ORIGINAL RESEARCH—PHYSIOLOGY

Thermography as a Physiological Measure of Sexual Arousal in Both Men and Women

Tuuli M. Kukkonen, BA,* Yitzchak M. Binik, PhD,*† Rhonda Amsel, MSc,* and Serge Carrier, MD††

*Department of Psychology, McGill University, Montreal, Canada; †Sex and Couple Therapy Service, Department of Psychology, McGill University Health Center, Montreal, Quebec, Canada; ††Department of Urology, McGill University, Montreal, Canada

DOI: 10.1111/j.1743-6109.2006.00399.x

ABSTRACT

Introduction. Current physiological measures of sexual arousal are intrusive, hard to compare between genders, and quantitatively problematic.
Aim. To investigate thermal imaging technology as a means of solving these problems.
Methods. Twenty-eight healthy men and 30 healthy women viewed a neutral film clip, after which they were randomly assigned to view one of three other video conditions: (i) neutral (N = 19); (ii) humor (N = 19); and (iii) sexually explicit (N = 20).
Main Outcome Measures. Genital and thigh temperatures were continuously recorded using a TSA ImagIR camera. Subjective measures of sexual arousal, humor, and relaxation were assessed using Likert-style questions prior to showing the baseline video and following each film.
Results. Statistical (Tukey HSD) post-hoc comparisons ($P < 0.05$) demonstrated that both men and women viewing the sexually arousing video had significantly greater genital temperature (mean = 33.89°C, SD = 1.00) than those in the humor (mean = 32.09°C, SD = 0.93) or neutral (mean = 32.13°C, SD = 1.24) conditions. Men and women in the erotic condition did not differ from each other in time to peak genital temperature (men mean = 664.6 seconds, SD = 164.99; women mean = 743 seconds, SD = 137.87). Furthermore, genital temperature was significantly and highly correlated with subjective ratings of sexual arousal (range $r = 0.51–0.68$, $P < 0.001$). There were no significant differences in thigh temperature between groups.
Conclusion. Thermal imaging is a promising technology for the assessment of physiological sexual arousal in both men and women. **Kukkonen TM, Binik YM, Amsel R, and Carrier S. Thermography as a physiological measure of sexual arousal in both men and women. J Sex Med 2007;4:93–105.**

Key Words. Thermography; Sexual Arousal; Measurement; Male; Female; Psychophysiology

Introduction

A variety of instruments have been introduced to measure the physiological markers of sexual arousal in men and women. For men, these include penile plethysmography, rigiscan monitoring, and penile ultrasonography; for women, vaginal photoplethysmography has become the gold standard, but pelvic magnetic resonance imaging, labial thermistors and photoplethysmography, clitoral ultrasonography, and the heated oxygen electrodes have also been used (see Janssen [1] for a review) [1,2].

Each of the above-mentioned technologies has significant limitations. Perhaps most important is the fact that none can be used for both men and women. While an anal probe capable of measuring vascular and muscular activity during sexual arousal for both genders does exist, it remains relatively rarely used in research and, to our knowl-

edge, has not been employed to compare male and female sexual response [3–5]. The lack of parallel measurement with the most widely used instruments leaves open the possibility that reported differences in sexual arousal between men and women may be the result of technological rather than actual gender differences. Furthermore, it is also possible that the reported lower correlations between physiological and subjective measures of sexual arousal in women as opposed to men may be the result of instrumentation artifacts. It is also a possibility, however, that the lower correlations between physiological and subjective arousal in women are due to inadequate methodology and statistical analyses as shown by Rellini and colleagues [6].

All of the above-mentioned devices to measure sexual arousal are potentially intrusive and require genital contact or insertion, either by the participant or by an experimenter. This intrusiveness is likely to affect the actual experience of arousal in a variety of ways for different participants [2,7].

Less obvious are the quantitative difficulties in interpreting the data from existing measures. For example, data derived from vaginal and labial photoplethysmography, as well as penile plethysmography, have no absolute measurement scale and are therefore difficult to interpret between subjects [1,2,8]. Moreover, in the case of penile plethysmography and rigiscan monitoring, it is not clear how closely the output measures correlate with clinical criterion of penile rigidity [1]. This quantitative problem makes it difficult to use current measures to establish diagnostic criteria, which require between-subjects comparability and standardization. It is also the case with women that none of the established measures of physiological sexual arousal have been reliably used to determine diagnostic criteria for female sexual arousal difficulties. For example, recent attempts to establish the validity of vaginal photoplethysmography in discriminating women with genital sexual arousal disorder from controls have yielded mixed results [9,10].

Normal anatomical variation may also interact with these other problems. For example, penile size differences cannot be easily calibrated between subjects using penile plethysmography or rigiscan monitoring [11,12]. Internal penile anatomical differences can lead to the misinterpretation of ultrasound differences [13]. For women, naturally occurring differences in the length of the vagina can result in positioning differences for vaginal probes used in plethysmography [14]. These vaginal length differences may further be accentuated by sexual arousal, which is thought to affect the length of the vaginal barrel [15]. While it is a standard procedure in vaginal photoplethysmography to have a plastic stopper attached to the vaginal probe to control for the length of insertion, subject movement is a known artifact and is likely to be accentuated by the experience of sexual arousal [8]. Although the heated oxygen electrode appears to be less influenced by anatomical variation than the vaginal photoplethysmograph, it cannot be used for long periods of time due to the damage it can cause to the vaginal walls [16].

Current thermal imaging technology has the capability to address the methodological problems mentioned above in the following ways: (i) it can be used for both men and women; (ii) it does not require genital contact; and (iii) it provides an absolute temperature measure. The two basic principles upon which this technology works are as follows: (i) human skin or various membranes constantly emit electrochemical energy, such as infrared radiation, and are very efficient radiators of such energy; and (ii) it is possible to detect infrared emission from the skin by remote sensing. Although these principles have been known for some time, a convenient technology to implement them was not available until the 1990s when high-resolution, fast-scanning cameras became readily available. This new equipment can produce thermal images where the average temperature of less than 1 millimeter of skin can be determined with a precision of 0.07°C in a very short period of time. Thermographic imaging is now being used in numerous medical diagnostic situations, including dermatology (e.g., detection of lesions and inflammatory conditions), rheumatology (inflammation and blood flow in fibromyalgia, scleroderma, and rheumatoid arthritis), breast cancer detection, and surgery (detection of blood flow changes) [17–21]. With respect to sexual arousal, genital temperature is hypothesized to be directly related to the physiological mechanisms of sexual arousal, i.e., increased blood flow.

An earlier type of thermographic technology (UTI-SPECTROTHERM LWIR) was used in the 1980s to measure sexual arousal [22–25]. Although these studies included only a relatively small number of participants in one laboratory and the quantitative capacity of the thermography of the time was limited, the results were quite promising. Genital temperature increase in both men

and women appeared to be specific to sexual arousal induction and was highly correlated with subjective self-report.

There are also several reports of non-thermographic surface thermistor genital temperature measurements as an index of sexual arousal in both women and men [26–33]. Similar to early research with thermography, results from these studies demonstrate increases in labial and penile temperature during exposure to erotic stimuli. Furthermore, these temperature increases correlated well with subjective ratings of arousal.

The present research was designed to assess the feasibility of using current thermal imaging technology as a measure of sexual arousal in healthy men and women by recording and comparing penile and labial temperature during a sexual arousal condition, a positive mood-inducing arousal condition, and a neutral condition. Most previous research (see Kukkonen et al. [7] and Redoute et al. [34] for exceptions) attempted to distinguish sexual arousal from general physiological arousal by using control groups experiencing negative mood inductions such as anger or fear. A positive emotional state, humor, was chosen as the control for this study because research and theory indicates that humor may better represent a similar psychophysiological reaction in the body to sexual arousal than negative emotional states [35]. This would be particularly true in nonsexually dysfunctional populations, and would thus serve as a better control for general arousal.

We hypothesized that penile and labial temperature, as measured through a thermal imaging camera, would significantly differentiate the sexual arousal condition from the humor and neutral conditions, with the sexual arousal condition demonstrating higher genital temperatures than the other two conditions. In addition, we predicted that genital temperature would significantly correlate with subjective ratings of sexual arousal for both men and women, and that both genders would show similar patterns of temperature change that are consistent with the traditional Masters and Johnson model of the sexual response cycle [36].

Materials and Methods

The experiment was reviewed and approved by the McGill University Faculty of Medicine Institutional Review Board; written informed consent was obtained from each participant.

Participants

Potential participants were recruited through university advertisements. Healthy men and women aged 18–40 years were eligible to participate; however, our final sample consisted of 60 English-speaking, heterosexual individuals ranging in age from 18 to 28 years. Two men failed to reach a stable baseline temperature and were thus excluded from the analysis, leaving us with a total of 58 participants: 19 in the neutral condition, 19 in the humor condition, and 20 in the erotic condition. An additional 13 potential participants were excluded from the experiment for the following reasons: two could not be matched with existing participants; one moved away before a testing session could be scheduled; seven were not eligible due to the medications they were taking; one reported difficulties with sexual arousal; and two had difficulties with sexual arousal and were also taking medication. Our exclusion criteria consisted of the absence of intercourse experience, never having seen pornography, a history of sexual arousal difficulties or sexual dysfunction of any kind, any medication use that interferes with sexual arousal, or major medical and/or psychiatric illness. Participants were reimbursed $CN50 to cover expenses related to their participation in this study.

Experimental Manipulation

Participants were matched in groups of six (three men and three women) for age (±3 years), as well as oral contraceptive use in women, and then were randomly assigned to one of three experimental conditions (neutral, humor, or sexual arousal). All women were tested during the follicular phase of the menstrual cycle to control for the possible effects of the menstrual cycle on sexual arousal. The follicular phase was estimated by testing women within 12 days of the start day of their menstruation, but only once bleeding had ended. Six separate 15-minute film segments were used as stimuli. Two of these segments were shown to all participants and included the following: (i) a neutral video segment that consisted of still images of nature accompanied by calming music to allow for body temperature to stabilize; and (ii) a baseline video segment that consisted of a travelogue of the Yukon and Alaska [37,38]. The other video clips were viewed for the experimental manipulation and included the following: (i) the neutral control condition that consisted of a travelogue of the Amazon; (ii) a humor control video that comprised three separate segments of *The Best Bits of Mr.*

Bean; (iii) and (iv) a male-oriented erotic film clip validated at the Kinsey Institute and a female-oriented one based on criteria deemed to be sexually arousing to women [39–41].

Equipment

A TSA ImagIR thermal imaging system provided by Seahorse Bioscience (North Billerica, MA) was used to monitor genital temperature. The sampling interval was set at eight frames per second for this experiment. The sensitivity of this camera is 0.07°C. For men, the camera was placed 1.0 m diagonally left from the participant, at a height of 1.09 m, and angled at 30 degrees. For women, the camera was situated directly facing the examination table at a distance of 0.5 m, at a height of 1.09 m, and angled at 20 degrees. The slight difference in camera placement was necessary to have a clear image of the genital region for men and women. If the camera were to be placed directly facing the examination table for men as with women then, as erection occurs, the tip of the penis would obstruct the view of the rest of the penis.

Olympus eyetrek FMD-250W goggles (Center Valley, PA, USA), connected to a DVD player and laptop computer through a switchbox, were used to privately display the videos and subjective questionnaires to each participant. A standard intercom was used for communication between the participant and female investigator, who was in the adjoining room.

Background Information

Demographic information was collected from each participant using open-ended questions concerning age, place of birth, mother tongue, occupational status, and years of schooling. A question on current relationship status (*which of the following best describes your current dating/couple/marital situation*) included the following response options: no regular partner at the moment; dating one partner regularly; dating more than one partner; living with a partner; married; separated/divorced; widowed; and other—explain. Basic health/medical history included the following: (i) *are you currently taking any medications—if yes, which ones, and what dosage*; (ii) *are you suffering from any chronic illnesses*, e.g., *diabetes, hypertension—if yes, which ones*; (iii) *have you had a gynecologic exam in the past year—if no, why not*; (iv) *have you ever been to see a urologist—if yes, why*; (v) *when was the start day of your last period*; and (vi) *have you experienced childbirth—if yes, how many children*. Basic sexual health information included the following questions: (i) *are you primarily heterosexual, gay or bisexual*; (ii) *do you currently suffer from any sexual problems*; (iii) *have you ever watched a sexually explicit video or movie*; (iv) *do you feel uncomfortable about or object to the idea of watching a sexually explicit video or movie*; (v) *do you have any difficulty getting aroused at sexually explicit videos or movies*; (vi) *do you have any difficulty getting aroused by yourself (e.g., masturbation)*; and (vii) *are you concerned over your ability to get sexually aroused—if yes, would you like a referral*. Questions 2–7 had the following response options: yes, no, or I don't know. For those questions that were answered with a yes or I don't know, participants were prompted to elaborate on their answers.

Outcome Measures

Genital Temperature

Genital temperature was assessed through a region of interest situated on the shaft of the penis for men and on the left labia majora for women. A nongenital temperature control was continuously monitored on the inner right thigh of all participants.

Subjective Arousal

Subjective arousal was assessed with a series of separate Likert-style questions. Questions on relaxation (*overall, how relaxed did you feel during this film*), enjoyment (*overall, how much did you enjoy the film*), humor (*overall, how funny did you find the film*), and sexual arousal (*overall, how sexually aroused did you become during this film*; *how would you rate your peak sexual arousal*; *overall, how sexually aroused were you mentally during this film*; *did watching the video make you feel like having sex with a partner*; *did watching the video make you feel like masturbating*; *overall, how sexually aroused were you physically during this film*; *how much genital change did you feel during this film*; *how much lubrication did you feel during this film and how much genital tingling or fullness did you feel during this film (for women); how would you rate your erection in response to this film—men*) had response options ranging from 0 (*not at all*) to 10 (*the most ever*). A question on when peak sexual arousal occurred (*at what point during the film would you say that you were most sexually aroused*) included the following response options: (i) was not at all sexually aroused; (ii) within the first 5 minutes; (iii) between 5 and 10 minutes; (iv) during the last 5 minutes; (v) varied throughout; and (vi) other (explain). A question on comparison of sexual arousal (*how sexually aroused did you feel during the film as compared with how sexually aroused*

you typically are with a partner) ranged from −5 (*much less sexually aroused*) to +5 (*much more sexually aroused*), with 0 indicating no difference from with a partner. Finally, questions regarding the influence of the camera on arousal were included (*did the process of having your genitals filmed affect you in any way (Yes—describe or No)*; *did it increase or decrease sexual arousal and to what extent 0 (not at all) to 10 (the most possible)*; *did it increase or decrease how funny you thought the film was, and to what extent*; *did it increase or decrease how relaxed you felt during the video, and to what extent*).

Procedure

After a telephone screening, participants arrived at the laboratory in which the study procedures and equipment were explained again and informed signed consent was obtained. A brief semi-structured interview was conducted to collect sociodemographic and basic health and sexual health information. Once the female experimenter left the room, participants were instructed to get undressed from the waist down, and men were asked to sit on the examining table with their legs apart, whereas women were asked to assume the lithotomy position. All participants were instructed to put on the DVD goggles to view the videos. The thermal imaging camera recorded temperature for the duration of the experiment, and was focused on the penis and an area of the inner thigh of the right leg for men, and the labia majora and inner right thigh for women. Ambient room temperature was monitored for each participant and maintained constant with less than 1°C variation within each testing session. The first 15-minute neutral video segment was used to allow for skin temperature to adjust and to stabilize with the room temperature. Within this 15-minute period, all but two of the men achieved the required 3-minute period of stable temperature allowing them to progress to the next stage of the experiment. For men, stable temperature required a change of less than 0.5°C over 3 minutes, whereas for women, the criterion was more stringent, requiring a change of less than 0.05°C over a 3-minute period. Differences in required temperature stabilization reflect the smaller degree of temperature change expected from women due to the proximity of the labia to the body as compared with the penis, which can cool down to a greater degree. Following temperature stabilization, participants answered questions on subjective arousal. Immediately following the questionnaire, all participants were shown another 15-minute neutral travelogue, which served as the baseline measure of their temperature. Subjective ratings of arousal were obtained once more through the questionnaire upon completion of the video. The final video sequence presented was either the sexually arousing video, the humorous film, or another neutral travelogue followed again by questions on subjective arousal. Once all three videos were viewed, participants were instructed to remove the goggles and to get dressed at their convenience. The investigator then met with each participant to discuss the study and answer any additional questions.

Data Analysis

In order to assess differences in genital temperature, a three-way ANOVA with one repeated factor was conducted on average genital temperature between minutes 5 and 10 of each film. The middle 5 minutes of temperature was used to minimize possible carry-over effects from the previous film and to give a more conservative and stable measure of genital temperature change by avoiding the highest temperatures recorded toward the end of the erotic condition. The independent variables for the analysis were gender (male or female), experimental condition (neutral, humor, or erotic), and time of genital temperature recording as the repeated factor (baseline vs. experimental). In addition, to examine patterns of sexual arousal, we assessed time to peak genital temperature during the experimental condition with a univariate ANCOVA, in which gender and experimental condition were used as the independent variables and baseline time to peak temperature as a covariate. Finally, a three-way ANOVA with one repeated factor was conducted on average thigh temperature between minutes 5 and 10 of each film to determine whether temperature differences were specific to the genital region. Differences between groups on subjective ratings of arousal were measured using MANOVAs. All significant results were further assessed using tests of simple main effects and Tukey HSD post-hoc tests. Pearson's correlations between each subjective arousal measure and genital temperature were calculated by taking the difference scores between baseline average genital temperature for the middle 5 minutes of recording and experimental condition average genital temperature for the middle 5 minutes of testing (time period 2) and correlating that with the differences scores of the 11 questions on subjective arousal. As our subjective arousal questions do not specifically ask partici-

pants to respond regarding their arousal during the middle 5 minutes of the film, additional correlational analyses were carried out using subjective arousal difference scores and the following three time points to determine if there were notable differences in correlations when different time points were used: (i) average genital temperature difference scores for the first 5 minutes of baseline and experimental films (time period 1); (ii) average genital temperature differences scores for the last 5 minutes of baseline and experimental films (time period 3); and (iii) overall average genital temperature difference scores for the whole 15 minutes of baseline and experimental films (time period 4). In order to compare correlations between men and women, correlations were transformed to Fisher's *z*. Finally, a principal components analysis with varimax rotation for significant factors was conducted to determine if the 11 questions measuring subjective arousal could be reduced to a smaller number of factors. Using Kaiser's rule, factors were only considered significant if they had eigenvalues over 1. In addition, a factor was considered reliable only if it had four or more variable loadings above 0.6. Pearson's correlations were then conducted between reliable factors and the four time periods for genital temperature in order to examine whether our correlations of the 11 individual questions of subjective arousal and genital temperature remain consistent while using factor scores.

Results

Sample Characteristics

Fifty-eight participants were included in our final analyses: 19 in the neutral condition, 19 in the humor condition, and 20 in the erotic condition. There were no significant differences between experimental groups with regards to age (mean = 21.16 years, SD = 2.11), education (range = 13–19 years, mean = 15.36 years, SD = 1.35), place of birth (86.2% North America), or relationship status (43.1% single, 51.7% dating, 5.2% cohabiting/married). Sixty percent of women were using oral contraceptives, and all were nulliparous. None of the participants were virgins, and all of them had experience viewing pornographic videos. Finally, none of the participants reported any difficulties with sexual arousal.

Subjective Measures of Arousal

Changes in subjective arousal from baseline to experimental condition were measured through difference scores. MANOVA analysis of difference scores indicated significant differences among film groups on various ratings of arousal, which were further assessed by univariate ANOVAs. Participants in the erotic condition found their video to be significantly less relaxing (mean = –1.85, SD = 2.08) than those in the neutral condition (mean = 0.32, SD = 2.11) (F (2, 52) = 5.09, $P = 0.01$, $\eta_p^2 = 0.16$). Individuals in the humor condition did not report significant differences in relaxation from either of the other two groups (mean = –0.32, SD = 2.81). All three film conditions differed significantly from each other in reported humor level of the film (F (2, 52) = 31.05, $P < 0.001$, $\eta_p^2 = 0.54$), with participants in the humor condition rating their film as the funniest (mean = 4.84, SD = 2.14), followed by the erotic (mean = 2.9, SD = 2.61) and then neutral (mean = –0.42, SD = 1.39) conditions. All questions on subjective sexual arousal significantly differentiated the erotic condition from the two control conditions (see Table 1). The only significant difference between men and women was that women overall experienced a greater decrease in relaxation from baseline to experimental condition (mean = –1.43, SD = 2.13) than men (mean = 0.21, SD = 2.60) (F (1, 52) = 8.31, $P = 0.006$, $\eta_p^2 = 0.14$). Finally, there was one gender (male/female) × film (neutral/humor/erotic) interaction concerning desire to masturbate (F (2, 52) = 3.26,

Table 1 Means (standard deviations) of difference scores for subjective ratings of sexual arousal

Question	Erotic	Humor	Neutral	η_p^2
Desire to have sex with partner*	5.15 (2.62)	–0.32 (1.42)	–0.58 (1.07)	0.70
Desire to masturbate*	5.10 (2.24)	–0.53 (1.17)	–0.32 (0.75)	0.77
Overall sexual arousal*	4.60 (1.67)	0.11 (1.29)	–0.21 (0.71)	0.76
Peak sexual arousal*	4.55 (2.06)	0.05 (1.72)	–0.37 (0.68)	0.68
Physical sexual arousal*	4.30 (1.56)	–0.16 (1.07)	–0.58 (0.69)	0.80
Perception of genital change*	4.00 (1.89)	–0.21 (1.69)	–0.21 (0.71)	0.65
Mental sexual arousal*	3.80 (2.29)	–0.32 (1.67)	–0.53 (0.91)	0.60
Comparison of current arousal to that with a partner*	2.35 (1.53)	–0.26 (1.1)	–0.16 (0.38)	0.56

*$P < 0.0001$.

Table 2 Percentage of participants who indicated that having a camera film their genitals increased, decreased, or did not affect their sexual arousal

	Increase % (N)	Decrease % (N)	No effect % (N)
Baseline	36.2 (21)	12.1 (7)	51.7 (30)
Experimental			
Neutral	21.0 (4)	15.8 (3)	63.2 (12)
Humor	31.6 (6)	15.8 (3)	52.6 (10)
Erotic	20.0 (4)	55.0 (11)	25.0 (5)

$P = 0.046$, $\eta_p^2 = 0.11$), where men experienced a greater decrease in desire to masturbate from baseline following the humorous film (mean = –1.0, SD = 1.33) than women (mean = –0.1, SD = 0.88).

When asked if the process of recording their genitals affected their sexual arousal, 55% of the participants in the erotic condition responded that it decreased their arousal, while 20% and 25% said that it increased and had no effect on their arousal, respectively. Participant reports of intrusiveness or sexually enhancing effects of the thermographic recording for each condition are reported in Table 2.

Measure of Nongenital Control Temperature

A three-way ANOVA with one repeated factor for average thigh temperature did not reveal any significant interactions between time of recording (baseline/experimental) × gender (male/female) (F (1, 52) = 0.70, $P = 0.41$), time of recording × film condition (neutral/humor/erotic) (F (2, 52) = 0.38, $P = 0.69$), or time of recording × gender × film condition (F (2, 52) = 0.03, $P = 0.97$) (see Figure 1).

Physiological Measures of Sexual Arousal

The three-way ANOVA with one repeated factor for average genital temperature during time period 2 (middle 5 minutes) revealed significant interactions with respect to time of recording (baseline/experimental) × gender (male/female) (F (1, 52) = 8.12, $P = 0.006$, $\eta_p^2 = 0.14$), time of recording (baseline/experimental) × film condition (neutral/humor/erotic) (F (2, 52) = 30.05, $P < 0.001$, $\eta_p^2 = 0.54$), and time of recording × gender × film condition (F (2, 52) = 6.99, $P = 0.002$, $\eta_p^2 = 0.21$). The univariate ANCOVA for time to peak temperature with baseline time to peak temperature as a covariate revealed a significant difference in film conditions (F (2, 51) = 30.46, $P < 0.001$, $\eta_p^2 = 0.54$), as well as a gender film condition interaction (F (2, 51) = 3.42, $P = 0.041$, $\eta_p^2 = 0.12$). The comparison of time to peak temperature between genders was not significant (F (1, 51) = 3.64, $P = 0.062$).

Comparison of Genital Temperature across Film Conditions

Using simple main effects wherever significant interactions were found, we determined that there were no significant differences among film conditions (neutral, humor, and erotic) at baseline for average genital temperature ($P = 0.16$). Similarly, there were no significant differences in time to peak temperature at baseline ($P = 0.14$). During the experimental recording, however, significant differences in average genital temperature were detected ($P < 0.001$, $\eta_p^2 = 0.40$). Specifically, participants in the erotic condition showed significantly greater average genital temperatures (mean = 33.89°C, SD = 1.0) than those in the humor (mean = 32.09°C, SD = 0.93) or neutral (mean = 32.13°C, SD = 1.24) control groups, who did not differ from each other (see Figure 1). Furthermore, participants in the erotic condition had significantly longer time to peak temperature (mean = 703.8 seconds, SD = 153.35) than either the neutral (mean = 355.63 seconds, SD = 284.44) or humor control conditions (mean = 197.89 seconds, SD = 198.58) ($P < 0.001$, $\eta_p^2 = 0.54$).

Comparison of Genital Temperature across Men and Women

Tests of simple main effects revealed that, when comparing genital temperature between men and women irrespective of film condition, women had

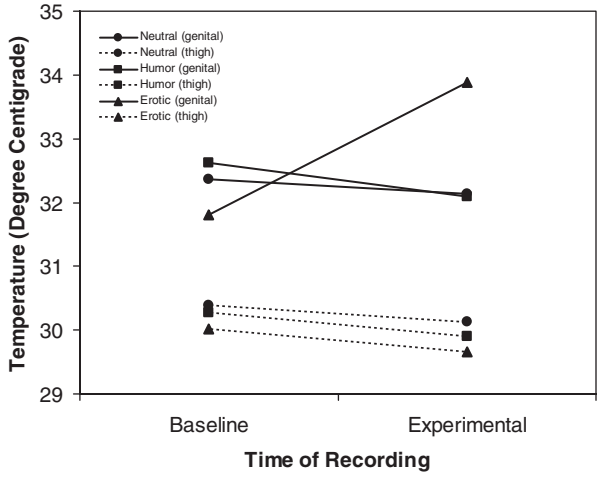

Figure 1 Mean genital (solid line) and thigh (dotted line) temperature during baseline and experimental recording for neutral (N = 19), humor (N = 19), and erotic (N = 20) groups.

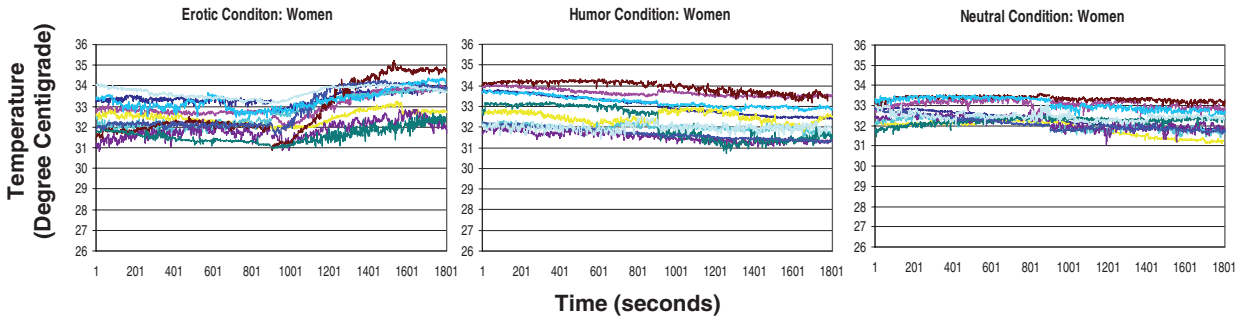

Figure 2 Labial temperature in degrees Celsius for all female participants in erotic (N = 10), humor (N = 10), and neutral (N = 10) conditions over baseline and experimental conditions.

significantly higher baseline genital temperature (mean = 32.63°C, SD = 0.71) than men (mean = 31.86°C, SD = 1.74) ($P = 0.03$, $\eta_p^2 = 0.08$). Women also had significantly shorter time to peak temperature during baseline (mean = 287.9 seconds, SD = 290.07) than men (mean = 483.75 seconds, SD = 296.02) ($P = 0.014$, $\eta_p^2 = 0.11$). These differences are no longer present during the experimental recording where men and women, averaged across film groups, did not differ significantly from each other with regards to average genital temperature ($P = 0.4$) or time to peak temperature ($P = 0.06$). Due to the differences in baseline genital temperature between men and women, baseline temperature was included as a covariate for the following analyses of simple main effects. Within each film group, only men and women in the erotic condition differed significantly from each other during experimental recording, in that men had significantly higher average genital temperature (mean = 34.47°C, SD = 0.84) than women (mean = 33.3°C, SD = 0.81) ($P = 0.021$, $\eta_p^2 = 0.28$). While genital temperatures differed between men and women in the erotic condition, both genders recorded similar patterns of genital arousal, in that average length of time to peak genital temperature did not differ between men (mean = 664.6 seconds, SD = 164.99) and women (mean = 743 seconds, SD = 137.87) in the erotic condition, using baseline time to peak temperature as a covariate ($P = 0.41$). While there were also no differences in time to peak genital temperature between men and women in the humor control group (men mean = 258.22 seconds, SD = 228.95; women mean = 143.6 seconds, SD = 159.25), a significant difference in time to peak temperature was found for men and women in the neutral control condition (men mean = 499.11 seconds, SD = 305.08; women mean = 226.5 seconds, SD = 199.91) ($P = 0.031$, $\eta_p^2 = 0.24$), with men taking a greater amount of time to reach their peak temperature than women. The general pattern of temperature change in each of the three experimental conditions is similar for men and women despite differences in time to peak temperature for the neutral condition, as illustrated in Figures 2 and 3, which show the temperature graphs for each participant.

Correlation Between Subjective and Physiological Measures

To examine the relationship between genital temperature and subjective ratings of arousal, corre-

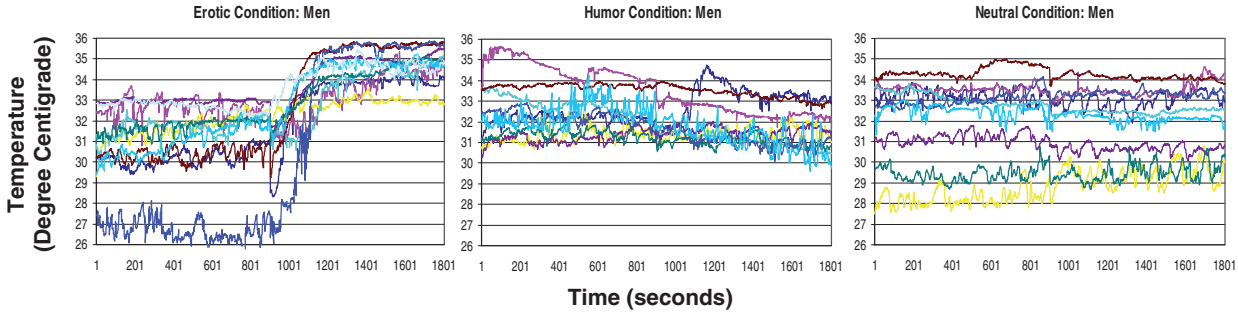

Figure 3 Penile temperature in degrees Celsius for all male participants in erotic (N = 10), humor (N = 9), and neutral (N = 9) conditions over baseline and experimental conditions.

lational analysis was performed using Pearson's method on the difference scores of subjective ratings of arousal and the difference scores from baseline to experimental condition for average genital temperature for the first 5 minutes (time period 1), middle 5 minutes (time period 2), last 5 minutes (time period 3), and the entire 15 minutes (time period 4) of recording. Each measure of subjective arousal (e.g., overall sexual arousal, peak sexual arousal, etc.) was significantly positively related to each genital temperature measure (period 1 range $r = 0.34–0.52$, $P < 0.01$; period 2 range $r = 0.51–0.68$, $P < 0.001$; period 3 range $r = 0.57–0.71$, $P < 0.001$; period 4 range $r = 0.46–0.61$, $P < 0.001$). Using Fisher's transformation, we determined that there were no significant differences in correlations of subjective and physiological arousal between men and women using average genital temperature difference scores of the middle 5 minutes of each condition (range $z = –0.14$ to 1.12, $P = 0.13–0.45$), last 5 minutes of each condition (range $z = –0.11$ to 0.98, $P = 0.16–0.46$), and overall 15 minutes of each condition (range $z = –0.06$ to 1.08, $P = 0.14–0.20$). While all of the male ratings of subjective sexual arousal were significantly positively correlated with the average genital temperature difference score during the first 5 minutes of baseline and experimental conditions (time period 1) (range $r = 0.48–0.68$, $P < 0.01$), only one female rating of subjective sexual arousal, genital tingling, was significantly correlated with genital temperature during this period ($r = 0.37$, $P < 0.05$).

To further examine the relationship between genital temperature and subjective ratings of arousal, a principal components analysis with varimax rotation was conducted on the difference scores for the 11 subjective arousal questions. Only one reliable factor consisting of all eight of the sexual arousal questions emerged with a range in factor scores of 3.96, with –1.51 as a minimum score and 2.45 as a maximum. A second factor consisting of the humor and enjoyment questions was not considered reliable as it had only two variables with significant loadings (the question on relaxation did not load significantly on either of these two factors). Similar to the individual question correlations, the sexual arousal factor was significantly positively correlated with genital temperature during period 1 ($r = 0.50$, $P < 0.001$), period 2 ($r = 0.67$, $P < 0.001$), period 3 ($r = 0.71$, $P < 0.001$), and period 4 ($r = 0.62$, $P < 0.001$). In addition, the only difference between men and women was again that women's subjective sexual arousal was not correlated with genital temperature during period 1 (first 5 minutes of testing).

Discussion

Thermal imaging is a promising tool for the physiological assessment of sexual arousal. Results from this first study indicate that thermal imaging can clearly differentiate sexual arousal from humor and neutral conditions in healthy young men and women. Participants in the sexually arousing condition experienced an average increase of 2.08°C in genital temperature from baseline in response to the erotic film, whereas participants in the neutral and humor conditions experienced relatively stable genital temperatures from baseline to experimental condition (decreases of 0.24°C and 0.53°C, respectively). In contrast to genital temperature change during sexual arousal, thigh temperature remained stable for all three conditions throughout testing, suggesting that increases in temperature during sexual arousal are centered in the genital region. Furthermore, the increases in genital temperature were significantly associated with increases in subjective ratings of sexual arousal, providing support for the physiological measure of genital temperature corresponding to the subjective experience of sexual arousal. The clarity of the results is such that one can simply look at participants' temperature graph to determine whether or not they were in the erotic condition. This type of "eyeball data" is a relative rarity in psychophysiological research and suggests that the further development of this methodology is worthwhile.

What is also striking about these results are the similarities between men and women. Both men and women in the erotic condition had significantly higher genital temperatures than men and women in the neutral and humor conditions. While men had greater increases in genital temperature (mean = 3.3°C) than women (mean = 0.86°C), women started off with significantly higher baseline genital temperature (mean = 32.63°C) than men (mean = 31.86°C). The proximity of the labia to the body compared with that of the shaft of the penis is likely to account for this difference. In addition, the dorsal artery of the penis, which runs through the shaft, would likely increase temperature to a greater extent than any of the capillaries located throughout the labia majora, thus potentially accounting for the higher temperatures recorded in men.

Our results suggest that there are no differences between men and women in length of time to peak sexual arousal during the erotic condition. Men averaged 11 minutes 5 seconds to recorded peak genital temperature, whereas women had an average of 12 minutes 23 seconds. Although showing men and women different videos introduces the possibility that the similarities in time to peak temperature are an artifact of differing visual stimuli, research suggests that showing the same video may not be ecologically valid [41]. Indeed, examining the graphs of all participants visually demonstrates similar patterns of temperature change for men and women in the erotic condition when gender-appropriate videos are used. Furthermore, the erotic condition for both genders can be clearly distinguished from the relatively stable temperature graphs for participants in the two control conditions (see Figures 2 and 3). The differences in time to peak temperature between the genders during baseline and for the neutral control condition are likely due to the increased variability of temperature in men. Whereas women's labial temperature remains fairly stable in neutral conditions (again due to the proximity of the labia to the body), men's penile temperature tends to vary more, creating a situation in which peak temperature might take longer to reach. In examining the standard deviations of time to peak temperature, men appear to have more variation in the neutral and humor conditions; men's standard deviations for time to peak temperature were 305.1 and 229 seconds, respectively, whereas for women, the standard deviations for neutral and humor control videos were 199.9 and 159.2 seconds, respectively.

The similarities between men and women are also present in their subjective ratings of sexual arousal. There is some evidence that suggests that women are able to indicate levels of genital arousal that correlate with physiological measures; however, in most previous research, women's physiological and subjective reports of sexual arousal have been poorly correlated, if at all [6,42,43]. Although we cannot say for sure whether the process of having a camera filming their genitals directed women to be more aware of vascular changes in the genital region, the DVD goggles block external stimuli and make it unlikely that there would be more focus on the genitals than with other available measures.

The poor correlations between subjective and physiological sexual arousal in women from previous research have led to the suggestion that women are not as adept at detecting physiological differences in their bodies as men are, and that women are more highly influenced by cognitive and emotional factors than men [43]. In addition, recent research comparing male and female sexual arousal suggests that women's sexual arousal is nonspecific and fundamentally different from men's [44]. While it was not a goal of this study to examine these theories, the overall similar correlations between physiological and subjective sexual arousal in men and women certainly introduce the possibility that disparities in male and female sexual arousal could be due in part to measurement or instrumentation error rather than to true differences. The one time period in this study in which women's physiological and subjective arousal was not consistently correlated was when we averaged the temperature recorded during the first 5 minutes of the experimental condition and correlated it with reported subjective arousal. It may be that our method of averaging the first 5 minutes is not sensitive enough for the lower levels of temperature change experienced in the beginning of the condition. It is also possible that a continuous measure of subjective arousal, like that of Rellini and colleagues [6], would be more sensitive to detecting a relationship between these measures at early stages of arousal.

The most obvious disadvantage of thermal imaging technology is its cost. Equipment similar to what we have used is advertised on the Internet at prices ranging from US$55,000 to 100,000. While this technology is less intrusive than others in that it requires no genital contact, roughly half of our participants indicated that having a camera film their genitals did influence their subjective sexual arousal. Unfortunately, most previous research, except for that of Prause and colleagues [2], does not report whether participants find the methodology used intrusive, and we are not aware of other studies except for our own [7] that have investigated the sexually enhancing effects of measuring arousal. As thermography does not require genital contact, however, it is likely better suited than other technologies for women suffering from dyspareunia and vaginismus.

Another limitation of this technology is that there is no standardized method for examining the data. Following testing, we checked each recorded data frame for each participant to ensure that the genital region of interest we were monitoring (an area on the labia majora and shaft of the penis) was the same throughout. This is necessary because the subject may move during the experiment to

find a more comfortable position or his/her genitalia may move as a result of sexual arousal. Any movement required us to manually reposition the thermography's "region of interest" on the data image after the actual monitoring session is over. This manual repositioning is a standard feature of the currently available technology, but it is impossible to ensure exactly the same location. It is unlikely, however, that genital location errors of 10–15 mm would seriously affect our data. A more serious issue might be how to measure analogous genital structures in men and women. For example, clitoral temperature could only be measured if the external genitalia were held open.

Although temperature provides a known interval scale that can be used to compare men and women, this does not mean that a two-degree change in women is directly equivalent to a two-degree change in men. In addition, while there is a certain degree of variability between subjects, body temperature is a tightly regulated system that should produce very little variability within one participant measured repeatedly in the same condition. Indeed, examining the data from our neutral control condition provides initial support for the stability of genital temperature within participants. This presumed consistency within a condition, as well as a sensitivity to change if a new condition is introduced, would make genital temperature a reliable measure of sexual arousal. While we have demonstrated a sensitivity to change in genital temperature and have some support for its stability, further research is required to establish the degree of variability within participants measured repeatedly in the same condition as well as how to translate temperature change between genders.

Previous research measuring genital temperature has suggested that this measure has a slow return to baseline [33]. Unfortunately, we did not measure this in the current study. We also do not know whether genital temperature can differentiate between genital blood flow and pooling. Finally, it is crucial using this technology to control variations in genital temperature resulting from external factors such as room temperature or internal factors such as menstrual cycle effects.

Conclusion

Our research is consistent with, but improves upon, older thermography research and previous surface thermistor genital temperature research [22–33]. With present equipment we were able to continuously and remotely monitor a specific area and show that sexual arousal is differentiable from neutral and positive mood induced states, and that temperature increases during sexual arousal are specific to the genital region when compared with a control area on the thigh. While one previous study has recorded temperature changes in the pectoral region during sexual arousal [22], we did not measure this area and cannot confirm whether this is the case.

Thermography is a promising technology for the measurement of physiological sexual arousal. Future research should replicate these findings with older participants and also demonstrate that thermography can differentiate sexual arousal from arousal induced by negative emotional states. Additionally, determining the ranges of temperature associated with no arousal and high sexual arousal, as well as better understanding the between- and within-subject variability of temperature, would be useful for mapping human sexual response. If such research is successful, then we believe that thermography should be tested with clinical populations to determine its discriminant validity and suitability as a diagnostic tool for male and female sexual arousal disorder.

Acknowledgments

We would like to thank Seahorse Biosciences (North Billerica, MA) for their generosity in providing us with the thermal imaging equipment. We would also like to thank Melissa Farmer, Marie-Andrée Lahaie, Alina Kao, Laurel Paterson, Shiri Freiwald, and Stephanie Boyer for their comments during the preparation of this manuscript, as well as Natalie Cartwright and Katherine Muldoon for their assistance with recruitment and scheduling. This research was supported by a Canadian Institutes of Health Research grant to Y.M. Binik, as well as a Pfizer grant and a Canadian Male Sexual Health Council grant to Y.M. Binik and S. Carrier. This article stands in partial fulfillment of T.M. Kukkonen's PhD requirements, supervised by Dr. Y.M. Binik.

Corresponding Author: Tuuli M. Kukkonen, BA, McGill University—Psychology, 1205 Dr. Penfield Ave, Montreal, Quebec, H3A 1B1, Canada. Tel: (+1) 514 398 5323; Fax: (+1) 514 398 4896; E-mail: kukkonen@ego.psych.mcgill.ca

Conflict of Interest: None declared.

References

1 Janssen E. Psychophysiological measurement of sexual arousal. In: Weiderman MW, Whitley BE,

eds. Handbook for conducting research on human sexuality. Mahwah, NJ: Erlbaum; 2001:131–71.
2 Prause N, Cerny J, Janssen E. The labial photoplethysmograph: A new instrument for assessing genital hemodynamic changes in women. J Sex Med 2005;2:58–65.
3 Bohlen JG, Held JP. An anal probe for monitoring vascular and muscular events during sexual response. Psychophysiology 1979;16:318–23.
4 Bohlen JG, Held JP, Olwen Sanderson M. The male orgasm: Pelvic contractions measured by anal probe. Arch Sex Behav 1980;9:503–21.
5 Bohlen JG, Held JP, Olwen Sanderson M, Ahlgren A. The female orgasm: Pelvic contractions. Arch Sex Behav 1982;11:367–86.
6 Rellini AH, McCall KM, Randall PK, Meston CM. The relationship between women's subjective and physiological sexual arousal. Psychophysiology 2005;42:116–24.
7 Kukkonen TM, Paterson L, Binik YM, Amsel R, Bouvier F, Khalifé S. Convergent and discriminant validity of clitoral color doppler ultrasonography as a measure of female sexual arousal. J Sex Marital Ther 2006;32:281–7.
8 Prause N, Janssen E. Blood flow: Vaginal photoplethysmography. In: Goldstein I, Meston CM, Davis SR, Traish AM, eds. Women's sexual function and dysfunction: Study, diagnosis and treatment. New York: Taylor & Francis; 2006:359–67.
9 Brotto LA, Basson R, Gorzalka BB. Psychophysiological assessment in premenopausal sexual arousal disorder. J Sex Med 2004;1:266–77.
10 Rellini AH, Meston CM. The sensitivity of event logs, self-administered questionnaires and photoplethysmography to detect treatment-induced changes in FSAD diagnosis. J Sex Med 2006;3:283–91.
11 Udelson D, Nehra A, Hatzichristou DG, Azadzoi K, Moreland RB, Krane J, Saenz de Tejada I, Goldstein I. Engineering analysis of penile hemodynamic and structural-dynamic relationships: Part I—Clinical implications of penile tissue mechanical properties. Int J Impot Res 1998;10:15–24.
12 Wespes E, Schulman CC. Parameters of erection. Br J Urol 1984;56:416–7.
13 Sakamoto H, Nagata M, Saito K, Okumura T, Yoshida H. Anatomic variations of cavernous arteries and their effect on measurement of hemodynamic parameters: A power Doppler study. Urology 2004;63:539–44.
14 Gillan P, Brindley GS. Vaginal and pelvic floor responses to sexual stimulation. Psychophysiology 1979;16:471–81.
15 Rosen RC, Beck JG. Patterns of sexual arousal: Psychophysiological processes and clinical applications. New York: The Guilford Press; 1988.
16 Levin RJ. Blood flow: Heated electrodes. In: Goldstein I, Meston CM, Davis SR, Traish AM, eds. Women's sexual function and dysfunction: Study, diagnosis and treatment. New York: Taylor & Francis; 2006:391–8.
17 Di Carlo A. Thermography and the possibilities for its applications in clinical and experimental dermatology. Clin Dermatol 1995;13:329–36.
18 Ecker RD, Goerss J, Meyer B, Cohen-Gadol AA, Britton JW, Levine JA. Vision of the future: Initial experience with intraoperative real-time high resolution dynamic infrared imaging. J Neurosurg 2002;97:1460–71.
19 Martini G, Murray KJ, Howell KJ, Harper J, Atherton D, Woo P, Zulian F, Black CM. Juvenile onset localized scleroderma activity detection by infrared thermography. Rheumatology 2002;41:1178–82.
20 Parisky YR, Sardi A, Hamm R, Hughes K, Esserman L, Rust S, Callahan K. Efficacy of computerized infrared imaging analysis to evaluate mammographically suspicious lesions. Am J Roentgenol 2003;180:263–9.
21 Szabo T, Fazekas L, Geller L, Horkay F, Merkely B, Gyongy T, Juhasz-Nagy A. Cardiothermographic assessment of arterial and venous revascularization. IEEE Eng Med Biol Mag 2000;19:77–82.
22 Abramson PR, Pearsall EH. Pectoral changes during the sexual response cycle: A thermographic analysis. Arch Sex Behav 1983;12:357–68.
23 Abramson PR, Perry LB, Rothblatt A, Seeley T, Seeley DM. Negative attitudes toward masturbation and pelvic vasocongestion: A thermographic analysis. J Res Pers 1981;15:497–509.
24 Abramson PR, Perry LB, Seeley T, Seeley DM, Rothblatt AB. Thermographic measurement of sexual arousal: A discriminant validity analysis. Arch Sex Behav 1981;10:171–6.
25 Seeley T, Abramson PR, Perry LB, Rothblatt A, Seeley DM. Thermographic measurement of sexual arousal: A methodological note. Arch Sex Behav 1980;9:77–85.
26 Fisher C, Gross J, Zuch J. Cycle of penile erection synchronous with dreaming (REM) sleep. Arch Gen Psychiat 1965;12:29–45.
27 Henson DE, Rubin HB. A comparison of two objective measures of sexual arousal of women. Behav Res Ther 1978;16:143–51.
28 Henson DE, Rubin HB, Henson C, Williams JR. Temperature changes of the labia minora as an objective measure of female eroticism. J Behav Ther Exp Psychiatry 1977;8:401–10.
29 Slob AK, Ernste M, van der Werff ten Bosch JJ. Menstrual cycle phase and sexual arousability in women. Arch Sex Behav 1991;20:567–77.
30 Slob AK, Koster J, Radder JK, van der Werff ten Bosch JJ. Sexuality and psychophysiological functioning in women with diabetes mellitus. J Sex Marital Ther 1990;16:59–69.
31 Solnick RL, Birren JE. Age and male erectile responsiveness. Arch Sex Behav 1977;6:1–9.

32 Webster JS, Hammer D. Thermistor measurement of male sexual arousal. Psychophysiology 1983; 20:111–5.
33 Payne KA, Binik YM. Letter to the editor: Reviving the labial thermistor clip. Arch Sex Behav 2006;35:111–3.
34 Redouté J, Stoleru S, Gregoire MC, Costes N, Cinotti L, Lavenne F, Le Bars D, Forest MG, Pujol JF. Brain processing of visual sexual stimuli in human males. Hum Brain Mapp 2000;11:162–77.
35 Fry WF. Humor and the brain: A selective review. Humor 2002;15:305–33.
36 Masters WH, Johnson VE. Human sexual response. New York: Bantam Books; 1966.
37 LaBarge R (producer). Natural splendors volume 2 [motion picture]. Mountain Lakes, NJ: Alpha DVD; 2002.
38 Glusic R (producer). Glacier National Park [Motion Picture]. Chatsworth, CA: Wilderness Video; 1994.
39 Day M (Producer), Cook M (Producer), Wolfe M (Director). The greatest places [Motion picture]. St. Paul, MN: Science Museum of Minnesota; 2001.
40 Vertue S (Producer), Davies JH (Director), Birkin J (Director), Weiland P (Director). The best bits of Mr. Bean [Motion Picture]. Hollywood, CA: Universal Studios; 1999.
41 Janssen E, Carpenter D, Graham CA. Selecting films for sex research: Gender differences in erotic film preference. Arch Sex Behav 2003; 32:243–51.
42 Brotto LA, Gorzalka BB. Genital and subjective sexual arousal in postmenopausal women: Influence of laboratory-induced hyperventilation. J Sex Marital Ther 2002;28(suppl):39–53.
43 Laan E, Janssen E. How do men and women feel? Determinants of subjective experience of sexual arousal. In: Janssen E, ed. The psychophysiology of sex. Bloomington, IN: Indiana University Press (in press).
44 Chivers M. A brief review and discussion of sex differences in the specificity of sexual arousal. Sex Rel Ther 2005;20:377–90.