

Assessment of Introital Lubrication

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Abstract Vaginal vasocongestion and lubrication serve to prepare the vaginal lumen for sexual activity. Lubrication is important for sexual functioning and difficulties with lubrication are one of the most commonly reported symptoms of sexual dysfunction. Few studies have empirically examined how vasocongestion and lubrication relate to one another and there are currently no well-established measures of lubrication. In this study, we designed and tested a simple method to assess lubrication at the vaginal introitus in 19 healthy women, using litmus test strips. We examined the relationship between lubrication and vaginal vasocongestion (measured with a photoplethysmograph) when elicited by audiovisual sexual stimuli (male–female sexual interactions). Lubrication was elicited by the sexual stimuli and was strongly correlated with reports of sexual arousal. Unexpectedly, lubrication was not correlated with vasocongestion, even though the latter was also elicited by the sexual stimuli. We discuss the implications of these findings for informing our understanding of the female sexual response and the potential clinical and scientific utility of this new measure.

Keywords Genital responses · Vaginal vasocongestion · Lubrication · Self-reported sexual arousal · Vaginal photoplethysmography

Introduction

The female sexual response consists of several related physiological processes (Janssen, Prause, & Geer, 2006; Levin, 2003, 2004). Two of these processes, vaginal vasocongestion and vaginal lubrication, serve to prepare the vaginal lumen for sexual activity (Levin, 2003, 2004). Vaginal vasocongestion is elicited through sexual stimulation and contributes to the formation of transudate (i.e., lubrication). The main function of this transudate is to enable painless vaginal penetration and to protect the lumen against friction-related injuries incurred through sexual activity (Levin, 2003). Despite its importance to women's sexual functioning, few studies have measured vaginal lubrication directly during sexual arousal and even fewer have examined how vaginal vasocongestion and lubrication relate to each other.

The most commonly used measure to assess changes in blood flow to the vaginal epithelium is the vaginal photoplethysmograph. Once inserted into the vagina, the small tampon-shaped device measures changes in light reflectance in the vaginal tissues associated with each heartbeat (Hatch, 1979). The vaginal photoplethysmograph has been shown to be a sensitive measure of genital response to sexual stimuli, with increases observed during exposure to sexual stimuli, but not during non-sexual stimuli (Laan, Everaerd, & Evers, 1995; Suschinsky, Lalumière, & Chivers, 2009).

Within the first few seconds of sexual stimulation, arterial dilation enables blood to flow to the vaginal tissues resulting in increased capillary surface area and pressure (i.e., vasocongestion) (Levin, 2003). Vasocongestion forces interstitial fluid to move, via transudation, through the epithelial tissues onto the surface of the vaginal lumen (Levin, 1992, 2003). As sexual stimulation continues, these droplets of fluid coalesce into a film lining the luminal surface (i.e., lubrication) (Levin, 2003, 2004; Masters, 1959; Masters & Johnson, 1966). Masters (1959) observed that lubrication becomes visible on the vaginal

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walls within 10–30 s of sexual stimulation. Thus, vaginal vasocongestion precedes and is responsible for vaginal lubrication; this relationship, however, has rarely been assessed quantitatively.

At present, there are no well-established measures of vaginal lubrication, limiting our understanding of the processes involved in the female sexual response. Most researchers have relied on women's experiences of their arousal, which are typically assessed via self-report items or sexual functioning scales (e.g., Female Sexual Function Index) (Rosen et al., 2000). This is problematic, given evidence of low sexual concordance—the agreement between measures of genital blood flow and self-reported experience of sexual arousal or genital sensations—in women (Chivers, Seto, Lalumière, Laan, & Grimbos, 2010), and impression management biases in assessment of self-reported sexual arousal (Huberman, Suschinsky, Lalumière, & Chivers, 2013). It may, therefore, be imprecise to solely rely on women's self-reported perceptions of their degree of lubrication.

The earliest studies of vaginal lubrication quantified basal (i.e., not sexually-stimulated) levels of vaginal lubrication using tampons (e.g., Dusitsin, Gregoire, Johnson, & Rakoff, 1967; Godley, 1985; Odeblad, 1964; Preti, Huggins, & Silverberg, 1979; Wagner, 1979; Wagner & Levin, 1980), cotton swabs (Stone & Gamble, 1959), cervical caps (Dusitsin et al., 1967), and evaporimeters (Wagner, 1979). In their review, Owen and Katz (1999) calculated the quantity of lubrication (in mL) assessed using these measures and reported substantial variability in lubrication quantity. Much of this variability was due to differences in the duration of the measurement (e.g., assessing lubrication produced in 15 min compared to 8 h).

Other studies have focused on elucidating the constituents of lubrication before and after sexual arousal. Vaginal lubrication pre-arousal consists of significant concentrations of sodium, potassium, chloride, and calcium (Levin & Wagner, 1977; Stamey & Timothy, 1975; Wagner & Levin, 1978), with sodium and chloride increasing significantly following arousal (Levin & Wagner, 1977). Lubrication is also composed of a variety of acids (lactic, acetic) as well as glycerol and glucose (reviewed in Owen & Katz, 1999), with small but significant increases in vaginal pH after sexual stimulation (e.g., Berman et al., 2001; Masters & Johnson, 1966; Wagner, 1979; Wagner & Levin, 1984; reviewed by Woodward & Diamond, 2009).

A few researchers have attempted to quantify the amount of vaginal lubrication produced during and immediately following sexual stimulation. Using weighed filter paper and tampons (weighed pre- and post-orgasm or sexual stimulation) and evaporimeters (used to measure humidity pre- and post-orgasm), Wagner and Levin (1977), Preti et al. (1979), and Wagner (1979), respectively, observed substantial increases in vaginal lubrication within the vaginal lumen as a result of sexual stimulation. Riley and Riley (1983) used a weighed tampon method to

assess both vaginal and vulvar lubrication in six women, observing an increase in both after orgasm. Weighed methods, however, can be problematic due to the high absorbency and wicking qualities of filter paper and tampons, which have a tendency to dry out the epithelium preventing multiple measurements of lubrication across a short time period (Levin, 2003).

Carranza-Lira et al. (2003) assessed vaginal dryness/wetness in 40 post-menopausal women pre- and post-hormonal treatments (estrogen based), using a pH test-strip placed at the introitus, and found that the hormone therapy resulted in a significant increase in the degree of wetness (in mm) observed on the pH test-strip at the three-month follow-up. There was no manipulation of sexual stimulation or arousal in the Carranza-Lira et al. study, so it remains unclear whether this method would be suitable to detect changes in lubrication as a function of sexual stimulation. Because of the low wicking property of the pH test-strips, compared to weighed tampons, this method may be well suited for studies using repeated sexual stimulation, as is often done in modern psychophysiological studies of female genital responses (e.g., Chivers, Seto, & Blanchard, 2007; Prause, Barela, Roberts, & Graham, 2013; Suschinsky & Lalumière, 2011).

Given the functional significance of lubrication, and inspired by the method described by Carranza-Lira et al. (2003), we set out to develop a method to quantify the amount of lubrication at the introitus in response to sexual stimuli. The aims of the study were threefold: (1) design and test a measure of lubrication; (2) examine the relationship between lubrication and vaginal vasocongestion; and (3) examine the relationships between the two physiological measures and self-reported sexual arousal.

Pilot testing revealed that concurrent assessment of vaginal vasocongestion and lubrication was problematic. Specifically, the placement device of the vaginal photoplethysmograph made it difficult to position the lubrication measure at the introitus without it coming into contact with the photoplethysmograph cable. In addition, the signal from the vaginal photoplethysmograph was often unreliable due to movement and light exposure when lubrication was assessed simultaneously. To address these issues, in one half of the session vasocongestion was assessed and in the other half lubrication was assessed. This enabled a within-subjects design without the complications of concurrent assessment.

Method

Participants

The final sample consisted of 19 women with a mean age of 21.2 ($SD = 2.3$). Most of the women reported being exclusively or predominantly attracted to men ($n = 18$) and were in sexual and romantic relationships ($n = 14$) at the time of testing. Fifteen women reported using hormonal contraceptives at

the time of data collection. Of the four naturally-cycling participants, three were tested during their luteal phase and one was tested during her follicular phase. Menstrual cycle phase at testing was determined using the reverse-counting calendar method (Lamprecht & Grummer-Strawn, 1996).

Forty-four women indicated their interest in the study by responding to printed recruitment advertisements posted at a Canadian university. Of these, 32 underwent eligibility screening. To be eligible for the study, women were required to be between 18 and 30 years of age, predominantly or exclusively attracted to men (the stimuli depicted heterosexual interactions), sexually-experienced (i.e., had engaged in penetrative sexual activity and had previously used erotica), and were unaware of or did not report any sexual dysfunctions, sexually-transmitted infections, or mental disorders. Women were ineligible if they were pregnant or trying to conceive, or if they were currently taking medication that could affect their sexual functioning (e.g., antidepressants). Nine women were excluded based on these eligibility criteria. Twenty-three women were deemed eligible for the study and scheduled an appointment in the laboratory. During the data cleaning stage, four women were excluded because their photoplethysmograph waveform data had uncorrectable movement artifacts ($n = 3$) or there were software problems that affected data collection ($n = 1$). Uncorrectable artifacts were defined as spurious waveforms (i.e., extreme increases in vaginal pulse amplitude) that constituted a large proportion of the trial (i.e., more than 25%), where manual correction by removal would have resulted in a large proportion of missing data.

Measures

Experimental Stimuli

The experimental stimuli consisted of eight, 300-s audio-visual film clips. Four of the film clips were sexually explicit, depicting a man and a woman engaging in sexual activities that increased in intensity from kissing and undressing, to oral sex, to penetrative intercourse culminating in female orgasm (different couples in each clip). The sexual film clips were selected from female-oriented commercially available DVDs. The other four film clips were from four different non-sexual nature documentaries during which there was no reference to sex or reproduction. Pilot testing using the vaginal photoplethysmograph revealed that each film clip elicited the intended physiological and subjective sexual response (i.e., a genital response during sexual film clips but not during non-sexual film clips). Two additional 90-s non-sexual film clips were used as adaptation stimuli. All stimuli were presented on a 52 cm computer monitor situated at eye-level approximately 1.5 m from the participant. Participants heard the audio component through noise-cancelling headphones.

Vaginal Vasocongestion

A vaginal photoplethysmograph (VPP; Technische Handel-sonderneming Coos, Purmerend, The Netherlands) was used to assess changes in vaginal pulse amplitude (VPA). Data were recorded continuously throughout each stimulus at a rate of 10 samples/s, band-pass filtered (0.5–10 Hz) and digitized (40 Hz) using a Limestone Technologies Inc. (Odessa, ON, Canada) DataPac_USB and Preftest software, Version 10. A placement device attached to the cable of the VPP ensured that the orange-red spectrum light source and phototransistor (i.e., light detector) remained inserted to the correct depth (5 cm from the placement device) and orientation. Prior to data analysis, an experimenter (masked to experimental conditions) removed movement artifacts by visual inspection (M movement artifacts per valid participant = 4.7). After each testing session, the VPPs were subjected to a high-level disinfection protocol (Prause & Janssen, 2005).

Introital Lubrication

Inspired by Carranza-Lira et al. (2003), we designed a measurement device to assess lubrication at the introitus (*litmus test strip*, LTS). Using medical-grade adhesive, a strip of blue litmus paper (4.7 cm × 0.6 cm; Precision Laboratories, Cottonwood, AZ) was attached to a white plastic applicator (14.7 cm × 1.7 cm). Participants were instructed to place the LTS at their introitus for 60 s immediately following each film clip; new LTSs were used for each trial. The LTSs were inserted with the litmus paper side of the applicator facing downwards so that it was not visible to the participant. On the side facing upwards, a horizontal blue line was used as a placement marker, indicating the target depth (1 cm) of insertion. This marker ensured that participants would insert the LTS to a similar depth and that 3.7 cm of the litmus paper remained outside of the introitus. Participants were instructed to position a mirror in front of their vulva (propped against the chair and their leg) enabling them to see that the LTSs were consistently inserted to the correct depth. The participants were asked to place the mirror on a side table when not in use. To prevent the labia from touching the litmus paper (and affecting the measurement), participants were asked to keep their labia parted with one hand, while they inserted the LTSs with their other hand. This position was held for the entire 60 s while lubrication was assessed.

The amount of lubrication was quantified by measuring the length (in mm) of pink color change on the litmus paper. Based on pilot data, we recorded the highest continuous point of color change from the base of the litmus paper as an indication of lubrication. For some women, there were discrete color changes on other areas of the LTS that were likely caused by the labia coming in contact with the litmus paper.

Immediately following the session, two independent raters (masked to the trial number) measured the LTSs to the nearest .01 mm using digital calipers. The within-participant inter-rater Pearson r correlation for the six trials (four experimental and two adaptation trials) varied from 0.62 to 1.00 (overall average across all 19 participants = 0.92; median = 1.00). The average values for the two raters were used in the analyses reported below.

Self-Reported Arousal

After each stimulus presentation, participants rated their sexual arousal (*How aroused did you feel during the film?*) and perceived genital arousal (*How aroused did your genitals feel during the film?*) using a 9-point Likert scale, where 1 was the lowest level of response (i.e., no arousal) and 9 was the highest level of response (i.e., similar to the arousal experienced before orgasm). Questions were presented individually on the computer monitor; participants reported their arousal by pressing a button on a keypad.

Questionnaires

Participants completed a questionnaire regarding their biographical information, sexual history, and sexual interests. Sexual orientation was assessed using a series of questions adapted from the Kinsey scale (Kinsey, Pomeroy, Martin, & Gebhard, 1953).

Procedure

The Human Subject Research Committee at the University of Ottawa reviewed and approved all experimental procedures according to the ethical guidelines of the Canadian Tri-Council Policy Statement.

Screening

Prospective participants responded to advertisements via phone or e-mail and received preliminary information about the study. Eligibility was determined by a phone or e-mail interview. Participants who met the eligibility criteria and who remained interested in participating scheduled an appointment with the experimenter (second author). Participants were instructed to refrain from sexual activity for 24 h prior to testing and all forms of physical exercise for 1 h prior to testing (Meston & Gorzalka, 1996). Participants were also asked to refrain from using alcohol, tobacco, cold medications, and recreational drugs on the day of testing. Responses included in the questionnaire confirmed that all participants complied with these instructions.

Session

Participants were assessed individually. After the experimenter provided an explanation of the experimental procedure, including instructions on how to use the VPP and LTS, they read and signed the consent form. The experimenter then dimmed the lights and left the room, leaving participants to undress from the waist down. Participants were instructed to sit comfortably in the recliner situated in front of the computer monitor and to tell the experimenter when they were ready to begin. Communication was possible via an intercom system and text messages that appeared on the monitor in the participant room.

For 11 participants, genital responses were first assessed with the VPP and then assessed using LTSs. For the other eight participants, the order was reversed (the order was randomly determined). For each half of the session, participants were first presented with the two 90-s non-sexual adaptation stimuli. The adaptation trials served to familiarize participants with the procedure (these data were not used in the analyses). After the adaptation trials, participants were asked via a message that appeared on the computer monitor whether they had any questions or concerns before continuing with the session.

The experimental stimuli for each half of the session consisted of two 300-s sexual film clips and two 300-s non-sexual film clips (randomly selected from each set of four film clips). Film clip order alternated between sexual and non-sexual (e.g., sexual, non-sexual, sexual, non-sexual), and the type of film clip (sexual or non-sexual) shown first was counterbalanced. The interstimulus interval was 300 s. Participants were asked to respond to the films as naturally as possible and to avoid movement (e.g., muscle contractions, genital touching, coughing, or talking) during the films.

Prior to starting the half of the session involving the LTSs, participants were asked to lightly dry their vulva using a tissue provided (to remove or minimize any excess vaginal fluid that was not elicited by any of the films). Immediately following the end of each film clip, participants removed the LTS from the plastic resealable bag and placed it at the introitus, using the mirror to ensure proper placement. Once placed at the introitus, participants would say “start” out loud. After 60 s (timed by the experimenter), participants were presented with the word “stop” on the computer monitor. At this time, they removed the LTS and placed it back into the same plastic resealable bag. Each plastic bag was labeled and organized numerically on a side table next to participants so that they would know which LTS to use for each film (e.g., after the first film participants would use the bag labeled “1”).

The two post-stimulus questions appeared on the computer monitor 120 s after the end of the film clip to ensure that participants would answer the questions at exactly the same time in both halves of the session. Participants rated their

sexual arousal and perceived genital response using the keypad (in that order). After making the ratings, they were instructed to sit comfortably until the word “read” appeared on the computer monitor (180 s after the end of the film clip). At this time, participants were instructed to read aloud from a magazine (with no sexual content) for 120 s. This distraction task allowed the opportunity for the genital response to return to baseline levels. The beginning of the next film signaled to the participant to cease reading and watch the film.

With the exception of placing the LTS at the introitus following each film clip, the procedure and timing for the two half sessions were identical. Between each half of the session participants were given a short break to use the restroom (approximately 5 min). During this time, the experimenter prepared the room for the next half of the session.

After all experimental stimuli were presented, participants were asked to redress and complete the questionnaire. Upon completion of the questionnaire, the experimenter debriefed and compensated the participants \$50 (CDN). The entire study was approximately 2.5 h in length.

Design and Data Analysis

We used a 2 (Stimulus Type: Sexual/Non-sexual) \times 2 (Film Exemplar: First/Second) \times 2 (Film Presentation Order: Sexual First/Non-sexual First) \times 2 (Session Order: LTS First/VPP First) repeated-measures design for each of the dependent measures (VPP and LTS). We calculated overall mean VPA during the 300 s film clip, mean minus baseline (MMB; i.e., mean minus initial response at the film onset) as well as mean VPA during the final 60 s of the film clip. Overall mean VPA across the two sexual stimuli and VPA during the final 60 s for the sexual stimuli were highly correlated, $r(17) = .97$, as were mean VPA and MMB VPA, $r(17) = .79$, and MMB VPA and VPA during the final 60 s of the stimuli, $r(17) = .85$.

Results

Self-Reported Arousal

To examine if sexual films elicited self-reported arousal and if the device or the order of session had an impact on self-reported arousal, we used a 2 (Device: VPP/LTS) \times 2 (Stimulus Type) \times 2 (Film Exemplar) \times 2 (Session Order) mixed-design ANOVA. It was not possible to include the order of Film Presentation Order as a factor in this analysis because it was not crossed with the Device factor. The four-way interaction between device, stimulus type, film exemplar, and order of session was not significant, $F(1, 17) < 1$. Device did not interact significantly with any of the other factors and there was no main effect of device on self-reported arousal, $F(1, 17) < 1$,

suggesting similar levels of arousal were elicited by the films when the VPP and the LTSs were used.

There was a significant three-way interaction between stimulus type, film exemplar, and order of session, $F(1, 17) = 5.29, p = .03$. For participants who had the LTS measure first, the interaction between stimulus type and film exemplar, $F(1, 7) < 1$, was not significant and there was no main effect of film exemplar, $F(1, 7) < 1$; there was a significant main effect of stimulus type, $F(1, 7) = 37.85, p < .001, d = 2.91$, such that sexual stimuli ($M = 5.0, SD = 1.9$) elicited significantly greater self-reported arousal than non-sexual stimuli ($M = 1.0, SD = 0.0$). For participants who had the VPP measure first, there was a significant interaction between stimulus type and film exemplar, $F(1, 10) = 7.37, p = .02$. Follow-up *t* tests revealed that the first sexual film ($M = 4.6, SD = 1.4$) was significantly more arousing than the first non-sexual film ($M = 1.1, SD = 0.2$), $t(10) = 5.45, p < .001, d = 3.51$, and the second sexual film ($M = 5.2, SD = 1.7$) was significantly more arousing than the second non-sexual film ($M = 1.1, SD = 0.2$), $t(10) = 6.44, p < .001, d = 3.49$. In sum, the sexual stimuli were rated as more arousing than the non-sexual stimuli and equally so for the two genital measures.

Vaginal Vasocongestion

When examining the entire 300 s of the film clips, Fig. 1 shows that the sexual films produced more vasocongestion than the non-sexual films. A 2 \times 2 \times 2 \times 2 ANOVA revealed that the four-way interaction between stimulus type, film exemplar, order of film presentation, and order of session was not significant, $F(1, 15) < 1$. There were no significant interactions between any of the factors. There was no significant main effect of film exemplar, $F(1, 15) < 1$, order of film presentation, $F(1, 15) < 1$, or order of session, $F(1, 15) = 1.79, p = .20$. As expected, there was a significant main effect of stimulus type, $F(1, 15) = 27.24, p < .001, d = 0.85$, such that sexual stimuli ($M = 3.5 \text{ mV}, SD = 2.8$) resulted in significantly greater mean VPA than non-sexual stimuli ($M = 1.6 \text{ mV}, SD = 1.5$). The same pattern was found when examining MMB VPA and mean VPA during the final 60 s of each of the stimuli.

Introital Lubrication

Figure 2 shows the mean lubrication response to the sexual and non-sexual films. The four-way interaction between the type of stimulus, film exemplar, order of film presentation, and order of session was not significant, $F(1, 15) < 1$. All other interactions were not significant. There was no significant main effect of film exemplar, $F(1, 15) = 2.36, p = .15$, order of film presentation, $F(1, 15) < 1$, or order of session, $F(1, 15) = 1.84, p = .20$. There was a significant main effect of stimulus type, $F(1, 15) = 9.19, p = .008, d = 0.53$, such that sexual stimuli ($M = 16.9 \text{ mm}, SD = 6.6 \text{ mm}$) resulted in significantly

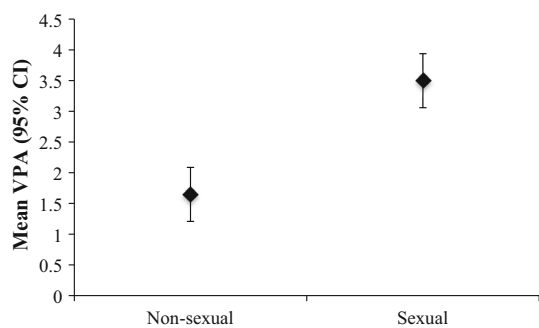


Fig. 1 Mean VPA (in mV) elicited by non-sexual and sexual films. Within-subjects 95 % confidence intervals were calculated using the method described in O'Brien and Cousineau (2014)

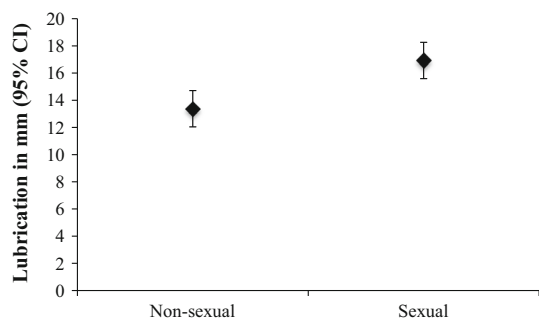


Fig. 2 Vaginal lubrication (in mm) elicited by non-sexual and sexual films. Within-subjects 95 % confidence intervals were calculated using the method described in O'Brien and Cousineau (2014)

greater lubrication than non-sexual stimuli ($M = 13.4$ mm, $SD = 6.7$ mm).

Figure 3 shows participant-level VPA (300 s) and LTS responses to non-sexual and sexual film clips. It can be seen that there was a wide range of baseline responding for both measures. All 19 participants (100 %) showed higher average VPA responses to sexual than to non-sexual film clips; 15 of 19 participants (79 %) showed higher average LTS responses to sexual than to non-sexual film clips.

Correlations Between Lubrication, VPA, and Reports of Arousal

Table 1 shows the between-subjects correlations between lubrication, VPA, self-reported arousal, and perceived genital response for sexual stimuli (averaged over the two sexual stimuli). All variables showed adequate normality; thus, parametric Pearson r correlations are reported. Lubrication was not significantly correlated with mean VPA for the entire stimulus, MMB VPA, or mean VPA during the final 60 s of the stimulus. Lubrication was, however, significantly positively correlated with both self-reported arousal and perceived genital arousal. None of the VPA measures were significantly correlated with either self-report measure of arousal.

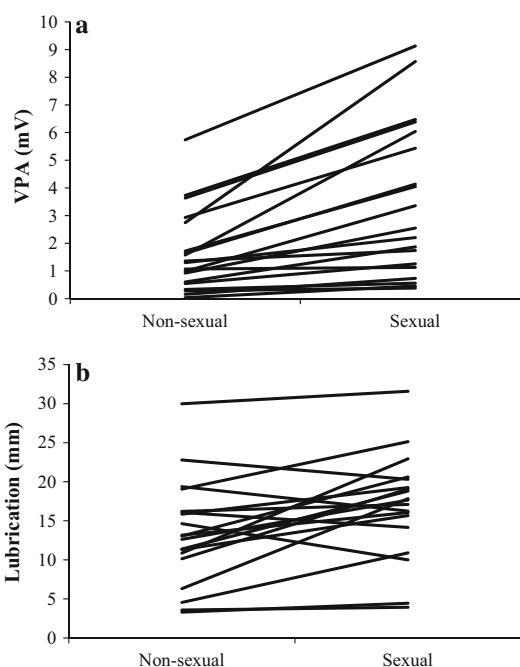


Fig. 3 Individual mean responses to non-sexual and sexual films for VPA (a) and LTS (b)

Discussion

We designed and assessed a method to quantify the amount of lubrication at the introitus elicited during the presentation of sexual and non-sexual stimuli. We also explored the relationships between introital lubrication, vasocongestion, and self-reported sexual arousal. The results of this initial study were promising, showing that the amount of lubrication elicited during sexual stimulation was higher than during non-sexual stimulation. Lubrication was significantly and positively correlated with self-reported sexual arousal, providing evidence of high sexual concordance (and convergent validity) using this new measure. Contrary to the hypothesis that vaginal vasocongestion would precede lubrication—and therefore be strongly related—we did not observe a significant relationship between VPA and introital lubrication.

The amount of lubrication was significantly greater after sexual stimuli compared to non-sexual stimuli, suggesting response specificity for this measure. This finding was consistent with our understanding of female sexual response, such that lubrication should be elicited in the presence of sexual cues to facilitate and prepare the lumen for pending sexual activity (Chivers, 2005, 2010; Laan, 1994; Laan & Everaerd, 1995; Laan & Janssen, 2007; Suschinsky & Lalumière, 2011).

Similar to studies assessing external genitalia and surface blood flow (e.g., thermal imaging and laser Doppler imaging) (Kukkonen, Binik, Amsel, & Carrier, 2010; Waxman & Pukall, 2009), we found a strong relationship between lubrication and self-reported sexual arousal. This high agreement suggests that

Table 1 Correlations between the measures of sexual arousal for sexual stimuli [95 % CI]

	Lubrication	Self-reported sexual arousal	Self-reported genital arousal
Lubrication	–	0.61 [0.22, 0.83]	0.51 [0.07, 0.78]
VPA (300 s)	0.13 [–0.34, 0.55]	0.006 [–0.45, 0.46]	0.06 [–0.41, 0.50]
VPA (final 60 s)	0.15 [–0.33, 0.57]	–0.08 [–0.52, 0.39]	0.02 [–0.44, 0.47]
VPA (MMB)	0.09 [–0.38, 0.52]	–0.07 [–0.51, 0.40]	0.05 [–0.41, 0.49]

women may use cues of wetness or lubrication when appraising their degree of arousal. Internal blood flow (as measured by the VPP) may be less perceptible to women, resulting in lower concordance estimates with this measure. Caution should be exercised when interpreting this result: Women may have received feedback when placing the LTS (e.g., differences in the ease of insertion between sexual and non-sexual films), thus inflating the concordance estimate. The strong correlation between lubrication and perceived genital arousal provides initial evidence of convergent validity for the new measure.

Lubrication was not significantly related to VPA in our sample. There are several possible explanations for this unexpected finding. First, perhaps the physiological process that the VPP purports to measure (i.e., vasocongestion) is not, in fact, the process that it actually measures (Levin & Wiley, 2008; Prause et al., 2013; Prause & Janssen, 2005). This idea is not new; other researchers have questioned the mechanism responsible for the increase in vaginal blood flow detected by the VPP (reviewed in Prause & Janssen, 2005), especially in light of the low correspondence between the VPP and self-reported arousal (Chivers et al., 2010). Gerritsen et al. (2009) suggested that the VPA signal might reflect an automatic preparatory response or genital activation, rather than a sexual response specifically. They observed an inverse relationship between VPA and clitoral blood volume (CBV) measured by a clitoral photoplethysmograph, which they used as evidence to suggest that these two signals may reflect different physiological processes involved in sexual arousal.

Consistent with the current finding that VPA and lubrication were not related, Heiman and Maravilla (2007) found that VPA was not significantly correlated with self-reported genital wetness or lubrication ($r = .10$). If changes in VPA reflect one of many co-occurring physiological processes involved in sexual arousal, rather than vasocongestion specifically (Prause & Janssen, 2005), or if VPA reflects an automatic preparatory response (Gerritsen et al., 2009), then we might not predict that changes in VPA be necessarily related to epithelial lubrication. Additional research is needed to decipher the physiological processes that the VPA signal reflects and how this relates to other processes involved in the female sexual response.

A second explanation for the lack of an observed relationship between the VPP and LTS measures may be the procedure

used in this study. Despite using a within-subjects design, it is possible that we did not find a significant relationship between the two measures because they were not acquired simultaneously. For instance, different degrees of genital arousal may have been elicited in the different sessions when assessed by the different devices. Examination of our self-report data provides some evidence against this possibility: Women reported similar levels of arousal regardless of the device used or the order of session.

Another difference is that VPA is a continuous measure and the response was recorded throughout the stimulus, whereas our LTS measure is discrete and was obtained post stimulus at the introitus, rather than within the vaginal lumen. These factors may have prevented a significant relationship to be detected. Our reliance on between-subjects correlations (necessary because of the small number of data points per participant) rather than within-subjects cross correlations to explore the relationship between VPA and LTS may have also prevented us from detecting an association (Chivers et al., 2010).

One final possibility for the absence of a significant relationship between VPA and lubrication is that lubrication, measured at the introitus, may have included fluids arising from areas other than the vaginal epithelium. For instance, the two Bartholin's glands that flank the opening of the vagina are thought to secrete a minute amount of fluid upon sexual arousal to lubricate the introitus and vulvar vestibule (for reviews, see Belzer, 1981; Berman & Bassuk, 2002; Masters, 1959; Wagner & Levin, 1978). It is possible that part of the lubrication captured by the LTS originated from the Bartholin's glands. If this was the case, then blood flow to the vagina would not necessarily be expected to relate to fluid secreted by the Bartholin's glands.

Limitations

It would be useful in future studies to measure lubrication both before and after each stimulus presentation to examine changes in lubrication attributable to the sexual and non-sexual films. This would control for individual variability in degree of lubrication, as well as provide an indication of whether or not lubrication was sustained throughout the testing session or whether lubrication returned to basal levels during the inter-stimulus intervals. Odeblad (1964) observed that a proportion

of vaginal fluids were reabsorbed by the vaginal epithelium, but little is known about the timing of this process. Using a pre- and post-design could provide valuable information on the time course of lubrication and reabsorption.

Unlike the VPP, the LTS did not include a placement device to ensure that it was inserted to a correct depth for each trial, which may have created inconsistencies in the measurement of lubrication. It would be ideal to create a device whereby actual quantity of lubrication is assessed rather than using the degree of color change as a proxy for the amount of lubrication. It is possible that individual differences in the viscosity of lubrication may have influenced how easily lubrication was absorbed by the litmus paper and consequently the length of color change. In addition to this, we did not control for menstrual cycle phase or hormonal influences in the current study. Changes in hormones throughout the menstrual cycle influence basal vaginal fluids (Eschenbach et al., 2000; Traish, Kim, Munarriz, Moreland, & Goldstein, 2002), but it is unclear how these changes influence the quantity of vaginal or introital lubrication formed during sexual stimulation. Future studies should control for cycle phase when assessing lubrication.

The larger effect size for VPA may mean that this measure is more sensitive and specific to sexual stimuli than the LTS, but it should be kept in mind that the sexual and non-sexual stimuli were chosen on the basis of such sensitivity and specificity in pilot work. Future studies should compare the two measures using other sexual stimuli.

Conclusions and Future Directions

Our results suggest that it is possible to quantify degree of lubrication at the introitus in women using a simple measurement device. These results extend our understanding of the female sexual response, demonstrating that lubrication is elicited in the presence of sexual cues in the laboratory and is strongly related to the subjective experience of arousal. This new measure offers a way to test hypotheses about the automaticity of women's genital responses (e.g., Chivers, 2005, 2010; Laan, 1994; Laan & Everaerd, 1995; Laan & Janssen, 2007; Suschinsky & Lalumière, 2011). In addition, this new measure, along with other measures of lubrication, may be of clinical utility, making it possible to physiologically measure the effects of pharmacotherapy and psychological treatments aimed at improving sexual difficulties (e.g., reduced genital arousal in women with Sexual Interest/Arousal Disorder) (American Psychiatric Association, 2013) and other physiological processes affecting sexual function (e.g., vaginal atrophy during menopause) in women (Sturdee & Panay, 2010).

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