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Concurrent Measurement of Genital Lubrication and Blood Flow During Sexual Arousal

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Highlights

- Sexual arousal measured in response to stimuli of varied sexual activity intensity.
- Genital lubrication measured using litmus test strips.
- Genital blood flow assessed using laser Doppler imaging.
- Greater genital responses for high-intensity sexual stimuli relative to nonsexual.
- Genital lubrication and blood flow correlated for high-intensity sexual stimuli.

Abstract

Genital lubrication and blood flow are theoretically related outcomes of women's sexual response that prepare the genitals for sexual activity. Despite its importance for sexual function, few experimental studies have directly assessed genital lubrication or empirically demonstrated how genital lubrication and blood flow relate during sexual arousal. In this study, 36 women viewed stimuli that varied by sexual activity intensity (nonsexual, low-intensity sexual, and high-intensity sexual) while their genital responses were assessed using concurrent measures of genital lubrication (using litmus test strips) and genital blood flow (using laser Doppler imaging). Both measures of genital response detected a genital response to high-intensity sexual stimuli relative to nonsexual; however, only the laser Doppler imager was sensitive to varying degrees of genital response elicited by stimuli of different sexual activity intensities. The two measures of genital response were suitable for repeated measurement within a single session. Genital lubrication and blood flow were positively correlated for the high-intensity sexual stimuli. Implications for the assessment of women's genital response and understanding women's sexual arousal are discussed.

Keywords: genital response; laser Doppler imaging; lubrication; sexual psychophysiology.

Concurrent Measurement of Genital Lubrication and Blood Flow

Female sexual response is composed of several related and observable physiological processes (Masters & Johnson, 1966). In terms of genital response, blood flow to the genitals increases during sexual stimulation, which results in genital swelling and lubrication, preparing the vaginal canal for penetrative sexual activity (Levin, 2003, 2004). Specifically, increased blood flow builds pressure within the blood vessels of the vaginal wall, forcing fluid from the vessels through the tissues and onto the surface of the vagina, where droplets of fluid combine to form a thin layer of lubrication (Levin, 2003; Masters & Johnson, 1966). A similar process is thought to occur in the labia minora to produce labial lubrication (Levin, 2003; Riley & Riley, 1983; cf. Masters & Johnson, 1966). Genital lubrication, which is comprised of vaginal and labial lubrication, increases comfort and pleasure during vaginal penetration and serves the function of protecting the vaginal tissues from friction and potential injury occurring during sexual activity (Levin, 2003). Despite its importance for sexual function, few experimental studies have directly assessed genital lubrication in the laboratory or empirically demonstrated how the processes of genital lubrication and blood flow relate during sexual arousal.

A variety of measurement methodologies have been used to assess women's genital response in the laboratory, with a primary focus on assessing genital swelling or *vasocongestion* (for reviews, see Kukkonen, 2014, 2015). In addition to measures of genital vasocongestion, initial methods of assessing lubrication included the use of absorbent filter paper or tampons which were weighed pre- and post-orgasm or sexual stimulation (Preti, Huggins, & Silverberg, 1979; Riley & Riley, 1983; Wagner & Levin, 1977), or an evaporimeter which measured humidity pre- and post-orgasm (Wagner, 1979). These methods detected increases in vaginal lubrication during sexual arousal; however, they were limited due to their invasive testing procedures (e.g., insertion of the

filter paper by an experimenter), and potential for vaginal drying precluding repeated measurements within a single session (Levin, 2003). The assessment of genital lubrication remained largely unaddressed until Carranza-Lira et al. (2003) used a pH test strip to assess vaginal dryness in postmenopausal women in a study that was not related to sexual arousal. Of note, none of these studies examined the relationship between genital lubrication and blood flow.

Recently, Dawson, Sawatsky, and Lalumière (2015) developed and tested a measure of genital lubrication—the litmus test strip—inspired by the pH test strip used by Carranza-Lira et al. (2003). The litmus test strip consists of a strip of blue litmus paper affixed to a plastic applicator, which is placed by the participant at the vaginal opening for 1 minute. The amount of genital lubrication is quantified by measuring the length of colour change on the litmus paper (in mm), with longer lengths indicating more lubrication. Dawson et al. (2015) found that the litmus test strip was a specific measure of genital response, such that the length of colour change on the litmus paper was longer in response to sexual stimuli ($M = 16.9$ mm, $SD = 6.6$) than nonsexual stimuli ($M = 13.4$ mm, $SD = 6.7$ mm). The litmus test strip exhibited convergent validity with subjective sexual arousal, such that the length of colour change on the litmus paper was strongly correlated with ratings of subjective sexual arousal across the group of participants ($r = .61$ [0.22, 0.83]). Interestingly, the length of colour change on the litmus test strip was not correlated with vaginal vasocongestion ($r = .13$ [-0.34, 0.55]), assessed by the vaginal photoplethysmograph, a tampon-shaped probe that is inserted vaginally to measure changes in the opaqueness of vaginal tissues using light-reflectance (Hatch, 1979).

In a second study employing the litmus test strip, Sawatsky, Dawson, and Lalumière (2018) presented a range of sexual stimuli from categories that have been shown to elicit varying degrees of genital response in previous research (i.e., male masturbation; female masturbation; male-male

oral sex and anal penetration; female-female oral sex and vaginal penetration; male-female oral sex and vaginal penetration; Chivers, Seto, & Blanchard, 2007). Contrary to their hypothesis that sexual stimuli of low versus high sexual intensity would elicit different lengths of colour change on the litmus paper (i.e., masturbation vs. partnered sex), Sawatsky et al. found that genital lubrication was specific to a single stimulus category (i.e., male-female partnered sex; $M = 19.0$ mm, $SD = 10.4$ mm) and that all other sexual stimuli elicited similar amounts of genital lubrication as the nonsexual stimulus ($M = 13.3$ mm, $SD = 7.4$ mm). For the male-female partnered sex stimulus, the length of colour change on the litmus paper was moderately correlated with subjective sexual arousal across the group of participants ($r = .34$ [-0.21, 0.73]), though not significantly so. Consistent with Dawson et al. (2015), genital lubrication was not correlated with vaginal vasocongestion ($r = .05$ [-0.47, 0.55]), assessed by the vaginal photoplethysmograph.

The findings that genital lubrication was not correlated with vaginal vasocongestion is puzzling (Dawson et al., 2015; Sawatsky et al., 2018), given that genital lubrication is purported to arise from increased genital vasocongestion (Levin, 2003; Masters & Johnson, 1966). Though the vaginal photoplethysmograph is a specific measure of genital response, detecting changes in vaginal vasocongestion in response to sexual (but not emotionally laden nonsexual) stimuli (Laan, Everaerd, & Evers, 1995; Suschinsky, Lalumière, & Chivers, 2009), it provides an indirect measure of vasocongestion and the precise physiological process it measures remains unclear (Prause & Janssen, 2005). Thus, the relationship between genital vasocongestion and lubrication during sexual arousal may be better assessed using a direct, rather than indirect measure of genital blood flow, such as the laser Doppler imager (LDI).

The LDI measures blood flow beneath the surface of the skin by shining an infrared laser beam onto the tissue to measure the concentration and speed of moving blood cells, using the

principles of the Doppler effect (i.e., the change in frequency that light undergoes when interacting with objects in motion; Wårdell, Jakobsson, & Nilsson, 1993). It was initially applied to the study of women's genital response by Styles, Maclean, Reid, and Sultana (2006) and subsequently found to be a specific measure of genital response, detecting changes in blood flow in response to sexual, but not emotionally laden, nonsexual stimuli (Waxman & Pukall, 2009). The LDI is also sensitive to the differences in genital blood flow produced by women with and without a genital pain disorder (i.e., provoked vestibulodynia; Boyer, Pukall, & Chamberlain, 2013) as well as women who have given birth vaginally or not given birth (Cappell, Bouchard, Chamberlain, Byers-Heinlein, & Pukall, 2018). Furthermore, changes in blood flow assessed by the LDI exhibits moderate convergent validity with subjective sexual arousal (Waxman & Pukall, 2009; cf. Boyer, Pukall, & Holden, 2012) and with vaginal vasocongestion assessed using the vaginal photoplethysmograph (Bouchard, Chivers, & Pukall, 2017). Given its measurement properties, the LDI is an ideal device to use for examining the relationship between genital blood flow and lubrication.

Previous research has established the specificity with which the litmus test strip and LDI measure genital responding in women; however, neither measure has been shown to be sensitive to varying degrees of genital response (Bouchard et al., 2017; Sawatsky et al., 2018). Conversely, studies of genital response using vaginal photoplethysmography and thermography demonstrate an intensity effect whereby reliable differences are detected across stimuli of varying sexual activity intensities (e.g., Chivers et al., 2007; Prause & Heiman, 2009; Suschinsky et al., 2009). Given that the sensitivity of the litmus test strip and LDI have each only been examined in a single study (with small sample sizes), it remains unclear whether these direct measures of genital response are sensitive enough to detect varying degrees of genital lubrication and blood flow,

including low levels of responding, or if the litmus test strip and LDI tend to measure the presence/absence of genital response to sexual stimuli.

An additional consideration is whether the litmus test strip and LDI are amenable to repeated measurement within a single session, with each measure being vulnerable to distinct challenges. Previous measures of genital lubrication tended to induce vaginal drying (Levin, 2003), and although there is no evidence that the litmus test strip reduces moisture with repeated measurement, this question has not been directly tested. The effects of vaginal drying (if any) during repeated measurement could be directly tested by comparing baseline lubrication at the outset of a session to subsequent responses measured after the presentation of a nonsexual stimulus during the experimental session. For LDI, a potential concern for repeated measurement is the lack of a return to baseline response between each stimulus presentation, resulting in a gradual increase in blood flow across the experimental session. The potential effect of repeated measurement on genital blood flow can be assessed by comparing baseline blood flow at the outset of a session to blood flow during subsequent presentations of nonsexual stimuli in the experimental session.

The purpose of this study was to further assess the measurement properties of the litmus test strip and LDI. Specifically, we aimed to: (1) assess the sensitivity of the litmus test strip and LDI to different degrees genital response elicited by stimuli of varying sexual activity intensities; (2) investigate whether genital lubrication and blood flow are affected by repeated measurement in terms of vaginal drying and poor return to baseline blood flow, respectively; and (3) examine the relationship between genital lubrication (litmus test strip) and genital blood flow (LDI). For the first aim, we predicted that the litmus test strip and LDI would be sensitive to varying degrees of genital lubrication and blood flow elicited by nonsexual, low-intensity sexual, and high-intensity sexual stimuli. For the second aim, we expected that genital responses for the initial

baseline stimulus and subsequent nonsexual stimuli would be similar for genital blood flow and lubrication, respectively, as indicated by small effect sizes. For the third aim, we hypothesized that genital lubrication and blood flow would be positively correlated for low- and high-intensity sexual stimuli.

Method

Participants

Participants were recruited through advertisements for a “women’s sexual arousal study” posted in the Kingston, Ontario community and on the Queen’s University campus as well as on classified advertisement (i.e., Kijiji) and social networking (i.e., Facebook, Twitter) websites between January and September 2015. The inclusion criteria required women to be between the ages of 18 and 40 years; be fluent in English; not be experiencing menopause; not smoke cigarettes (see Battaglia et al., 2011); have no history of sexual response difficulties; have no history of mental illness or substance abuse; have no genital piercings; have no current use of medication known or suspected to influence sexual functioning (see Meston & Frolich, 2000); have no known active sexually transmitted infections (STIs); report being sexually aroused by depictions of men and women engaging in sexual activities; have previously watched a sexually explicit film; have a regular menstrual cycle; and not be pregnant or have given birth.

There were 116 women who responded to the advertisements. Of these, 32 women expressed initial interest in the study, but did not follow-up after being contacted for screening, 12 declined participation after receiving more information about the study, and 20 were not eligible to participate. Of the 52 women who were eligible to participate, 41 scheduled an appointment, and 40 attended the experimental session. Four women were excluded from the analyses due to an absence of colour change on three or more of the litmus test strips ($n = 3$) and visible spotting on

the litmus test strips ($n = 1$). The final sample consisted of 36 cisgender women. Demographic characteristics are presented in Table 1.

Measures

Structured interview and questionnaires. Participants responded to a structured interview about demographic information, including their age (*range* = 18 to 26 years), cultural background, education level, and relationship status. Self-reported sexual attractions to men and women were assessed using a single item adapted from the Kinsey scale (Kinsey, Pomeroy, Martin, & Gebhard, 1953). Participants also self-reported their sexual identity. The Female Sexual Function Index (Rosen et al. 2000) and Sexual Arousalability Inventory (Hoon, Hoon, & Wincze, 1976) were collected but not analyzed in this study.

Experimental stimuli. The experimental stimuli comprised seven, 270 s audiovisual stimuli, with two exemplars from three stimulus categories: nonsexual (nature scenes), low-intensity sexual (clothed, mixed-sex couples kissing and caressing), and high-intensity sexual (nude, mixed-sex couples engaging in penile-vaginal intercourse) as well as an additional nonsexual stimulus presented to assess baseline genital responding (nature scenes). The sexual stimuli included sexual vocalizations and the nonsexual stimuli were narrated by a male actor. To create the low-intensity sexual stimuli, six 90 s film clips were selected from commercially available films and grouped into sets of three to create two 270 s exemplars. For the high-intensity sexual stimuli, six 90 s film clips were selected from open-access pornography websites and grouped into sets of three to create the two exemplars. This montage stimulus format was selected to ensure that the intensity of sexual activity was maintained for the duration of the stimulus, as opposed to using stimuli that follow a traditional sexual script of increasing stimulus intensity. This approach was adopted with the aim of maintaining participants' attention and interest

throughout each 270 s sexual stimulus so as to prevent habituation effects (Dawson, Lalumière, Allen, Vasey, & Suschinsky, 2013; Dawson, Suschinsky, & Lalumière, 2013). After each film, the participants were asked to rate the sexual intensity of the sexual activity depicted in the stimulus (*“How sexually intense was the activity in the film?”*) which was rated on a 10-point Likert scale, where 0 represented the lowest level of sexual intensity (*not at all*) and 9 was the highest level (*extremely*).

Two additional 30 s nonsexual stimuli were used as adaptation stimuli (data not used in analyses). The adaptation stimuli provided two practice trials to ensure that participants knew how to use litmus test strip prior to the baseline measurement of genital lubrication. The adaptation stimuli and nonsexual stimuli contained a single film segment. Nonsexual stimuli were selected from commercially available nature documentaries about plants and animals and were devoid of sexual content (i.e., no discussion or depiction of reproduction).

Subjective sexual arousal. Participants were instructed to rate their subjective sexual arousal continuously on a 10-point Likert scale from 0 (*no arousal at all*) to 9 (*highest arousal ever experienced*) throughout each stimulus presentation using a handheld remote. Orgasm was not included as part of the upper limit of the scale because orgasm rarely occurs in laboratory experiments (Laan, Everaerd, van der Velde, & Geer, 1995). Computer software read back the participant's numerical rating on the scale each time they changed their rating or if their rating remained stable for 30 s (Kukkonen, Binik, Amsel, & Carrier, 2010).

Participants were also asked to rate their sexual arousal (*“How aroused do you feel?”*), perceived genital arousal (*“How aroused do your genitals feel?”*), and perceived genital lubrication (*“How wet or lubricated do your genitals feel?”*) before and after each stimulus on a 10-point Likert scale, where 0 represented the lowest level of response (e.g., *no arousal*) and 9 was the

highest level of response (e.g., *highest arousal ever experienced*). The pre- and post-stimulus questions appeared successively on the same television screen as the experimental stimuli. Participants answered the questions out loud and a research assistant recorded their responses.

Genital lubrication. Genital lubrication was assessed using a litmus test strip (Dawson et al., 2015). The litmus test strip consists of a strip of blue litmus paper (4.7 cm x 0.6 cm; Precision Laboratories, Cottonwood, AZ) attached lengthwise to a sterile white plastic applicator (14.7 cm x 1.7 cm) using double-sided medical-grade adhesive tape. On the other side of the applicator (the marker side), a piece of blue litmus paper (1.7 cm x 0.6 cm) was attached widthwise, 1 cm from the base of the applicator to aid with the placement of the litmus test strip during testing.

Consistent with Dawson et al. (2015), participants used a small, freestanding mirror to place the litmus test strip applicator at their vaginal opening for 60 s after the presentation of each stimulus. Participants were instructed to separate their labia with one hand to prevent them from coming into contact with the litmus paper. With the other hand, participants placed the litmus test strip applicator with the marker side facing up to assist with proper depth of insertion. A new litmus test strip applicator was used for each stimulus and placed in a resealable plastic bag after use.

Immediately following the experimental session, two independent raters (blind to stimulus type) used digital calipers to measure the length of colour change on the litmus paper (in mm). The highest continuous point of colour change was measured from the base of the litmus paper to the nearest 0.01 mm. The within-subjects interrater Pearson r correlation for the six experimental stimuli ranged from 0.60 to 1.00 ($M = 0.95$ for 36 participants; median = 0.98). The mean of the two raters' measurements was used in the analyses presented below.

Genital blood flow. Genital blood flow was assessed using a laser Doppler imager (moorLDI2-IR laser Doppler imager, Axminster, England). Three 90 s scans were taken during each of the 270 s experimental stimuli. A low power laser beam scanned the genital region, generating a 9.6 cm high and 4.8 cm wide colour image on a laptop computer (Toshiba Corp., Tokyo, Japan) where the continuum of colours represents differing amounts of perfusion (i.e., blood flow to the tissue). The sensitivity of the laser was preset for each participant for a distance of 40-50 cm and room temperature was maintained between 22-26°C throughout testing (Waxman & Pukall, 2009). To facilitate the identification of different structures in the scanned area, a photograph of the genital region was generated prior to the presentation of the adaptation stimuli. Blood flow was measured in flux units, which consist of the product of the mean concentration and speed of moving blood cells (Leahy, de Mul, Nilsson, & Maniewski, 1999).

Using the photograph of the scanned area, two independent raters (blind to stimulus type) generated an elliptical region of interest (ROI) for each participant, which spanned from the anterior to the posterior commissures and included the visible areas of their clitoral hood, labia minora, and vaginal opening. Genital blood flow was measured within each ROI, which were consistent within participants across all scans, but varied between participants due to individual variation in genital morphology. The within-subjects interrater Pearson r correlation for the six experimental stimuli ranged from 0.78 to 1.00 ($M = 0.97$ for 36 participants; median = 1.00). The mean of the two raters' measurements was used in the analyses presented below.

Procedure

The Health Sciences Research Ethics Board at Queen's University reviewed and approved all experimental procedures. Prospective participants responded to advertisements and were screened for eligibility. Interested and eligible women were scheduled for an appointment and

instructed to refrain from sexual activity for 24 hours and physical exercise 1 hour prior to testing (Meston & Gorzalka, 1996) as well as from using alcohol or recreational drugs on the day of testing. Naturally-cycling women were tested between days 5 and 12 of their menstrual cycle (Slob, Bax, Hop, Rowland, & van der Werff Ten Bosch, 1996), whereas those taking hormonal contraceptives were tested when they were not menstruating.

Participants were tested individually by a female research assistant. After receiving a detailed explanation of the study procedures, participants provided verbal and written consent. The experimental session involved a structured interview, questionnaires completed on an iPad (Apple Inc., Cupertino, California, USA), and the sexual arousal assessment in this order. The sexual arousal assessment was conducted in a dimly lit, private area of the laboratory that was completely enclosed by floor-to-ceiling length curtains. The participant was asked to undress from the waist down, sit in the lithotomy position on the gynecological examination table, and lightly dry her vulva with a tissue to remove any excess vaginal fluid. Once the participant was in position, the research assistant positioned the LDI scan head without touching the participant's genital region or body. After positioning the LDI, the research assistant left the curtained area and communicated with the participant via text prompts presented on the television screen (1.5 m from the participant).

The participant first watched the two 30 s adaptation stimuli to practice using the litmus test strip, followed by the baseline stimulus. The remaining six experimental stimuli were presented in a quasi-randomized order (i.e., no two stimuli of the same type were presented consecutively). Pre- and post-stimulus questions appeared on the television screen before and after each stimulus. Subjective sexual arousal was assessed continuously throughout each of the seven experimental stimuli. Upon completion of the 2-hour study, the research assistant debriefed and thanked the participant for their time and provided \$25 CAD compensation.

Data Reduction

Data were analyzed using IBM SPSS Data Analysis software (Version 25). For LDI data, we calculated the overall mean flux units across the three 90 s scans for each stimulus (270 s) as well as mean flux units during the final 90 s of the experimental stimuli. We followed the same data reduction procedures for the continuous subjective sexual arousal data, whereby we calculated an overall mean rating across each stimulus (270 s) as well as the mean of the ratings during the final 90 s of the experimental stimuli.

Manipulation Check

Sexual activity intensity and subjective sexual arousal were subjected to separate 3 (stimulus type) $\times$ 2 (stimulus exemplar) within-subjects ANOVAs. There was no significant interaction or main effect of stimulus exemplar ($ps \geq .13$) for sexual activity intensity. Ratings of sexual activity intensity differed significantly as a function of stimulus type, $F(2, 70) = 217.65$, $p < .001$, $\eta_p^2 = .86$. A similar pattern was observed for subjective sexual arousal. Paired samples t -tests revealed that high-intensity sexual stimuli elicited the greatest intensity and arousal ratings, followed by low-intensity sexual stimuli, and then nonsexual stimuli (see Table 2).

Results

Do genital lubrication or blood flow differ by stimulus type?

Figure 1 shows the mean genital lubrication to the nonsexual, low-intensity sexual, and high-intensity sexual stimuli (270 s). A 3 (stimulus type) $\times$ 2 (stimulus exemplar) within-subject ANOVA revealed a significant main effect of stimulus type, $F(2, 70) = 3.71$, $p = .03$, $\eta_p^2 = .10$. There was no significant main effect of stimulus exemplar, $F(1, 35) = .09$, $p = .77$, $\eta_p^2 = .002$, and no significant interaction between stimulus type and stimulus exemplar, $F(2, 70) = .40$, $p = .67$, $\eta_p^2 = .01$. Follow-up paired-samples t -tests revealed that the high-intensity sexual stimuli ($M =$

16.40, $SD = 9.86$) elicited significantly greater genital lubrication than the nonsexual stimuli ($M = 13.52$, $SD = 7.09$), $t(35) = 2.55$, $p = .02$, $d = .46$. The low-intensity sexual stimuli ($M = 14.56$, $SD = 8.03$) did not elicit a significantly different amount of genital lubrication than the nonsexual stimuli, $t(35) = 1.08$, $p = .29$, $d = .18$, or the high-intensity sexual stimuli, $t(35) = 1.65$, $p = .11$, $d = .28$. Of the 36 participants in the sample, 20 participants (56%) exhibited greater genital lubrication in response to low-intensity sexual stimuli than to nonsexual stimuli and 24 participants (67%) exhibited greater genital blood flow to the high-intensity sexual stimuli than to nonsexual stimuli.

Figure 2 shows the mean genital blood flow to the nonsexual, low-intensity sexual, and high-intensity sexual stimuli (270 s). A 3 (stimulus type) $\times$ 2 (stimulus exemplar) within-subject ANOVA revealed a significant main effect of stimulus type, $F(2, 70) = 74.07$, $p < .001$, $\eta_p^2 = .68$. There was no significant main effect of stimulus exemplar, $F(1, 35) = 1.99$, $p = .17$, $\eta_p^2 = .05$, and no significant interaction between stimulus type and stimulus exemplar, $F(2, 70) = 1.24$, $p = .28$, $\eta_p^2 = .03$. Follow-up paired-samples t -tests revealed that the high-intensity sexual stimuli ($M = 731.13$, $SD = 191.26$) elicited significantly greater genital blood flow than the nonsexual stimuli ($M = 506.02$, $SD = 85.19$), $t(35) = 8.98$, $p < .001$, $d = 1.95$, and the low-intensity sexual stimuli ($M = 532.11$, $SD = 102.19$), $t(35) = 8.41$, $p < .001$, $d = 1.71$. Similarly, the low-intensity sexual stimuli elicited significantly greater genital blood flow than the nonsexual stimuli, $t(35) = 4.20$, $p < .001$, $d = .78$. The same pattern was found when examining mean genital blood flow during the final 90 s of the experimental stimuli. Of the 36 participants in the sample, 27 participants (75%) exhibited greater genital blood flow in response to low-intensity sexual stimuli than to nonsexual stimuli and 35 participants (97%) exhibited greater genital blood flow to the high-intensity sexual stimuli than to nonsexual stimuli.

Are genital lubrication or blood flow impacted by repeated measurement?

To examine whether genital lubrication was impacted by repeated measurement of sexual response (i.e., vaginal drying), genital lubrication for the initial baseline stimulus was compared to the average genital lubrication elicited during the presentation of the nonsexual stimuli using a paired-samples *t*-test. Figure 1 shows that the nonsexual stimuli ($M = 13.52$, $SD = 7.09$) did not elicit a significantly different amount of genital lubrication than the initial baseline stimulus ($M = 13.38$, $SD = 8.62$), $t(35) = .11$, $p = .92$, $d = .02$.

The same pairwise comparison was conducted for genital blood flow, with the aim of assessing whether genital blood flow gradually increased with repeated measurement of sexual response (i.e., poor return to baseline). Figure 2 shows that genital blood flow was significantly greater during the presentation of the initial baseline stimulus ($M = 520.30$, $SD = 86.70$) compared to the nonsexual stimuli ($M = 506.02$, $SD = 85.19$), $t(35) = 2.11$, $p = .04$, $d = .35$.

Are the indices of sexual arousal correlated?

Between-subjects correlations showed that there was a moderate, positive, and significant relationship between genital lubrication and blood flow during the high-intensity sexual stimuli, $r(34) = .41$, $p = .01$, and a low, positive, and nonsignificant relationship for the low-intensity sexual stimuli, $r(34) = .25$, $p = .15$. The same pattern was found for mean genital blood flow during the final 90 s and genital lubrication for the high-intensity sexual stimulus, $r(34) = .40$, $p = .02$, and the low-intensity sexual stimulus, $r(34) = .26$, $p = .13$.

Table 3 shows the between-subjects correlations for ratings of subjective sexual arousal and each measure of genital response for the low- and high-intensity sexual stimuli. Continuous ratings of subjective sexual arousal exhibited a moderate, positive, and nonsignificant correlation with mean genital blood flow during the high-intensity sexual stimuli. Between-subjects correlations for post-stimulus ratings of sexual arousal and the two types of genital response were

in the low, positive range for the low- and high-intensity sexual stimuli. The same pattern was found when examining mean genital blood flow during the final 90 s of the sexual stimuli.

Discussion

The aims of the current study were to further investigate the measurement properties of the litmus test strip and LDI and, for the first time, examine the relationship between these direct measures of genital response in women. Replicating previous research, the litmus test strip detected a sexual response for high-intensity sexual stimuli (Dawson et al., 2015), but did not show evidence of sensitivity to varying degrees of genital response (Sawatsky et al., 2018). As expected, the LDI was sensitive to varying degrees of genital response elicited by low- and high-intensity sexual stimuli. With respect to the use of repeated measurement within a single session, genital lubrication assessed during initial baseline stimulus was similar to genital lubrication for subsequent nonsexual films, whereas initial genital blood flow during baseline stimulus was significantly greater than blood flow assessed during subsequent nonsexual films. Genital lubrication and blood flow were significantly and positively correlated for the high-intensity sexual stimuli; however, contrary to previous research, neither genital response type was significantly related to ratings of subjective sexual arousal.

Litmus Test Strip

This study replicated the initial litmus test strip study by Dawson et al. (2015), using concurrent rather than sequential measurement of genital blood flow. The three studies conducted to date exhibited remarkably consistent lengths of colour change for nonsexual stimuli ($M = 13.3$ to 13.5 mm, $SD = 6.7$ to 7.4 mm), which may reflect the basal amount of fluid that is present in the genital region (Levin, 2003) and could be used as indicator of standard, nonaroused lubrication. This study was the first to show that an initial assessment of genital lubrication prior to the

presentation of any sexual stimuli does not significantly differ from assessments following subsequent nonsexual stimuli, thus supporting the viability of repeated measurements using the litmus test strip and reinforcing the standard litmus test strip measurement of ~13 mm, on average, for basal lubrication in control samples of premenopausal women.

There was more variability in the average length of genital lubrication produced by the high-intensity sexual stimuli across studies ($M = 16.4$ to 19.0 mm, $SD = 6.6$ to 10.4 mm), likely owing to the use of different sexual stimuli (i.e., penile-vaginal penetration vs. kissing, undressing, oral sex, and penile-vaginal penetration) and the variations in methodology needed to accommodate concurrent measurement of genital blood flow in this study (i.e., lithotomy position with legs apart vs. seated with legs closed). There was also substantial variability in genital lubrication assessed within this study. The overall observed pattern of lubrication was consistent with our expected stimulus intensity effect, albeit not significant for the low-intensity stimulus. This is interesting given that we did observe a stimulus intensity effect for genital blood flow and the two genital measures were moderately correlated. The detection of small changes in genital blood flow in the absence of changes in genital lubrication could be interpreted as the relative insensitivity of the litmus test strip to capture small changes in genital lubrication or perhaps genital lubrication is only appreciably produced at greater levels of genital response (Sawatsky et al., 2018).

Laser Doppler Imager

This study is the first to show that the LDI is sensitive to participants' varying degrees of genital response, suggesting that the device is suitable for assessing even small changes in genital blood flow (cf. Bouchard et al., 2017). The capability to detect small changes in genital blood flow in this study means that the LDI can be used to examine relative responding to varied stimulus

categories using a within-subjects design as well as with clinical populations that are expected to have reduced genital responses (e.g., Sexual Interest/Arousal Disorder [SIAD]).

The greater degree of genital blood flow elicited during the initial baseline compared to the subsequent nonsexual stimuli suggests that repeated exposures to sexual stimuli during an experimental session does not result in a gradual increase in genital blood flow, once again supporting the feasibility of repeated measurements using the LDI. Heightened genital blood flow during the initial baseline stimulus compared to subsequent nonsexual stimuli—albeit with a small to moderate effect size—may have been the result of anticipatory sexual arousal at the outset of the experimental session. Although this study presented participants with two 30 s adaptation stimuli prior to the presentation of the baseline stimulus, typical LDI procedures consist of showing a 15-minute nonsexual stimulus (acclimatization) prior to the presentation of the baseline stimulus to ensure that participants have acclimated to the experimental setting (e.g., Boyer et al., 2012, 2013; Waxman & Pukall, 2009). Findings from this study support the continued use of an acclimatization film, in addition to the presentation of additional nonsexual exemplars within a single session to acquire more reliable estimates of genital blood flow at nonaroused levels. Doing so also ensures that changes in genital blood flow elicited by sexual stimuli are not obscured by inflated estimates of baseline blood flow, particularly if mean minus baseline scores are calculated.

Correlations Among Measures of Sexual Arousal

Genital lubrication and blood flow exhibited a moderate, positive, and significant correlation in this study, but only for the high-intensity sexual stimuli. This finding supports the hypothesis that the previously observed weak correlations between vaginal vasocongestion and genital lubrication ($r = .13$ [-0.34, 0.55] and $r = .05$ [-0.47, 0.55], respectively) may be specific to using the vaginal photoplethysmograph—an indirect measure of vaginal vasocongestion (Dawson

et al., 2015; Sawatsky et al., 2018). Genital lubrication and blood flow exhibited a low, positive, and nonsignificant correlation for the low-intensity sexual stimulus in this study. Taken together, the results of this study are consistent with physiological models of genital response suggesting that heightened blood flow increases pressure within the blood vessels of the vaginal wall, and this increase in pressure forces fluid from the blood vessels through the tissues of the vaginal wall onto the surface of the vagina (Levin, 2003, 2004). With this process in mind, we hypothesize that the low-intensity sexual stimulus did not elicit a sufficient genital blood flow response to produce a measurable amount of genital lubrication, which in turn resulted in a low correlation between the genital response types. Alternatively, genital lubrication may have been produced in the vaginal canal but did not descend to the introitus, perhaps due to insufficient time during a relatively short experimental trial (i.e., 270 s) or due to insufficient fluid volume, or both.

The correlation between subjective sexual arousal and each genital response type was low. That is, across this sample, participants with a greater degree of genital lubrication or blood flow did not tend to report a greater degree of subjective sexual arousal for a given stimulus and vice versa. Findings have been mixed with respect to between-subjects correlations between genital response and subjective sexual arousal for litmus test strip and LDI studies, with some samples exhibiting strong correlations (Dawson et al., 2015; Waxman & Pukall, 2009) and others exhibiting lower degrees of correspondence between genital response and subjective sexual arousal (Bouchard et al., 2017; Boyer et al., 2012; Sawatsky et al., 2018). Nonetheless, the low correlation between subjective sexual arousal and genital response in this study, particularly for genital lubrication, is surprising. We hypothesize that a number of factors may have contributed to this unexpected result, including differences in the sample sizes across studies, which would impact variability in response magnitude and the strength of the relationship between indices of

sexual arousal. Furthermore, methodological differences, including the use of different sexual stimuli and the timing of the assessment of subjective sexual arousal (Chivers, Seto, Lalumière, Laan, & Grimbos, 2010)¹, may have further contributed to differences in the strength of correlations between subjective sexual arousal and genital lubrication across studies.

Limitations

Given the sensitive nature of sexuality, responses to questions about sexual arousal may have been impacted by response biases in this study, particularly because participants were required to respond to pre- and post-stimulus questions out loud (cf. Boyer et al., 2012, 2013; Waxman & Pukall, 2009). If participants felt compelled to under-report their experience of subjective sexual arousal, the correlation between genital response and subjective sexual arousal may have been reduced in this study. However, the correlations between genital response and subjective sexual arousal remained low for the continuous subjective sexual arousal, which has been shown to be less biased by impression management than post-stimulus ratings (Huberman, Suschinsky, Lalumière, & Chivers, 2013). Also, participants did report differing degrees of subjective sexual arousal for the three stimulus types. As such, it is unlikely that the low correlations between subjective sexual arousal and genital response can be accounted for by underreporting. Nonetheless, future studies would benefit from using a more discrete method of collecting responses about subjective sexual arousal.

The litmus test strip is certainly a promising new measure of genital response that assesses an important outcome of sexual responding. As a measure, its chief limitation is the degree of subjectivity that is involved in measuring the length of colour change on the litmus paper. For the

¹ The degree to which genital response and subjective sexual arousal are related on an individual level—commonly known as *sexual concordance*—was not assessed in this study.

most part, colour changes are straightforward to assess—as evidenced by the high inter-rater reliability between the two raters in this study—however, some patterns of colour change are more ambiguous, and thus more difficult to measure with precision. If independent laboratories seek to employ the litmus test strip for future studies, having access to an instructional guide that outlines measurement procedures would be beneficial to ensure that a consistent method is used and that findings can be compared across studies.

Conclusions and Future Directions

This study extends previous research by showing that the LDI is sensitive to varying degrees of genital response, including small changes in genital blood flow. Additionally, the litmus test strip is capable of detecting a genital response, but perhaps only for stimuli that reach a certain threshold of genital blood flow. The results suggest that the litmus test strip and LDI are suitable for research designs involving repeated measurement of genital response in women. Further research is needed to understand the measurement properties of the litmus test strip in terms of sensitivity to varying degrees of genital response, but the relationship between genital lubrication and blood flow exhibited in this study is promising, especially because the two genital response types are theoretically related and are both direct measures of genital response. When used concurrently, the litmus test strip and LDI can provide insights about the various physiological components of women's genital response and could be used to investigate the time course of genital lubrication and blood flow. With continued development, the litmus test strip could be applied to the study of women's sexual dysfunction (e.g., Sexual Interest/Arousal Disorder [SIAD], Persistent Genital Arousal Disorder [PGAD]) with the aim of examining the correspondence between subjective and objective measures of sexual arousal at the extremes of women's genital response.

Declarations of interest: None.

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Table 1. *Demographic Characteristics.*

	<i>M (SD) or n (%)</i>
Age (in years)	20.7 (1.5)
Education	
Undergraduate	32 (89%)
Graduate or professional	4 (11%)
Relationship status	
Single	7 (19%)
Dating (geographically close)	13 (36%)
Dating (long-distance)	7 (19%)
Casual sex (one partner)	4 (11%)
Casual sex (multiple partners)	5 (14%)
Sexual attraction	
Androphilic	29 (81%)
Ambiphilic	6 (17%)
Gynephilic	1 (3%)
Cultural background	
Canadian	29 (81%)
Asian	3 (8%)
American	2 (6%)
Western European	2 (6%)
Hormonal contraceptive	
None	13 (36%)
Oral contraceptive pill	20 (56%)
Injection	2 (6%)
Vaginal ring	1 (3%)

Note. Androphilic = exclusive or predominant sexual attraction to men; Ambiphilic = substantial sexual attraction to men and women; Gynephilic = exclusive or predominant sexual attraction to women.

Table 2. *Ratings of sexual activity intensity and subjective sexual arousal elicited by nonsexual and sexual stimuli.*

	<i>M (SD)</i>	
	<u>Sexual activity intensity</u>	<u>Subjective sexual arousal</u>
Nonsexual	.01 (.08) ^a	.03 (.12) ^a
Low-intensity sexual	2.46 (1.62) ^b	1.76 (1.18) ^b
High-intensity sexual	5.78 (1.56) ^c	4.37 (1.43) ^c

Note. Different letters reflect significant differences for the pairwise comparisons of post-stimulus ratings of sexual activity intensity ($9.26 \leq ts \leq 22.29$, $ps < .001$, $1.80 \leq ds \leq 5.49$) and continuous ratings of subjective sexual arousal ($8.96 \leq ts \leq 18.25$, $ps < .001$, $1.88 \leq ds \leq 4.04$), respectively.

Table 3. *Correlations between sexual arousal ratings and genital response.*

	Genital lubrication		Genital blood flow	
	Low-intensity sexual	High-intensity sexual	Low-intensity sexual	High-intensity sexual
Continuous rating				
Subjective sexual arousal	.041 (.81)	.115 (.50)	.041 (.81)	.115 (.50)
Post-stimulus rating				
Subjective sexual arousal	.059 (.73)	.136 (.43)	.059 (.73)	.136 (.43)
Genital arousal	.168 (.33)	.111 (.52)	.168 (.33)	.111 (.52)
Genital lubrication	.167 (.33)	.258 (.13)	.167 (.33)	.258 (.13)

Figure 1. *Mean genital lubrication (mm) elicited by nonsexual and sexual stimuli.*

Note. Error bars represent within-subjects 95% confidence intervals, calculated using the method described in O'Brien and Cousineau (2014).

Figure 2. *Mean genital blood flow (flux units) elicited by nonsexual and sexual stimuli.*

Note. Error bars represent within-subjects 95% confidence intervals, calculated using the method described in O'Brien and Cousineau (2014).