Pupillary responses to static images of men and women. A possible measure of sexual interest?

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Abstract

The pupil dilates to images that are arousing. In Experiment 1 we examined if the pupil's response to brief presentations (2000 ms) of static images could be used to identify individuals' sexual orientation. Participants were grouped according to their self-reported gender and sexual orientation (male heterosexual $N = 20$, male bisexual $N = 13$, male homosexual $N = 19$, female heterosexual $N = 28$, female bisexual $N = 21$, female homosexual $N = 17$). Pupil size was monitored to images of men in semi-nude poses, women in semi-nude poses, or neutral images. Every group showed the same pattern of responses, with the greatest dilation to male images, then female images, and least dilation to the neutral images. Experiment 2 used more tightly controlled stimuli and tested at two different image durations (150 and 3000 ms). Both heterosexual men ($N = 18$) and women ($N = 20$) showed greater pupil dilation to images of nude men than to nude women. However, in Experiment 3, where we reduced the erotic content by using images of clothed models, both heterosexual men and women showed greater pupil dilation to images of women. The results showed that while the pupil does dilate strongly to sexual imagery, its response to these brief static images does not correspond to a person's sexual orientation in a simple manner.

Keywords: pupil dilation, bisexual, homosexual, heterosexual

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The pupil of the eye was first thought to respond to the affective content of images (Hess & Polt, 1960), with dilation or constriction depending on the affective valence of the stimulus. This early work has, however, been criticised due to the poor control of important stimuli parameters such as the luminance and contrast of the images (Bradley, Miccoli, Escrig, & Lang, 2008). More recent work has carefully controlled for these factors (Bradley et al., 2008; Snowden, O'Farrell, Burley, Erichsen, Newton, & Gray, 2016) and has demonstrated that the pupil dilates to stimuli with affective content irrespective of the valence of the affective content (i.e., to both positive and negative affective material). As images with erotic content should produce high levels of arousal they should also be associated with strong pupil dilations.

As expected, images with an erotic content have been shown to produce strong dilations (Henderson, Bradley, & Lang, 2014). It is, therefore, not surprising that people have tested whether the response of the pupil might be used to indicate sexual interest to specific stimuli. The earliest work in this area (Hess & Polt, 1960) suggested that heterosexual men and women could be clearly discriminated on the basis of their pupillary responses to images of nude men and nude women. In later work this was extended to show heterosexual and homosexual men could be discriminated using their pupillary response to similar stimuli (Hess, Seltzer, & Shlien, 1965). Indeed, the two groups showed no overlap at all in their pattern of results, which suggests that the technique could be highly accurate in its ability to identify sexual interest. However, these early studies were not well powered (N = 5 per group) and the stimuli were not well matched in term of physical properties (e. g., luminance of the images). Given that the primary role of pupil dilation and constriction is to regulate the amount of light reaching the retina, it is not surprising that the pupil's size is highly sensitive

to variations in luminance (Barbur, 2004) and that this variable needs to be carefully controlled before any claims that the affective content of the image causes changes in pupil size.

However, later studies, which attempted to compensate for these shortfalls, have not produced consistent results. Scott, Wells, Wood, and Morgan (1967) tested college students, but found no difference in the pupillary responses of men and women to slides of semi-nude male and female "pin-up" models, or between male heterosexual and male homosexual responses to these same stimuli. Hamel (1974) tested women's pupillary reactions to images of two men and two women in increasing states of undress. They claimed that pupil dilation increased with increasing state of undress only for male model number 1, but not for the three other models. However, they did find that responses to the male models were greater than for the female models, and that increasing states of undress were also associated with greater pupil dilation. The results of Hamel (1974) are hard to interpret given the very limited number of stimuli used, the lack of a control (neutral) stimulus, and that only women were tested (with no indication of their self-reported sexual preference). Aboyoun and Dabbs (1998) corrected many of these shortcomings and tested men and women who self-identified as heterosexual. They used several examples of each of the categories of stimuli (clothed men, clothed women, nude men and nude women), although no information was given about attempts to match the stimuli on any dimension (e.g., luminance). Following the initial pupillary light reflex (PLR; see Barbur, 2004), responses were greater to the nude stimuli than to the clothed stimuli. However, there were no differences in the responses of the men and women – both groups showed greatest pupil dilation when viewing nude male stimuli.

Interest in using the pupil as an indicator of sexual interest or sexual orientation has been recently renewed. Rieger and colleagues (Rieger et al., 2015; Rieger & Savin-Williams, 2012) have used video clips to investigate this issue. They demonstrated that, for men, pupil

responses followed stated sexual orientation, including dilation to both male and female images for bisexual men. Heterosexual women showed dilation to both male and female images. While these data do not fit closely to their stated sexual orientation, the results are commensurate with other measures that suggest that heterosexual women have a non-category specific sexual response (Chivers, Rieger, Latty, & Bailey, 2004; Chivers, Seto, Lalumiere, Laan, & Grimbos, 2010; Snowden & Gray, 2013). The video clips used in the Rieger and colleagues studies lasted many (30) seconds. Such stimuli may tap very different processes from the immediate reactions (within 1- 2 s) that some previous studies (e.g., Aboyoun & Dabbs, 1998) measured.

Attard-Johnson, Bindemann and Ciardha (2016) presented static images of males and females of different ages to groups of heterosexual men and women and also presented a "scrambled" version of the stimuli as a luminance control for the target images. They showed that images of females produced the greatest pupil dilation for both heterosexual men and heterosexual women, and that while responses to the images corresponded well to stated sexual interests for men, this was not so for the women.

Clearly, the early promise of pupillometry as a method to measure sexual interest has not yet been fulfilled. We, therefore, used more modern, well controlled, stimuli that were matched on luminance (see Snowden et al., 2016). Further, we attempted to examine sexual orientation across a wider range of sexual interests than previous studies using static images to see if pupillometry could be used a reliable indicator of a participant's sexual orientation. We hypothesised, in line with previous research on differences between men and women's sexuality (Chivers et al., 2004; Chivers et al., 2010; Chivers, 2017; Snowden & Gray, 2013) that men's pupil responses would follow their stated sexual preferences, with greater pupil dilation to female images for heterosexual men, and greater pupil dilation to male images for homosexual men. For bisexual men, we expected dilation to both male and female images,

and so included a control set of non-sexual images. For women, we expected heterosexual women to dilate to both the male and female images (in comparison to the non-sexual control images). For the homosexual women, most research (see Chivers, 2017) suggests a category specific response, so we hypothesised that homosexual women would show the greatest dilation to images of females. Finally, research on bisexual women is sparse and it is unclear as to whether they would show equal responses to male and female images (in line with their stated preference, and like we hypothesised for heterosexual women) or a greater response to female images (as might be predicted if they lie half-way between the predicted response of heterosexual and homosexual women).

Experiment 1

Method

All procedures for these experiments were given ethical approval from the Psychology Ethics Committee at Cardiff University.

Participants.

Participants were recruited from a range of advertisements, using both Facebook and Twitter. We also handed out leaflets and recruited participants from various events, including BiFest Wales, PrideCymru Mardi Gras, and the LGBT+ Society of Cardiff University. We encouraged participants to inform their friends about the experiment. We did not advertise for one or more particular group of people or sexual interest, but stressed that we were interested in human sexuality and that we wished to test people of all sexual interests. The leaflets/advertisements asked for participants willing to take part in research involving viewing images of a sexual nature and that we would be asking them about their sexual interests and behaviours. People who agreed to participate in the research gave contact details and were then contacted to arrange a time to be tested.

Our main hypothesis was that pupil dilation would be governed by the person's sexual interest in the picture and, based on the very strong results previously reported (see Hess & Polt, 1960; Hess et al., 1965), we expected to see large differences between our groups. Based on the aim of being able to detect these large effect sizes (d = .80) using standard conditions (α (two-tailed) = .05; β = .20) a power calculation produced N = 20 per cell (Cohen, 1988) and so we aimed to assess 120 people across the 6 cells of the research design.

In all, complete datasets were collected for 118 participants. The participants were assigned to one of six groups according to their scores on the Kinsey scale (Kinsey, Pomeroy, & Martin, 1948) and their stated gender. Scores of 0-1 were categorised as heterosexual, 2-4 as bisexual, and 5-6 as homosexual. Our group sizes were: female heterosexual = 28, female bisexual = 21, female homosexual = 17, male heterosexual = 20, male bisexual = 13, and male homosexual = 19. Demographic information for each group is given in Table 1. The groups did not differ in terms of age ($F(5, 117) < 1$). It should be noted that some of these groups fell below N = 20 suggested from the power analysis.

Stimuli and materials

Feeling thermometer. Direct ratings of feelings toward the construct pairs "sex with men" and "sex with women" were obtained using the feeling thermometer, which employs the heuristic of a thermometer. Participants rated feelings from "cold/unfavourable" at 0 to "warm/ favourable" at 100 by circling the appropriate number on the scale.

Pupillometry task. This task followed the procedures we had developed in previous studies of affective stimuli, and full details can be found in (Snowden et al., 2016). Test stimuli were chosen from the International Affective Picture System (IAPS: (Lang, Bradley, & Cuthbert, 2008) and contained three categories of stimuli: men (IAPs no: 4460, 4470, 4490, 4503, 4520, 4534, 4550, 4561), women (IAPs no: 4002, 4003, 4141, 4142, 4210, 4232, 4235, 4240), and neutral (landscapes and household objects; IAPs no: 5220, 5260, 5300, 5390,

5660, 5875, 7000, 7020). The pictures of men and of women all depicted a single person either nude or partially dressed. We made an approximate attempt to match the pictures according to pose, ethnicity, etc. but no formal measurements were made. In order to preserve the full effect of the stimuli it was decided to present the images in colour. The image properties were matched across groups. There were no differences in luminance values between any of the three image groups (p = .74), or any differences in contrast values (p = .17). This indicates that any differences observed between stimulus categories cannot be attributed to the physical properties of the stimuli, at least in terms of these dimensions.

All images were presented on a blank grey screen whose luminance was set to match the average luminance of the target images. This was set to 15 cd/m2 when the tasks were developed within the laboratory but may have differed for some people who were tested in other settings. We stress, however, that all measures presented as relative to the baseline pupil diameter; therefore, moderate changes in overall luminance would have no effect on this response. Each test stimulus was preceded by a blank grey screen presented for 2000 ms that was luminance matched to the target stimulus. The same blank grey screen followed all target stimuli as a recovery slide and was presented for 5000 ms to allow pupil size to return to baseline. All targets were presented for 2000 ms in a random order. Participants were simply told to maintain their fixation on the screen during the whole testing session. The experiment was controlled via Eprime software.

Pupil data acquisition, cleaning and reduction

A Tobii X2-60 Hz eye tracker recorded pupil data throughout each task, which allowed relatively free movement of the head during the task. The hardware consisted of an inconspicuous eye-tracking device located below the computer monitor that captured eye

movements by illuminating the pupil via an infrared light source and used two image sensors to record the reflection patterns. During recording, the eye tracker collected data every 16.67 ms. All measurements in this paper refer to the diameter of the pupil and are expressed in millimetres. The eye tracker was calibrated for each participant before each task using a 5-point calibration screen.

Data were recorded throughout each trial. We interpreted any pupil diameter change of +/- 0.38 mm within a 16.7 ms (one frame) interval as random fluctuations and removed these (Partala & Surakka, 2003). We also deleted data points surrounding missing data (within 33.34 ms) to avoid anomalous readings. A pre-stimulus baseline pupil size average of 200 ms was calculated for each trial and subtracted from each subsequent data recording to establish baseline-corrected pupil response across the trial. We calculated the mean pupil response at every data time-point across trials for each condition. Mean pupil response was not calculated at data time-points where there was missing data for more than 50 % of condition trials. Linear interpolation was used to estimate pupil diameter where missing pupil samples led to large fluctuations in the mean pupil change for the relevant condition, usually around image-offset.

Procedure

Participants were asked not to wear bifocal or varifocal glasses when they were tested. Before testing took place participants were given a detailed information sheet that explained the nature of the experiments, they were encouraged to ask questions, and informed that the data from the tasks would be kept confidential. All participants gave written, informed, consent to participate. We then asked participants to complete the demographic questionnaire that included questions about how they described themselves in terms of their sexuality, the Kinsey scale (Kinsey et al. 1948), and a ‘feeling thermometer’ about their sexual interests. Participants then completed a battery of tests that looked at different aspects of their sexuality

and included both the physiological recordings and behavioural tasks (for example using the implicit association test; Snowden, Wichter, & Gray, 2008). The pupil task was always completed as the final task in the series.

Participants were sat in a chair with their eyes approximately 57 cm from the screen. A brief (1 min) calibration task that involved the participant tracking a moving spot on the screen was then given. Participants were then given the following instructions:

"*You are going to see a fixation cross followed by several images. Some of these images will be of nude men/women. All you are required to do is look at these images – no response is required. It is important that you do not look away from the screen until instructed to do so by the experimenter. The experiment will last approximately 5 minutes*".

Results

Pupil size as a function of time from target stimulus onset is shown in Figure 1 for all participants combined. The onset of the stimulus triggered the PLR, with a latency of around 300 ms for all stimulus categories. However, from around 600 ms the data from the three categories begin to diverge.

The pupil showed the greatest dilation to the male stimuli, then the female stimuli, and the least dilation to the neutral stimuli. Figure 2 illustrates the data from each group individually. Visual inspection of these responses suggests that there are no obvious differences in the response of all six groups. Each group showed greater dilation to the sexual images in comparison to the control images, and greater dilation to the images of men in comparison to women.

This pattern of results was tested statistically. First, in order to quantify the response, we calculated the average pupil size over a test window of 1000 – 2000 ms (shaded area on Figure 1). This time window aims to avoid the pupil's initial light reflex but still index early activity due to dilation by the sympathetic system (Bradley, Sapigao, and Lang, 2017). This

time-window has also been shown to be robust against the effects of attention and habituation under similar paradigms (Snowden et al., 2016). The reliability of this measure was tested via split –half reliability using odd vs even numbered trials. Using the Spearman-Brown correction, the estimates were all reliable (male stimuli: $r = 0.81$; female stimuli: $r = 0.82$, neutral stimuli: $r = 0.69$, all ps < .001).

The means were inspected and showed no significant deviation from a normal distribution and so were subject to a mixed-factor analysis of variance (ANOVA) with a within participant factor of image (male, female, neutral) and a between participant factor of group (heterosexual men, heterosexual women, bisexual men, bisexual women, homosexual men, homosexual women). There was a main effect of image ($F(2, 224) = 253.0$, $p < .001$, $\eta p^2 = .69$). The main effect of image was further broken down in planned comparisons (t-tests), to show that in comparison to neutral stimuli, both male ($p < .001$) and female ($p < .001$) images produced greater pupil dilation. It was also found that male images produced a greater pupil dilation than the female images ($p < .001$).

There was no main effect of group ($F(10, 224) = 1.64$, $p = .10$, $\eta p^2 = .07$), nor any interaction between image and group ($F(10, 112) = 1.27$, $p = .28$, $\eta p^2 = .05$). Despite the lack of the predicted interaction within the ANOVA, possible differences between groups were further tested by calculating a “gender index” which was produced by calculating the difference in pupil size to the male and female images within the response window. These are displayed in Figure 3. For all groups, the score was positive and greater than zero (one-sample t-tests, all ps < .01), indicating greater pupil dilation to male images relative to female images. A series of t-tests between the conditions showed that homosexual women had a greater gender index than homosexual men ($p < .05$) and heterosexual women ($p < .05$). There was also a trend for homosexual men to have a smaller gender index compared to heterosexual and bisexual men ($p = .06$).

Discussion

Our results appear clear-cut in showing that the expected pupil dilation when a person is shown a semi-naked or naked picture of their "preferred" type of sexual stimuli is not present. Instead, all groups showed greater pupil dilation to the images of men as compared to images of women, irrespective of their stated sexuality. All groups showed the least pupil dilation to the neutral stimuli. A finer grain analysis showed that the tendency of the pupil to dilate more to images of men was smaller in homosexual men compared to heterosexual and bisexual men, and smaller in heterosexual women than homosexual women. This pattern is directly opposite to our predictions based on self-reported sexual interest.

Experiment 2

Clearly the results of Experiment 1 were not in line with our hypothesis. However, Experiment 1 had some limitations that may have influenced the results. First, while we matched the stimuli for brightness at a group level (in line with previous experiments – see Bradley, et al., 2008), we did not match them at an individual level. Second, the stimuli were presented in colour and there may have been unknown differences in colour content between the groups. Changes in stimulus colour from achromatic to chromatic have been shown to lead to a pupil response in both humans and animals (Barbur, Wolf, & Lennie, 1998; Gamlin, Zhang, Harlow, & Barbur, 1998), and complex images (such as used in the present experiments) presented in colour produce a greater pupillary light reflex than those in grayscale (Snowden et al., 2016). Finally, we presented the stimuli for 2000 ms which allowed time for several saccadic eye movements. Though recent evidence has shown that the pupil dilation to fear stimuli is apparent even for stimuli so brief that no eye movement can occur (Snowden et al., 2016), this has not been shown for sexual stimuli and cannot rule out that differential patterns of fixation may also contribute to the effects (see Bradley et al., 2017). Experiment 2, therefore, attempted to overcome these limitations by 1) ensuring all

images were greyscale, 2) ensuring all images were of equal luminance, 3) ensuring all images were of equal contrast, 4) presenting the images at either a long (3000 ms) duration or one so short (150 ms) that no saccade could be made. We also included, for comparison to the male and female only stimuli, images of couples in erotic positions (similar to those used in previous studies of sexual images; Henderson et al., 2014). We also examined if the mere presence of a person within the neutral images produced a different baseline to those without a person.

We again hypothesised that heterosexual men would show the greatest pupil response to the female images, while the heterosexual women would show dilation to both male and female images in comparison to the control images (of both types). We also hypothesised that both the heterosexual men and women would show strong dilation to images of couples (Henderson et al., 2014) and wanted to perform exploratory analyses to see if there were gender differences in levels of dilation. In line with most previous research (e.g., Rupp & Wallen, 2008) we hypothesised that men would have a greater dilation than women to this stimulus. Finally, we hypothesised that the results would be found at both stimulus durations.

Method

The procedures were similar in most details to those of Experiment 1, and so this section only highlights the differences from this study. The major differences were in the images used, the duration of the images, and that this study recruited from the general student population and therefore consisted of a large majority of students who described their sexual orientation as heterosexual. All statistical analyses only concern comparisons between heterosexual men and heterosexual women.

Participants were recruited via electronic noticeboard and word of mouth. The advertisement noted that the experiment would involve viewing images that had erotic content and a questionnaire that asked about their sexuality and attitudes towards sex, but not about

their own sexual activity. Based on a similar power calculation to Experiment 1, 43 participants were recruited (22 women, mean age = 21.7 years, *SD* = 2.0; 20 men, mean age = 21.6, *SD* = 3.72). Sexual orientation was again assessed via the Kinsey scale.

The images used were taken from both the IAPS and the Nencki Affective Picture System (NAPS; Marchewka, Zurawski, Jednorog, & Grabowska, 2014; Wierzba et al., 2015). The 50 images chosen fit into one of five categories: sexual images of males, sexual images of females; sexual images of heterosexual couples; neutral images of people; and neutral images without people. The images were chosen based on the arousal and valence ratings given by participants of the pilot studies for the IAPS and NAPS. The overall ratings (valence, arousal) of the images were: couples: *M* = 6.45, *SD* = 0.47; *M* = 5.67, *SD* = 0.40; females: *M* = 5.94, *SD* = 0.40; *M* = 5.35, *SD* = 0.21; males: *M* = 5.68, *SD* = 0.87; *M* = 4.87, *SD* = 0.74; neutral-person: *M* = 5.07, *SD* = 0.40; *M* = 3.19, *SD* = 0.36; neutral-no person: *M* = 5.31, *SD* = 0.35; *M* = 3.19, *SD* = 0.38.

Recent studies have highlighted the importance of the physical properties (e.g., luminance, contrast, colour) of images in determining pupil response (Bradley, et al., 2017; Snowden et al., 2016). Therefore, great care was taken to match the images on physical characteristics. Images were first edited to grayscale, using Photoshop Pro. Changes to grayscale do not seem to alter some physiological reactions to the emotional content (Codispoti, De Cesarei, & Ferrari, 2012). All 50 images were then edited to have a mean luminance of 95 units (*M* = 95.00, *SD* = 0.15), and a contrast of 60% (*M* = 60.01, *SD* = 0.35).

The 50 images were presented in a pseudorandom order for each block. In the first block the target duration was 150 ms and in the other it was 3000 ms. Each person took part in both blocks.

Results

In order to confine our analysis to people with a heterosexual orientation, five participants (3 men) were excluded as their Kinsey rating was 2 or more. The pupillometry data from one male participant were excluded as it did not meet our requirements for inclusion (see Experiment 1) in either task. Another male was excluded for the 3000 ms duration condition only for this reason. Hence, this left complete dataset for 20 women and 18 men (150 ms condition) or 17 men (3000 ms condition).

Pupil size as a function of time from target stimulus onset is shown in Figure 4 for all participants combined (left plot 150 ms duration, right plot 3000 ms duration). It is clear that image content produced dramatic differences for the 3000 ms condition, but only small changes for the 150 ms condition. We present the result separately for ease of understanding.

3000 ms condition. The onset of the stimulus triggered the PLR, with a latency of around 300 ms for all stimulus categories. However, from around 600 ms the data from the different categories begin to diverge. From this point to the end of the stimulus presentation (3000 ms), the pupil appeared most dilated to the couple stimulus, then the male stimulus, female stimulus, neutral person, and neutral no-person, in turn.

The pupil's response was quantified as in Experiment 1 by calculating the average pupil size within the response window (1000 – 2000 ms post stimulus onset). These data were then subjected to a mixed-factor ANOVA, with image condition (couple, male, female, neutral-person, neutral-object) and gender (heterosexual men, heterosexual women) as factors. There was a main effect for image ($F(4, 136) = 60.68$, $p < .001$, $\eta p^2 = .64$). There was no main effect for gender ($F(1, 34) = 1.76$, $p = .19$, $\eta p^2 = .05$), nor was there an interaction ($F(4, 136) = 0.50$, $p = .54$, $\eta p^2 = .02$). Despite this lack of a significant interaction, we tested our *a priori* hypothesis that men would have a greater response to the couple images than would the women but no difference emerged ($p > .10$).

Our main aim was to examine if pupil dilation was specific to stated sexual orientation. To examine this, we calculated the difference between the pupil size for each of the sexual stimuli in comparison to the neutral stimuli (using the neutral-person condition, although similar results held if the neutral-no person was used). For women, the male stimuli produced higher dilation than the female stimuli (p = .004). For men, there was a similar, but non-significant, trend (p = .07).

150 ms condition. The form of the pupil response was similar to the 3000ms condition, although the effect of the affective content appeared much smaller.

The pupil's response was again quantified by calculating the average pupil size within the response window. These data were then subjected to a mixed-factor ANOVA, with image condition and gender as factors. There was a main effect of image ($F(4, 140) = 5.67$, $p < .001$, $\eta p^2 = .14$), but no main effect of gender ($F(1, 35) = 0.32$, $p = .48$, $\eta p^2 = .02$), nor any interaction ($F(4, 140) = 1.56$, $p = .22$, $\eta p^2 = .04$). Despite this lack of a significant interaction, we tested our *a priori* hypothesis that men would have a greater response to the couple images than would the women but no difference emerged ($p > .10$).

Planned comparisons examined whether pupil dilation was specific to stated sexual orientation. We calculated the difference between the pupil sizes for each of the sexual stimuli in comparison to the neutral stimuli (using the neutral-person condition, although similar results held if the neutral-no person was used). For both the women and men, neither the male nor the female stimuli had an effect on the pupil size (ps > .10).

Discussion

Our results again showed that the pupil is sensitive to the sexual content of images and this can be revealed even by stimuli that are presented so briefly as to preclude any eye movements. We also showed that the pupil was again more dilated following images that contain a nude male than one that contained a nude female and that this result held for both

heterosexual men and women. We could find no evidence that the pupil measure was sensitive to the preferred sexual image, with both heterosexual men and heterosexual women producing similar responses to both the male and female images. Finally, we did not find any gender differences in the pupil response to images of couples.

The pupil's response to stimuli appeared to be governed by levels of arousal (e.g., Bradley et al., 2008) rather than *sexual* arousal *per se*. Hence, it may be that images of (semi-) naked men cause arousal due to the novelty (or even shock) of such images. Indeed, Aboyoun and Dabbs (1998) noted that pupil dilation was greater for images of naked people than clothed people, and that pupil dilation was greater for images of naked men than for naked women. The authors accounted for their results by arguing that nude images are less common than clothed images, and that nude images of men have the greatest novelty. Such an explanation based on novelty would explain why those groups who might encounter naked men, or see such images most often (the groups of heterosexual women and homosexual men) were the ones who showed the least male-female difference in pupil dilation. It would be of interest to see if these results are modified by levels of sexual experience.

Experiment 3.

Aboyoun and Dabbs (1998) have suggested that the finding that people generally have a greater pupil dilation to male nudes irrespective of their stated sexual orientation may be due to novelty. This would suggest that images with a lower erotic content might have a greater chance of demonstrating sexual-orientation specific pupil responses. We tested the pupil responses to images of attractive men and women that were fully clothed. Pilot testing showed that these images were viewed as very attractive.

Method

All procedures for these experiments were identical to Experiment 2 (save for those

outlined below) and this task followed that of Experiment 2 in the same data collection session.

In this experiment we used two classes of images: adult female and adult male. There were also two other classes of image that involved pictures of children on which we wished to collect pilot data, but these results are not reported here. All images were of fully clothed people and were taken from fashion magazines. The images were altered to greyscale, resized, and the brightness and contrast of each image were all adjusted to be equal (as in Experiment 2). There were 10 exemplars of each image type. Example images are shown in Figure 5.

The 40 images were presented in a pseudorandom order for each block. In the first block the target duration was 150 ms and in the other it was 3000 ms. Each person took part in both blocks.

Results

The data were analysed in the same manner as Experiment 2. Pupil size as a function of time from target stimulus onset is shown in Figure 6 for all participants combined (left plot 150 ms duration, right plot 3000 ms duration).

3000 ms condition. The pupil's response was quantified as in Experiment 1 by calculating the average pupil size within the response window (1000 – 2000 ms post stimulus onset). These data were then subjected to a mixed-factor ANOVA, with image condition (male image, female image) and gender (men, women) as factors. There was a main effect of image ($F(1, 36) = 27.79$, $p < .001$, $\eta p^2 = .436$). There was no effect of gender ($F(1, 36) = 0.94$, $p = .34$, $\eta p^2 = .03$), nor was there an interaction ($F(1, 36) = 0.94$, $p = .34$, $\eta p^2 = .03$). Examination of Figure 6 shows that the pupil was more dilated now to images of women than to images of men, and this was true for both men ($p = .001$) and women ($p = .003$)

150 ms condition. A mixed-factor ANOVA showed no main effect of image ($F(1, 34) = 0.01$, $p = .93$, $\eta p^2 < .001$), nor of gender, ($F(1, 34) = 0.38$, $p = .54$, $\eta p^2 = .01$), and no interaction ($F(1, 34) = 0.56$, $p = .46$, $\eta p^2 = .02$).

Discussion

In Experiment 3 we tested whether stimuli without erotic content would produce a different pattern of results to those that contained erotic content (Experiment 1 and 2). We no longer found universal stronger dilation to male stimuli and, instead, now found that the pupil dilated more to the images of females, at least for the longer duration stimuli. If we accept the argument that the reduced erotic content may have eliminated the novelty value from the stimuli, then the results from the male participants seem appropriate (i.e., that they showed greater dilation now to the female images). However, the women did not show greater dilation to the male stimuli. We note that Attard-Johnson et al. (2016) show a similar pattern of results, with the greatest dilation to the female images for both men and women. Several studies, using a range of techniques such as genital responses (Chivers et al., 2004), tests of implicit attitudes (Snowden & Gray, 2013), and automatic allocation of attention (Snowden, Curl, Jobbins, Lavington, & Gray, 2016), have now shown that heterosexual women do not seem to show category-specific responses to gender, and in many cases appear to show results that indicate a greater interest in women than in men. Hence, the images of women may have been arousing or interesting to them for reasons that are not sexual.

General Discussion

We hypothesised that pupil dilation would be indicative of sexual interest and that a person's sexual orientation might be indicated by which stimuli result in the greatest pupil dilation. However, our results across three experiments give little support to this notion. In Experiments 1 and 2, all groups gave the greatest dilation to male nudes (in comparison to female nudes). We hypothesised that this might be due to other affective and "non-sexual"

components, perhaps related to novelty of the stimuli. Experiment 3, therefore, used stimuli that were less erotic. However, we now found that both heterosexual men and women had greater dilation to the images of females than to images of males.

We note that our results differ from those of Rieger and colleagues (Rieger et al., 2015; Rieger & Savin-Williams, 2012) where pupillometry appeared to produce results that were more commensurate with people's stated sexual interests – i.e., heterosexual men showed greater pupil dilation to images of women, and homosexual men showed greater dilation to images of men. The stimuli used in those experiments (Rieger & Savin-Williams, 2012) were lengthy videos (30 s) of people masturbating, with the measurement of pupil dilation taken after many seconds of watching such a movie. Such a pupil response may be dependent on processing the meaning of such images in a deliberative manner (i.e., deliberately focussing on the sexual content for images of one's preferred sexual category or employing other strategies – for a review, see Rupp & Wallen, 2008), or on the development of conscious sexual arousal in the participants. We note, however, that a similar result (although with smaller effects sizes) was found for non-erotic stimuli (Watts, Holmes, Savin-Williams, & Rieger, 2017). This contrasts with the (relatively) rapid presentation (150 – 3000 ms) of the present stimuli, with the response window being completed within 2000 ms of presentation in order to isolate the early automatic components of perceptual processing of these images.

Attard-Johnson et al. (2016) reported on pupil responses to static images similar to those used in the present investigation. In two experiments, they showed the greatest pupil response to images of women for both heterosexual men and heterosexual women. However, in a later study (Attard-Johnson & Bindemann, 2017) they reported that pupil dilation was commensurate with stated sexual interest and was unaffected by the erotic content of the image. Clearly, these results contradict (some) of the present results. The reasons for these

different patterns of results is unclear, but we note that the studies used very different techniques to quantify the pupil's behaviour and that the Attard-Johnson and Bindemann (2017) study required the participant to deliberately consider and report upon the sexual appeal of the images, while the present studies merely required a passive viewing of the images. It is also possible that the various groups (e.g., heterosexual men vs heterosexual women) might have different patterns of fixations (for example, greater inspection of the face or body parts) that might produce different levels of illumination at the central fovea between these groups even for well-matched stimuli due to people fixating on different parts of the image (Bradley et al., 2017). Future research may try to take account of the changing pattern of luminance changes due to fixation change, or explore methods by which such changes can be nullified. Clearly, great care must be taken before the conclusion of different levels of sexual interest is the sole account of any differences in pupil sizes. The pupil response is not merely under the control of brain areas related to sexual interest or the processing of sexual information, but also reflects other processes of arousal (due to novelty, shock, or complexity of processing). The present paper highlights some of the difficulties inherent in using the pupil in this manner and suggests much further work is needed to understand the relationship between the response of the pupil and the nature of sexual images before the technique can be used as a reliable and valid assessment of sexual interest.

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Figure legends

Figure 1. Change in pupil size (mm) from the onset of the target stimuli for all observers for Experiment 1. The purple symbols are for the neutral stimuli, green for the female images, and blue for the male images. The shaded area (1000 – 2000 ms) is the response window that was used to calculate the response for statistical analyses.

Figure 2. Change in pupil size (mm) from the onset of the target stimuli for each group of observers for Experiment 1. Conventions are as in Figure 1.

Figure 3. Difference between pupil size to male vs. female images (positive to show greater response to male images) as a function of group. Error bars represent ± 1 standard error of the mean.

Figure 4. Change in pupil size (mm) from the onset of the target stimuli for all observers for Experiment 2. The dark purple symbols are for the neutral object images, light purple for neutral people images, green for the female images, blue for the male images, and red for the couple images. The shaded area (1000 – 2000 ms) is the response window that was used to calculate the response for statistical analyses. The left panel is for a stimulus duration of 150 ms, and the right panel for a stimulus duration of 3000 ms.

Figure 5. Examples of the images used in Experiment 3.

Figure 6. Change in pupil size (mm) from the onset of the target stimuli for all observers for Experiment 3. The green symbols are for the female images, and blue for the male images.

The shaded area (1000 – 2000 ms) is the response window that was used to calculate the response for statistical analyses. The left panel is for a stimulus duration of 150 ms, and the right panel for a stimulus duration of 3000 ms.

Table 1. Demographic information for the participants in Experiment 1.

Group (*N*)	Age *M* (*SD*)	Kinsey Score *M* (*SD*)	Feeling Thermometer Sex with men *M* (*SD*)	Feeling Thermon with women *M*
Male Heterosexual (20)	25.5 (7.3)	0.60 (0.50)	9.0 (13.3)	95.5 (9.9
Male Bisexual (13)	26.9 (14.2)	3.04 (0.66)	69.3 (26.3)	83.9 (20.6
Male Homosexual (19)	27.1 (6.4)	5.66 (0.47)	96.1 (7.6)	12.3 (3.4
Female Heterosexual (28)	23.1 (3.7)	0.58 (0.49)	96.8 (6.7)	21.4 (23.2
Female Bisexual (21)	24.3 (7.4)	2.69 (0.87)	81.9 (23.2)	64.3 (29.8
Female Homosexual (17)	26.1 (7.4)	5.47 (0.51)	16.5 (19.7)	92.9 (9.9

Figure 1

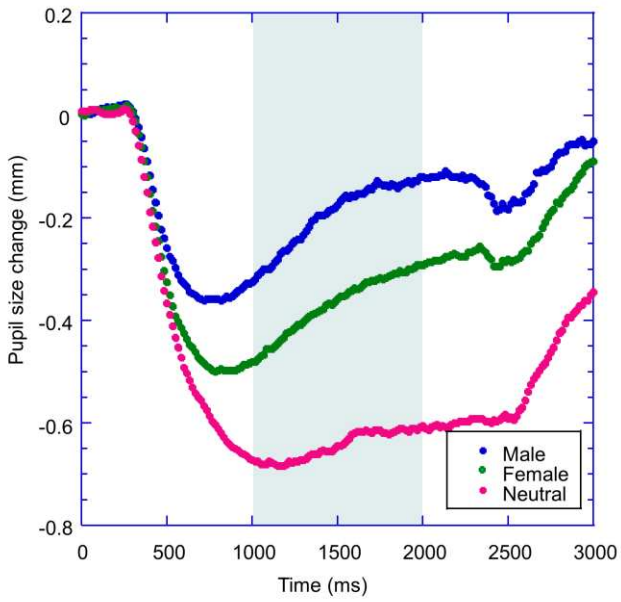

0.2
0
-0.2
-0.4
-0.6
-0.8
Pupil size change (mm)
0
500
1000
1500
2000
2500
3000
Time (ms)
Male
Female
Neutral

Figure 2

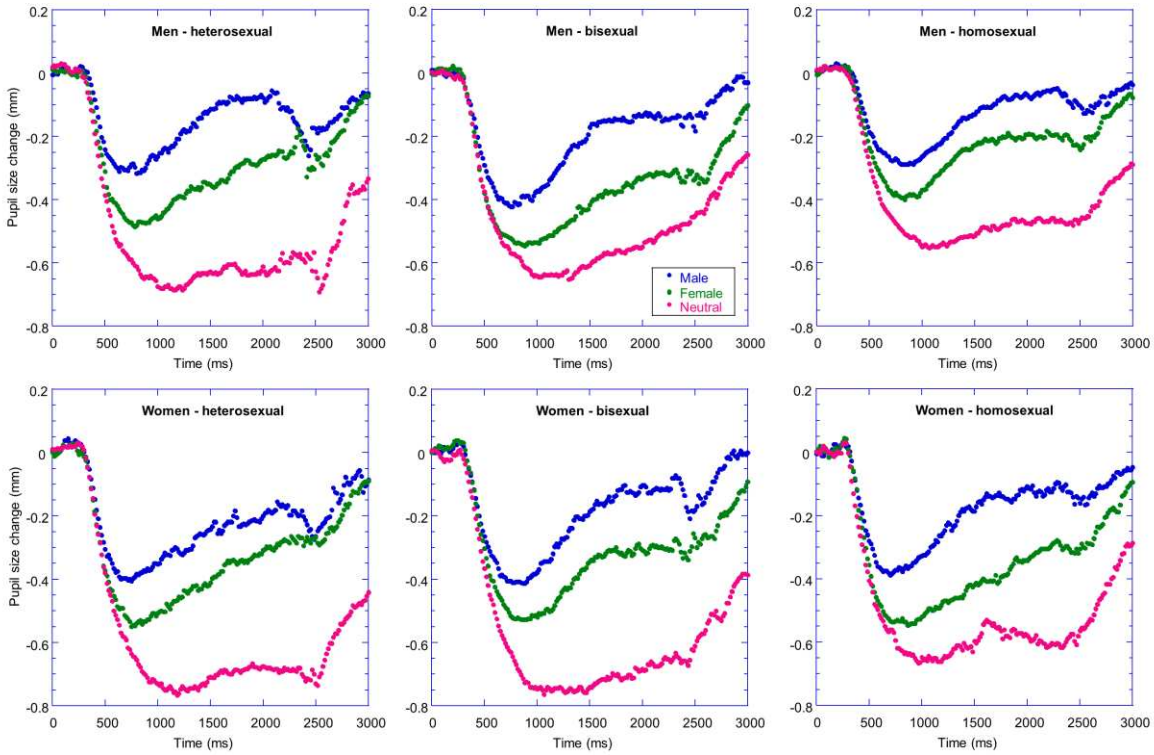

Men - heterosexual
Men - bisexual
Men - homosexual
Women - heterosexual
Women - bisexual
Women - homosexual
Pupil size change (mm)
Time (ms)
Male
Female
Neutral
0.2
0
-0.2
-0.4
-0.6
-0.8
0
500
1000
1500
2000
2500
3000

Figure 3

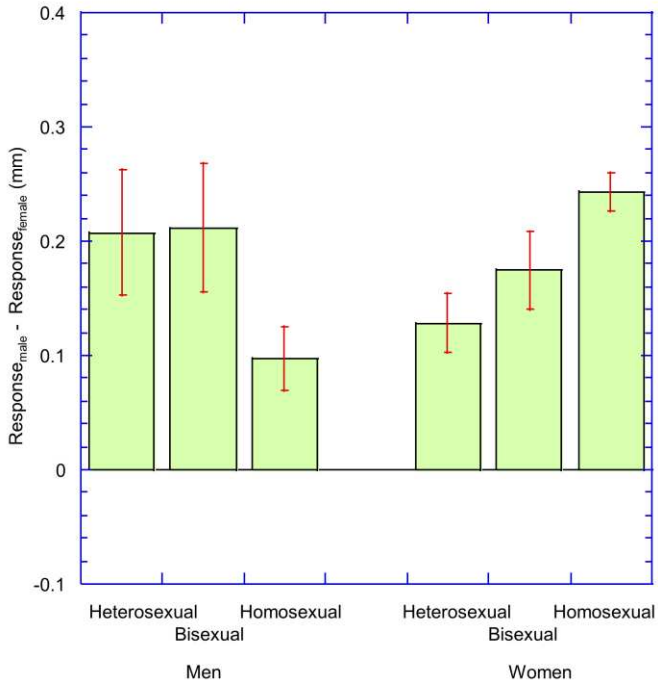

0.4
0.3
0.2
0.1
0
-0.1
Response$_{male}$ - Response$_{female}$ (mm)
Heterosexual
Bisexual
Homosexual
Men
Heterosexual
Bisexual
Homosexual
Women

Figure 4

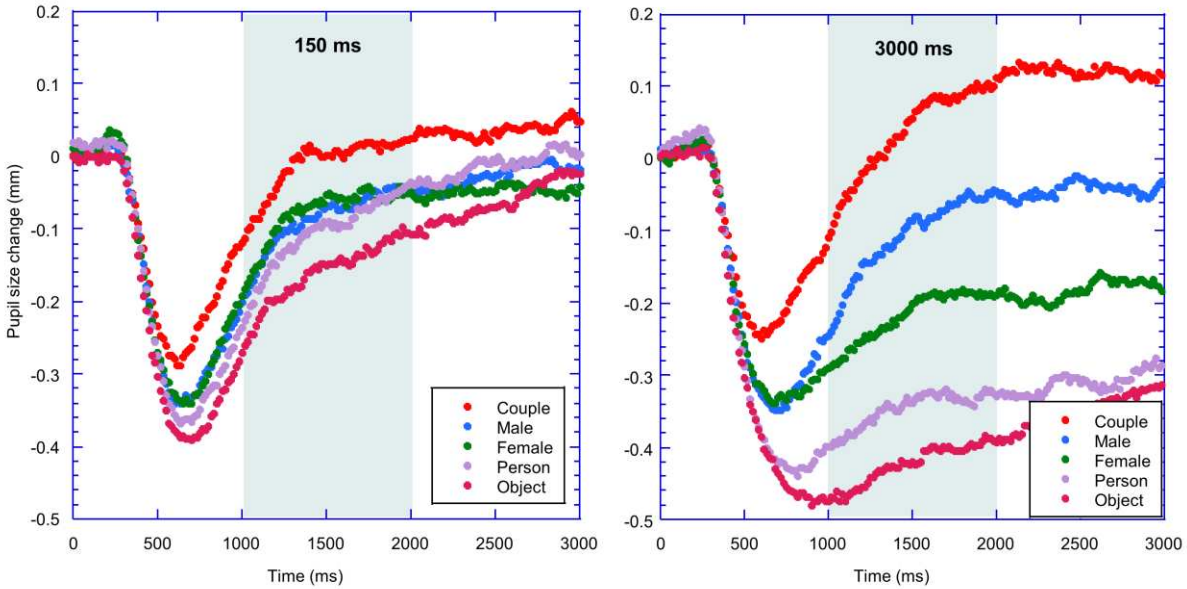
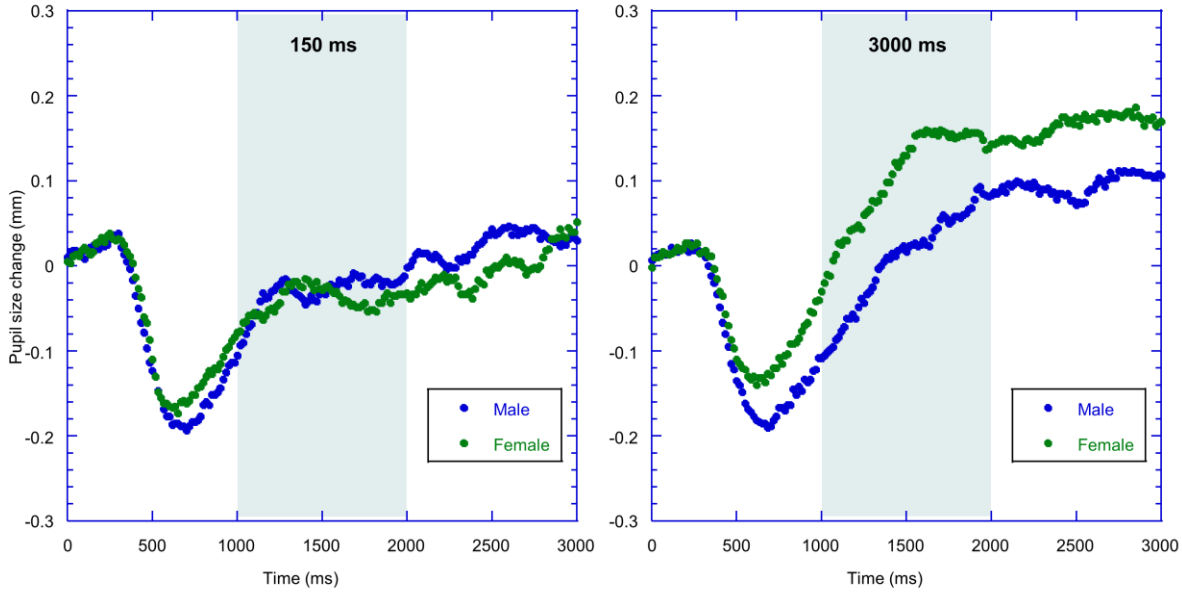

150 ms
3000 ms
Pupil size change (mm)
Time (ms)
Couple
Male
Female
Person
Object
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
500
1000
1500
2000
2500
3000

Figure 5

Figure 6


150 ms
3000 ms
Pupil size change (mm)
Time (ms)
Male
Female
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
500
1000
1500
2000
2500
3000