

Overall, a wide array of questions remains to be explored, such as what are the best ROIs and what factors should be taken into consideration in their selection, what is the validity and relevance of each ROI in reference to each other, and what do potential variations in the association among ROIs say about this method, about sexual response, and about its underlying physiology. Additional research efforts are needed to consider reliable comparisons among men and women, in terms of ROI selection, differences in size, anatomy, and physiology.

IRT is a remote sensing technique since it does not require genital contact or insertion, which is an important advantage over other sexual response measurement instruments. The level of discomfort and distraction associated with IRT as well as with VPP/PPG has been explored (Huberman and Chivers, 2015) and findings indicate that, overall, all measures were considered comfortable but may be slightly distracting. Still, the impact of the presence of a camera on sexual response patterns remains to be established.

The marked discrepancy in methodological procedures across studies calls for a more detailed description, justification, and discussion of the methodology guidelines and procedures used in previous and to be used in future studies. Nevertheless, the results of the present review indicate that the application of IRT to sexual psychophysiology has proven to be valuable and informative, with convincing evidence concerning its feasibility and validity.

Acknowledgements

This work was supported by grants from the Portuguese Foundation for Science and Technology (FCT) and the COMPETE 2020 program (CPUP UID/PSI/00050/2013, POCI-01-0145-FEDER-0072). IT is supported by a grant from FCT (SFRH/BD/131808/2017).Declarations of interest

None.

References

Abrahamson, D.J., Barlow, D.H., Beck, J.G., Athanasiou, R., 1985. Effects of distraction on sexual responding in functional and dysfunctional men. Behav. Ther. 16, 503–515. https://doi.org/10.1016/S0005-7894(85)80028-9.

Abramson, P.R., Pearsall, E.H., 1983. Pectoral changes during the sexual response cycle: a thermographic analysis. Arch. Sex. Behav. 12, 357–368.

Abramson, P.R., Perry, L.B., Rothblatt, A., Seeley, T., Seeley, D.M., 1981a. Negative attitudes toward masturbation and pelvic vasocongestion: a thermographic analysis. J. Res. Pers. 15, 497–509. https://doi.org/10.1016/0092-6566(81)90046-5.

Abramson, P.R., Perry, L.B., Seeley, T.T., Seeley, D.M., Rothblatt, A.B., 1981b. Thermographic measurement of sexual arousal: a discriminant validity analysis. Arch. Sex. Behav. 10 (2), 171–176.

Ammer, K., 2008. The Glamorgan Protocol for recording and evaluation of thermal images of the human body. Thermol. Int. 18, 125–144.

Ammer, K., Ring, E.F.J., 2012. Standard procedures for infrared imaging in medicine. In: Diakides, M., Bronzino, J.D., Peterson, D.R. (Eds.), Medical infrared imaging: principles and practices. CRC Press, Taylor & Francis Group (chapter 32).

Bacon, M., 1976. Thermography – explanation and description. Thermograph. Q. 1, 8.

Bancroft, J.H.J., Jones, H.G., Pullan, B.R., 1966. A simple transducer for measuring penile erection, with comments on its use in the treatment of sexual disorders. Behav. Res. Ther. 4, 239–241.

Barlow, D.H., 1986. Causes of sexual dysfunction: the role of anxiety and cognitive interference. J. Consult. Clin. Psychol. 54, 140–148.
Barlow, D.H., Becker, R., Leitenberg, H., Agras, W.S., 1970. A mechanical strain gauge for recording penile circumference change. J. Appl. Behav. Anal. 3, 73–76.
Beck, J.G., Baldwin, L.E., 1994. Instructional control of female sexual responding. Arch. Sex. Behav. 23 (6), 665–684.
Beck, J.G., Barlow, D.H., Sakheim, D.K., 1983. The effects of attentional focus and partner arousal on sexual responding in functional and dysfunctional men. Behav. Res. Ther. 21, 1–8. https://doi.org/10.1016/0005-7967(83)90120-1.
Bohlen, J.G., Held, J.P., 1979. An anal probe for monitoring vascular and muscular events during sexual response. Psychophysiology 16, 318–323. https://doi.org/10.1111/j.1469-8986.1979.tb02998.x.
Bohlen, J.G., Held, J.P., Sanderson, M.O., 1980. The male orgasm: pelvic contractions measured by anal probe. Arch. Sex. Behav. 9, 503–521. https://doi.org/10.1007/BF01542155.
Bohlen, J.G., Held, J.P., Sanderson, M.O., Ahlgren, A., 1982. The female orgasm: pelvic contractions. Arch. Sex. Behav. 11 (5), 367–386. https://doi.org/10.1007/BF01541570.
Both, S., Everaerd, W., Laan, E., 2003. Modulation of spinal reflexes by aversive and sexually appetitive stimuli. Psychophysiology 40, 174–183. https://doi.org/10.1111/1469-8986.00019.
Bradley, W.E., Timm, G.W., Gallagher, J.M., Johnson, B.K., 1985. New method for continuous measurement of nocturnal penile tumescence and rigidity. Urology 26 (1), 4–9.
Brauer, M., Laan, E., ter Kuile, M.M., 2006. Sexual arousal in women with superficial dyspareunia. Arch. Sex. Behav. 35, 191–200. https://doi.org/10.1007/s10508-008-9371-8.
Brauer, M., ter Kuile, M.M., Janssen, S.A., Laan, E., 2007. The effect of pain-related fear on sexual arousal in women with superficial dyspareunia. Eur. J. Pain 11, 788–798. https://doi.org/10.1016/j.ejpain.2006.12.006.
Brauer, M., ter Kuile, M.M., Laan, E., 2009. Effects of appraisal of sexual stimuli on sexual arousal in women with and without superficial dyspareunia. Arch. Sex. Behav. 38, 476–485. https://doi.org/10.1007/s10508-008-9371-8.
Buisson, O., Foldes, P., Paniel, B.J., 2008. Sonography of the clitoris. J. Sex. Med. 5 (2), 413–417. https://doi.org/10.1111/j.1743-6109.2007.00699.x.
Carmichael, M.S., Warburton, V.L., Dixen, J., Davidson, J.M., 1994. Relationships among cardiovascular, muscular, and oxytocin responses during human sexual activity. Arch. Sex. Behav. 23, 59–79. https://doi.org/10.1007/BF01541618.
Caton, J.R., Mole, P.A., Adams, W.C., Heustis, D.S., 1988. Body composition analysis by bioelectrical impedance: effect of skin temperature. Med. Sci. Sports Exerc. 20, 489–491. https://doi.org/10.1152/jappl.1996.81.2.838.
Cherner, R., Reissing, E., 2013. A psychophysiological investigation of sexual arousal in women with lifelong vaginismus. J. Sex. Med. 10 (5), 1291–1303. https://doi.org/10.1111/jsm.12102.
Di Carlo, A., 1994. Thermography in patients with systemic sclerosis. Thermology 4, 18–24 (Österreich).
Freund, K., 1963. A laboratory method for diagnosing predominance of homo- or hetero-erotic interest in male. Behav. Res. Ther. 1, 85–93. https://doi.org/10.1016/0005-7967(63)90012-3.
Foldes, P., Buisson, O., 2009. The clitoral complex: a dynamic sonographic study. J. Sex. Med. 6 (5), 1223–1231. https://doi.org/10.1111/j.1743-6109.2009.01231.x.
Geer, J.H., Janssen, E., 2000. The sexual response system. In: Cacioppo, J.T., Tassinary, L.G., Berntson, G. (Eds.), Handbook of Psychophysiology. Cambridge University Press, New York, N. Y., pp. 315–341.
Geer, J.H., Lapour, K.J., Jackson, S.R., 1993. The information processing approach to human sexuality. In: Birbaumer, N., Ohman, A. (Eds.), The Structure of Emotion: Psychophysiological, Cognitive, and Clinical Aspects. Hogrefe & Huber Publishers, Kirkland, W. A, pp. 139–155.
Gerritsen, J., Van Der Made, F., Bloemers, J., Van Ham, D., Kleiverda, G., Everaerd, W., Olivier, B., Levin, R., Tuiten, A., 2009. The clitoral photoplethysmograph: a new way of assessing genital arousal in women. J. Sex. Med. 6 (6), 1678–1687. https://doi.org/10.1111/j.1743-6109.2009.01228.x.
Goldstein, S.W., Gonzalez, J.R., Gagnon, C., Goldstein, I., 2016a. Peripheral female genital arousal as assessed by thermography following topical genital application of alprostadil vs placebo arousal gel: a proof-of-principle study without visual sexual stimulation. Sex. Med. 4, e166–e175. https://doi.org/10.1016/j.esxm.2016.03.026.
Goldstein, S., Goldstein, I., Millheiser, L., 2016b. The impact of Fiera™, a women's sexual health consumer product, on premenopausal genital engorgement as measured by thermography: a proof of concept study. J. Sex. Med. 13, S249–S250. https://doi.org/10.1016/j.jsxm.2016.04.024.
Henson, D.E., Rubin, H.B., 1978. A comparison of two objective measures of sexual arousal of women. Behav. Res. Ther. 16 (3), 143–151.
Henson, D., Rubin, H., Henson, C., Williams, J.R., 1977. Temperature change of the labia minora as an objective measure of female eroticism. J. Behav. Ther. Exp. Psychiatry 8, 401–410. https://doi.org/10.1016/0005-7916(77)90011-8.
Hodgson, B., Kukkonen, T.M., Binik, Y.M., Carrier, S., 2016. Using the Dual Control Model to Investigate the Relationship Between Mood, Genital, and Self-Reported Sexual Arousal in Men and Women. J. Sex Res. 53 (8), 979–993. https://doi.org/10.1080/00224499.2015.1110107.
Huberman, J.S., Chivers, M.L., 2015. Examining gender specificity of sexual response with concurrent thermography and plethysmography. Psychophysiology 52, 1382–1395. https://doi.org/10.1111/psyp.12466.
Huberman, J., Dawson, S., Chivers, M., 2017. Examining the time course of genital and subjective sexual responses in women and men with concurrent plethysmography and thermography. Biol. Psychol. https://doi.org/10.1016/j.biopsycho.2017.09.006.
Ishigaki, T., Ikeda, M., Asai, H., Sakuma, S., 1989. Forehead-back thermal ratio for the interpretation of infrared imaging of spinal cord lesions and other neurological disorders. Thermology 3, 101–107.
Issing, K., Hensel, H., 1982. Temperaturempfindung und thermischer Komfort bei statischen Temperaturreizen. Z. Phys. Med. Baln Med. Klim 11, 354–365.
Janssen, E., 2001. Psychophysiological measurement of sexual arousal. In: Weiderman, M.W., Whitley, B.E. (Eds.), Handbook for Conducting Research on Human Sexuality. Lawrence Erlbaum Associates, Mahwah, N. J, pp. 131–171.
Janssen, E., Everaerd, W., Spiering, M., Janssen, J., 2000. Automatic processes and the appraisal of sexual stimuli: toward an information processing model of sexual arousal. J. Sex Res. 37, 8–23. https://doi.org/10.1080/00224490009552016.
Johnson, J.M., Rowell, L.B., Brengelmann, G.L., 1974. Modification of the skin blood flow-body temperature relationship by upright exercise. J. Appl. Physiol. 37, 880–886. https://doi.org/10.1152/jappl.1974.37.6.880.
Johnson, J.M., Minson, C.T., Kellogg, D.L., 2014. Cutaneous vasodilator and vasoconstrictor mechanisms in temperature regulation. Compr. Physiol. 4, 33–89. https://doi.org/10.1002/cphy.c130015.
Jones, B., 1998. A reappraisal of the use of infrared thermal image analysis in medicine. IEEE Trans. Med. Imaging 17, 1019–1027. https://doi.org/10.1109/42.746635.
Jones, B.F., Plassmann, P., 2002. Digital infrared thermal imaging of human skin. IEEE Eng. Med. Biol. Mag. 21, 41–48.
Kukkonen, T.M., 2015. Devices and Methods to Measure Female Sexual Arousal. Sex. Med. Rev. 3 (4), 225–244. https://doi.org/10.1002/smrj.58.
Kukkonen, T.M., Paterson, L., Binik, Y.M., Amsel, R., Bouvier, F., Khalifé, S., 2006. Convergent and discriminant validity of clitoral color doppler ultrasonography as a measure of female sexual arousal. J. Sex Marital Ther. 32, 281–287. https://doi.org/10.1080/00926230600666220.
Kukkonen, T.M., Binik, Y.M., Amsel, R., Carrier, S., 2007. Thermography as a physiological measure of sexual arousal in both men and women. J. Sex. Med. 4, 93–105. https://doi.org/10.1111/j.1743-6109.2006.00399.x.
Kukkonen, T.M., Binik, Y.M., Amsel, R., Carrier, S., 2010. An evaluation of the validity of thermography as a physiological measure of sexual arousal in a non-university adult sample. Arch. Sex. Behav. 39, 861–873. https://doi.org/10.1007/s10508-009-9496-4.
Laan, E., Everaerd, W., Evers, A., 1995. Assessment of female sexual arousal: response specificity and construct validity. Psychophysiology 32, 476–485. https://doi.org/10.1111/j.1469-8986.1995.tb02099.x.
Landry, S., Goncalves, M.K., Kukkonen, T.M., 2016. Assessing differences in physiologic subjective response toward male and female orientated sexually explicit videos in heterosexual individuals. Can. J. Hum. Sex. 25, 208–215. https://doi.org/10.3138/cjhs.253-A4.
Levin, R.J., 1998. Sex and the human female reproductive tract—what really happens during and after coitus. Int. J. Impot. Res. 10, 14–21.
Levin, R.J., 2003. The ins and outs of vaginal lubrication. Sex. Relatsh. Ther. 18, 509–513. https://doi.org/10.1080/14681990310001609859.
Levin, R.J., 2006. Blood flow: heated electrodes. In: Goldstein, I., Meston, C.M., Davis, S.R. (Eds.), Women's sexual function and dysfunction, study, diagnosis, and treatment. Taylor & Francis, London, pp. 391–398.
Levine, L.A., Carroll, R.A., 1994. Nocturnal penile tumescence and rigidity in men without complaints of erectile dysfunction using a new quantitative analysis software. J. Urol. 152 (4), 1103–1107.
Levin, R.J., Riley, A., 2007. The physiology of human sexual function. Psychiatry 6, 90–94. https://doi.org/10.1016/j.mppsy.2007.01.004.
Mabuchi, K., Genno, H., Matsumoto, K., Chinzei, T., Fujimasa, I., J., F., 1995. Autonomic thermoregulation and skin temperature: the role of deep body temperature in the determination of skin temperature. In: Ammer, K., Ring, E. (Eds.), The Thermal Image in Medicine and Biology. Uhlen, Vienna, pp. 121–129.
Mabuchi, K., Kanbara, O., Genno, H., Chinzei, T., Haeno, S., Kunimoto, M., 1997. Automatic control of optimum ambient thermal conditions using feedback of skin temperature. Biomed. Thermol. 16, 6–13. https://doi.org/10.1111/apha.12231.
Maravilla, K.R., Yang, C.C., 2008. Magnetic Resonance Imaging and the Female Sexual Response: Overview of Techniques, Results, and Future Directions. J. Sex. Med. 5 (7), 1559–1571. https://doi.org/10.1111/j.1743-6109.2008.00839.x.
Maravilla, K.R., Cao, Y., Heiman, J.R., Yang, C.C., Garland, P.A., Peterson, B.T., Carter, W.O., 2005. Noncontrast dynamic MRI for quantitative assessment of female sexual arousal. J. Urol. 173, 162–166. https://doi.org/10.1097/01.ju.0000146643.00140.e3.
McCall, K.M., Meston, C.M., 2007. The effects of false positive and false negative physiological feedback on sexual arousal: a comparison with or without sexual arousal disorder. Arch. Sex. Behav. 36, 518–530. https://doi.org/10.1007/s10508-006-9140-5.
Meola, C., 2012. Infrared Thermography: Recent Advances and Future Trends. Bentham Science, New York, N. Y.
Meuleman, E.J., Bemelmans, B.L., Doesburg, W.H., van Asten, W.N., Skotnicki, S.H., Debruyne, F.M., 1992. Assessment of penile blood flow by duplex ultrasonography in 44 men with normal erectile potency in different phases of erection. J. Urol. 147 (1), 51–56.
Ng, W.K., Ng, Y.K., Tan, Y.K., 2009. Qualitative study of sexual functioning in couples with erectile dysfunction: prospective evaluation of the thermography diagnostic system. J. Reprod. Med. 54, 698–705.
Obayashi, K., Ando, Y., Terazaki, H., Yamashita, S., Nakagawa, K., Nakamura, M., Yamashita, T., Suga, M., Ishizaki, T., Uchino, M., Ando, M., 2000. Effect of sildenafil citrate (Viagra) on erectile dysfunction in a patient with familial amyloidotic polyneuropathy ATTR Val30Met. J. Auton. Nerv. Syst. 80, 89–92. https://doi.org/10.1016/S0165-1838(99)00081-8.
Parada, M., Gérard, M., Larcher, K., Dagher, A., Binik, Y.M., 2018. How Hot Are They? Neural Correlates of Genital Arousal: An Infrared Thermographic and Functional

Magnetic Resonance Imaging Study of Sexual Arousal in Men and Women. J. Sex. Med. 15 (2), 217–229. https://doi.org/10.1016/j.jsxm.2017.12.006.
Payne, K.A., Binik, Y., 2006. Letter to the editor: reviving the labial thermistor clip. Arch. Sex. Behav. 35, 111–113. https://doi.org/10.1007/s10508-005-9017-z.
Payne, K.A., Thaler, L., Kukkonen, T., Carrier, S., Binik, Y., 2007. Sensation and sexual arousal in circumcised and uncircumcised men. J. Sex. Med. 4, 667–674. https://doi.org/10.1111/j.1743-6109.2007.00471.x.
Prause, N., Heiman, J.R., 2009. Assessing female sexual arousal with the labial thermistor: response specificity and construct validity. Int. J. Psychophysiol. 72, 115–122. https://doi.org/10.1016/j.ijpsycho.2008.11.002.
Prause, N., Janssen, E., 2006. Blood flow: Vaginal photoplethysmography. In: Goldstein, I., Meston, C.M., Davis, S.R., Traish, A.M. (Eds.), Women's Sexual Function and Dysfunction: Study, Diagnosis and Treatment. Taylor & Francis, New York, N. Y., pp. 359–367.
Prause, N., Cerny, J., Janssen, E., 2005. The labial photoplethysmograph: a new instrument for assessing genital hemodynamic changes in women. J. Sex. Med. 2, 58–65. https://doi.org/10.1111/j.1743-6109.2005.20106.x.
Ring, E.F.J., 1976. Computerized thermography for osteoarticular diseases. Acta Thermograph. 1, 166–173.
Ring, E.F.J., Ammer, K., 2015. The technique of infrared imaging in medicine. In: Ring, F., Jung, A., Żuber, J. (Eds.), Infrared Imaging: A Casebook in Clinical Medicine. IoP Publishing (chapter 1).
Ring, E.F.J., Thomas, R., Howell, K., 2009. Sensors for medical thermography and infrared radiation measurements. In: Biomedical Sensors. Momentum, New York, pp. 417–441 (Chapter 9).
Roberts, D.L., Goodman, P.H., 1987. Dynamic thermoregulation of back and upper extremity by computer-aided infrared imaging. Thermology 2, 573–577.
Rosen, R.C., Beck, J.G., 1988. Patterns of Sexual Arousal. Guilford Press, New York.
Sakheim, D.K., Barlow, D.H., Abrahamson, D.J., Beck, J.G., 1987. Distinguishing between organogenic and psychogenic erectile dysfunction. Behav. Res. Ther. 25, 379–390. https://doi.org/10.1016/0005-7967(87)90015-5.
Sarin, S., Amsel, M.P.R., Binik, Y.M., 2014. How hot is he? A psychophysiological and psychosocial examination of the arousal patterns of sexually functional and dysfunctional men. J. Sex. Med. 11, 1725–1740. https://doi.org/10.1111/jsm.12562.
Sarin, S., Amsel, R., Binik, Y.M., 2016. A Streetcar Named "Derousal"? A Psychophysiological Examination of the Desire-Arousal Distinction in Sexually Functional and Dysfunctional Women. J. Sex Res. 53 (6), 711–729. https://doi.org/10.1080/00224499.2015.1052360.
Schwartz, R.G., Elliott, R., Goldberg, G.S., 2006. Guidelines for neuromusculoskeletal thermography. Thermol. Int. 16, 5–9.
Seeley, T., Abramson, P.R., Perry, L.B., Rothblatt, A., Seeley, D.M., 1980. Thermographic measurement of sexual arousal: a methodological note. Arch. Sex. Behav. 9, 77–85.
Slob, A.K., Ernste, M., van der Werff ten Bosch, J.J., 1991. Menstrual cycle phase and sexual arousability in women. Arch. Sex. Behav. 20, 567–577. https://doi.org/10.1016/0306-4530(95)00058-5.
Slob, A.K., Bax, C.M., Hop, W.C., Rowland, D.L., van der Werff ten Bosch, J.J., 1996. Sexual arousability and the menstrual cycle. Psychoneuroendocrinology 21, 545–558.
Styles, S.J., Maclean, A.B., Reid, W.M., Sultana, S.R., 2006. Laser Doppler perfusion imaging: a method for measuring female sexual response. BJOG 113 (5), 599–601. https://doi.org/10.1111/j.1471-0528.2006.00894.x.
Tortora, G.J., Derrickson, B., 2012. Principles of Anatomy & Physiology, 13th ed. Wiley, Hoboken, N.J.
Vardasca, R., Marques, A.R., Diz, J., Seixas, A., Mendes, J., Ring, E.F.J., 2017. The influence of angles and distance on assessing inner-canthi of the eye skin temperature. Thermol. Int. 27 (4), 130–135.
Vollmer, M., Klaus-Peter, M.Ã., 2017. Infrared Thermal Imaging: Fundamentals, Research and Applications. John Wiley & Sons.
Waxman, S.E., Pukall, C.F., 2009. Laser Doppler imaging of genital blood flow: a direct measure of female sexual arousal. J. Sex. Med. 6 (8), 2278–2285. https://doi.org/10.1111/j.1743-6109.2009.01326.x.
Webster, J., Hammer, D., 1983. Thermistor measurement of male sexual arousal. Psychophysiology 20, 111–115. https://doi.org/10.1111/j.1469-8986.1983.tb00911.x.
Zuckerman, M., 1971. Physiological measures of sexual arousal in the human. Psychol. Bull. 75, 297–329. https://doi.org/10.1037/h0030923.