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Do Women Expose Themselves to more Health-Related Risks in Certain Phases of the
Menstrual Cycle? A Meta-analytic Review

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Abstract

Over the past three decades, researchers have increasingly examined the menstrual cycle as a potential source of day-to-day variation in women's cognitions, motivations, and behavior. Within this literature, several lines of research have examined the impact of the menstrual cycle on women's engagement in activities that could negatively affect their health, including sexual behavior and alcohol and tobacco consumption, as well as their ability to recognize and avoid potentially threatening people and situations. However, findings have been mixed, leaving it unclear whether women may expose themselves to more health-related risks during certain phases of the cycle. To address this question, we conducted a meta-analysis of 23 published and 4 unpublished studies ($N = 7,527$). The meta-analysis revealed some shifts across the menstrual cycle in women's sexual behavior and risk recognition and avoidance, whereas patterns were less clear for alcohol and cigarette consumption. These findings help to clarify the proximate physiological and evolutionary mechanisms underlying women's health-related risk-taking and may inform new interventions.

Keywords: Menstrual Cycle, Risk-taking, Sexual Behavior, Cigarettes, Alcohol, Evolution

Do Women Expose Themselves to more Health-Related Risks in Certain Phases of the Menstrual Cycle? A Meta-analytic Review

Over the past three decades, dozens of studies have reported evidence that the menstrual cycle influences many aspects of women's cognition, motivations, and behavior, including, for example, emotion recognition (Sundström Poromaa & Gingnell, 2014), mental rotation abilities (Broverman et al., 1981; Zhu, Kelly, Curry, Lal & Josphe, 2015), verbal functions (Rosenberg & Park, 2002), mood (Maki, Rich, & Rosenbaum, 2002; Rubinow & Schmidt, 1995), empathy (Derntl, Hack, Kryspin-Exner, & Habel, 2013; Pfaff, 2012) and mate preferences (meta-analyzed by Gildersleeve, Haselton, & Fales, 2014; reviewed by Thornhill & Gangestad, 2008). Within this broad area of research, a growing literature has examined changes across the menstrual cycle in women's engagement in behaviors that could expose them to health-related risks, particularly sexual behavior, alcohol and cigarette consumption, and recognition and avoidance of potentially threatening people and dangerous situations. However, evidence in this area has been mixed. Furthermore, inconsistencies across study findings have been difficult to understand without a guiding theoretical framework or careful evaluation of differences in study methods (e.g., methods used to assess women's position within the menstrual cycle; different hormonal profile characterizations; within vs. between design).

Understanding how women's health-related risks change across the cycle could have important public health implications and may possibly lead to more accurate and individualized prevention programs. Studies of nonhuman animals in neuroendocrinology point to plausible physiological pathways through which women's position in the menstrual cycle could also influence such behaviors (e.g., through estradiol and progesterone receptors within the amygdala, hippocampus, hypothalamus and the frontal cortex, see Guerra-Araiza, Coyoy-Salgado, &

Camacho-Arroyo, 2002; Guerra-Araiza, Villamar-Cruz, Gonzalez-Arenas, Chavira, & Camacho-Arroyo, 2003; Kato, Hirata, Nozawa, & Yamada-Mouri, (1994). In addition, an evolutionary approach offers predictions regarding why women might engage in such risky behaviors within certain phases of the cycle (Bröder & Hohmann, 2003; Chavanne & Gallup, 1998; Fessler, Holbrook & Fleischman, 2014; Prokop, 2013). Therefore, an interdisciplinary evolutionary method is well suited to help organize and make sense of seemingly inconsistent findings within this literature.

In this review, we begin by providing a brief orientation to the physiological changes that occur during the menstrual cycle. We then define risk-taking and the key domains of risks examined within this meta-analysis. Next, we propose specific predictions regarding when, how (via what mechanisms), and why different forms of health-related risk-taking may change across the menstrual cycle. These predictions are informed by behavioral neuroendocrinology, studies of nonhuman animal species, and modern evolutionary theory. We then present a meta-analysis of 23 published and 4 unpublished studies (N=7,527) that examined changes in women's health-related risk-taking behaviors across the menstrual cycle, followed by a discussion of the implications of our findings for understanding the mechanisms underlying women's health risky behaviors.

Hormones across the Menstrual Cycle

Typically, the human female menstrual cycle lasts 28 days and is characterized by dramatic changes in ovarian hormones levels (Pfaff, 2012; Wilcox, Dunson & Baird, 2000). Menstruation marks the beginning of a new cycle and the start of the follicular phase, which extends from menstrual onset to ovulation and typically lasts approximately 10 to 14 days (Novak & Berek, 2007). As shown in Figure 1, in the early follicular phase, estradiol and

progesterone levels are low. At that time, the pituitary gland secretes two gonadotropins: luteinizing hormone (LH) and follicle-stimulating hormone (FSH). LH stimulates ovarian follicles (structures encasing microscopic egg cells) to produce androgens, while FSH stimulates the follicles to aromatize these androgens into estrogens (particularly estradiol) and also stimulates a cohort of several follicles to begin growing.

Eventually, one follicle becomes “dominant” and continues to secrete increasing amounts of estradiol, while the other follicles degenerate. A few days prior to ovulation, estradiol levels reach their peak. This triggers a surge in LH (Stricker et al., 2006), which causes the dominant follicle, now fully mature, to rupture and expel the egg (ovulation). Ovulation occurs around day 14 in an average cycle. The egg travels down the fallopian tube toward the uterus, and fertilization may occur if sperm are present. Women’s fertility – their likelihood of conceiving from unprotected sexual intercourse – is highest on the 5 days approaching ovulation and the day of ovulation itself, after which fertility declines precipitously (Wilcox, Dunson & Baird, 2000).

Ovulation marks the beginning of the luteal phase, which extends from ovulation to the next menstrual onset and lasts approximately 14 days (Novak & Berek, 2007; Prior, Vigna Schulzer, Hall & Bonen, 1990). Whereas progesterone levels were low throughout the follicular phase, in the luteal phase, the ruptured follicle — now called the “corpus luteum” — secretes large amounts of progesterone and a moderate amount of estradiol (Hall & Nieman, 2003). Together, these hormones prepare the endometrium (uterine lining) for possible pregnancy. If fertilization does not occur, the corpus luteum eventually degrades. The resulting drop in progesterone and estradiol causes the collapse and sloughing off the endometrium (menstruation), and the cycle begins again.

Figure 1. Estimated values of estradiol, progesterone and luteinizing hormone values across the phases in normal cycling women (based on Stricker et al., 2006).

Key Domains of Health-related Risk-taking

Risk-taking has been defined in a multitude of ways over time and across disciplines (Byrnes, Miller & Schafer, 1999; Hansson, 2010, 2014; Trimpop, 1994). In the present meta-analysis, risk-taking is defined as engaging in a behavior to obtain a reward, at the expense of exposing oneself to an elevated risk of undesired and negative health consequences. From a cost/benefit analysis perspective, risk-taking occurs when clear potential costs are outweighed by physiological or emotional benefits (Trimpop, 1994). For example, engaging in drug use, sexual behavior, gambling or other behaviors that enhance pleasure but are known to entail potential costs can be understood as risky.

As noted above, the domains of health-related risk taking that have been most widely studied in relation to the menstrual cycle to date are cigarette and alcohol consumption and sexual behavior. In addition, several studies have examined women's recognition and avoidance of threatening people and situations across the cycle. Although such studies do not assess risk-taking *per se*, they are relevant to understand how women's exposure to health-related risks may vary across the cycle. Here, we provide a brief overview of research on nonhuman animals and

on humans examining cycle shifts in each domain of health-related risk-taking and then outline our predictions based on insights from behavioral neuroendocrinology and evolutionary theory.

Alcohol and Tobacco Consumption

The long-term effects of both alcohol (ethanol) and tobacco consumption are well known and include upper aerodigestive tract cancers, lung cancer, cirrhosis and various cardiovascular and cerebrovascular accidents (WHO, 2014). Heavy drinking is common among college students and leads to short-term negative effects (Wechsler, Lee, Kuo, and Lee, 2000) but students also often report positive feelings such as mood enhancement, tension reduction or coping (Cooper, 1994; Cooper, Russell, Skinner & Windle, 1992). Tobacco initiation, on the other hand, may be due to self-image of maturity, sociability, independence, sexuality, weight control benefits with the highest rate among White girls and the lowest among African-American and Asians (French & Perry, 1995). Whereas the causes or correlates of alcohol and tobacco consumptions and maintenances are well studied, the biological mediators and their pathways remain largely unknown. This meta-analysis aims to evaluate whether certain hormonal profiles may play a role in those risky conducts.

State of the Evidence: Studies of Nonhuman Mammals

The relationship between smoking, alcohol consumption and hormonal profiles appears to be complex, based on studies of nonhuman mammals (Pfaff & Joëls, 2017). The study of human ovulatory cycle, despite differences with animals, still present many common patterns: pituitary gonadotropin luteinizing hormone (LH) and follicle-stimulating hormone (FSH), on the one hand, and estrogens and progesterone, on the other hand, play a necessarily role in regulating social behavior among mammals but little is known about whether the same patterns emerge at the human level (Fink, 2011; Thornhill & Gangestad, 2008; Pfaff & Joëls, 2017). More

specifically, human menstrual cycle differs from other animals on various points. Among rodents for instance, the cycle length is shorter than among humans and the estrogen and progesterone peaks demonstrate more overlapping. The four phases however (Proestrus, Estrus, Diestrus 1, Diestrus 2) largely match human's main phases in term of fluctuations in estrogen, progesterone, LH and FSH and may motivate to use the rat as a model (Staley & Scharfman, 2005, see figure 2 below). Moreover, the fact that the rat, as the primate, displays a diurnal change in LH secretion after the juvenile development can eventually restore his legitimacy as a model. However, non-human primates (NHPs) share even closer endocrine dynamics with human beings including a 28-days cycle in female macaques (Phillips et al., 2014) unlike many rodents that have a four-day estrus cycle (Steger and Peluso, 1987). They also share a similar menopause process, close responses to estrogen therapy and improvements in cognitive functions with estrogen (for a complete review, see Phillips et al., 2014).

Figure 2. Comparison of the menstrual cycle of the human and the estrous cycle of the rat. (a) The estrous cycle of the rat is the 4-day long (gray bars represent the night, from 6 p.m. to 6 a.m.) with variations in estrogen, progesterone, luteinizing hormone (LH) and follicle-stimulating hormone (FSH). (b) The human menstrual cycle is, on the other hand, 28-days long but also presents major fluctuations of the above-mentioned hormones. Adapted from Staley and Scharfman (2005).

One of the leading challenges is the integration of multiple levels of analysis in experimental design to understand endocrine, neural and psychological influences on social behaviors (Pfaff & Joëls, 2017). Consequently, inter-species comparisons represent a powerful method to illuminate the behavioral changes occurring during the menstrual cycle since hormonal manipulations are not ethically possible in human (ovariectomy, estrogen supplements as stated down below in the last section). Those comparisons permit to elucidate the neuroendocrinology pathways leading to certain type of risky behaviors. In monkeys, for instance, alcohol consumption has been found to decrease during the menstrual phase when compared to mid-cycle or to the luteal phase (Ford, Eldridge, & Samson, 2002; Mello, Bree & Mendelson, 1986; Pfaff & Joëls, 2017). In rats with synchronized cycles, self-administration of alcohol has instead been found to decrease during estrus, the ovulatory equivalent phase among humans, and proestrus which hormonal pattern resembles a follicular phase (Forger and Morin, 1982; Ford, Eldridge, & Samson, 2002; Roberts, Smith, Weiss, Rivier, & Koob, 1998; Staley & Scharfman, 2005). The similarity between rodents and humans in the cycling levels of hormones in brain region make it a good candidate as an animal model but does not overlap completely the women's menstrual pattern (Staley & Scharfman, 2005). Still, other authors found no relationship between estrous cycle and ethanol consumption in Wistar rats (van Haaren & Anderson, 1994). On the other hand, the few studies that had previously investigated the relationship between ovarian cycles and nicotine self-administration among rats failed to find an effect of natural (unmanipulated) estrous cycle (Donny, 1999; Perkins, Donny & Caggiula, 1999).

State of the Evidence: Human Studies

The menstrual cycle has also been investigated as a potential source of day-to-day variation

in women's alcohol and tobacco consumption, with similarly mixed results. Some studies have found an increase in women's alcohol and tobacco consumption near the ovulatory phase (Pomerleau et al., 2000), whereas others did not find that pattern but instead found a decrease in alcohol and tobacco consumption during menses (Charette, 1989; Dumas, Calliet, Tumbling, & King, 1984; Pomerleau et al., 1994; Pomerleau et al., 2000). The overwhelming majority of women experienced discomfort (e.g. headaches, irritability, pain), to some extent, when approaching menstruation (Dickerson, Mazyck, & Hunter, 2003; Reed, Levin & Evans, 2008) and since these are also tobacco withdrawal symptoms (Hughes & Hatsukami, 1986), one could expect women to smoke more during this period to ease those symptoms. However, the results are quite unclear, and under laboratory conditions, some studies identify an increase numbers of cigarettes puffs during menses (Steinberg & Cherek, 1989) whereas others found slight decrease in smoking self-report during high-fertility when compared to the rest of the cycle (Allen, 1996; DeBon, Klesges, & Klesges, 1995; Pomerleau, Cole, Lumley, Marks, & Pomerleau, 1994).

Insights from Evolutionary Theory

Evolutionary psychology may give some insights to elucidate the relationship between menstrual phase and alcohol and tobacco consumption. One explanation is that women might have evolved in the context of alcohol to decrease use of toxic substances in order to avoid dangerous and coercive sexual situations around ovulation. Moreover, an additional explanation might be that women are more averse to certain risk-taking situations at that time of the cycle (e.g., go out dancing with friends), and this could decrease their alcohol and cigarette consumption because of less exposure to such cues (Bröder & Hohmann, 2003; Chavanne & Gallup, 1998). Another explanation may come from the cyclic changes in mood that induce change in women's social abilities, clothing style (Haselton et al., 2007; Schwarz &

Hassebrauck, 2008) along with enhance self-rated attractiveness that would eventually reduce the tendency to drink (Haselton & Gangestad, 2006; Schwarz & Hassebrauck, 2008).

The results are quite mixed when it comes to evaluate women's social activities (such as going out dancing, attending a concert, invite a man for dinner, etc.) across the cycle and if those activities could lead to higher substance use. Bröder and Hohmann (2003), for instance, replicated a study by Chavanne and Gallup (1998), where women had to fill a questionnaire on four occasion at 1-week intervals with a list of 40 activities (20 risky and 20 non-risky). They showed that naturally cycling women reduced risky behaviors such as "going out dancing with friend", "going to a party alone in the evening" or, more directly, "getting drunk while going out" during the ovulatory phase. However, many animal studies have shown an increase in locomotion at estrous so apparent that it can be used as one of the most reliable indexes of fertility (Fessler, 2003). As Bröder and Hohmann (2003) noticed, women might be more active during high-fertility days by increasing nonrisky activities over risky ones that would lead to change in a risky activities ratio.

An alternative, not mutually exclusive hypothesis involves the latter portion of the menstrual cycle. The early luteal phase, which is characterized by a hormonal profile that resembles early pregnancy, could also lead to avoid toxic substance in order to enhance the survival of the potential fetus (Fleischman & Fessler, 2011). Indeed, the highest level of progesterone is observed during pregnancy but also during the early luteal phase when the woman's body is getting prepared for conception and implementation of a potential fertilized egg.

Tracing back the physiological mechanisms may also reveal more direct links between risky activities and ovarian hormones through brain structures, including the hypothalamic-

pituitary axis. Moreover, brain areas that control risk sensitivity have likely been shaped phylogenetically and have genetic underpinnings. Recent twin studies revealed that heritability accounts for 29% to 55% of individual variations in risk-taking (Bell, 2009; Wang, Zheng, Xuan, Chen & Li, 2016). Inherited and environmentally response genes affecting risk-taking have orthologues (gene evolving from common ancestral gene) with common function in humans and other animals permitting inter-species comparisons through the HPA axis for instance (Cesarini, Dawes, Johannesson, Lichtenstein & Wallace, 2009; Stern, 2010).

Insights from Behavioral Neuroendocrinology

Indeed, the hypothalamic-pituitary axis plays a central key role in the regulation of alcohol and tobacco use both in human and non-humans mammals. The relationship between this axis and ovarian hormones is complex because chronic alcohol might influence the level of circulating estrogen, especially in dependent women. Ford, Eldridge and Samson (2004), instead, found that physiological doses of estradiol in rats increase ethanol consumption by 10% without increasing water consumption, indicating possible modulation by estradiol. Past drinking experience along with expectancies must also influence those complex patterns. Regardless of the type of drug, ovarian hormones appear to have an impact on psychoactive drug use and alcohol and cigarette consumption (Kuhar, 2011). For instance, in cocaine intake, ovariectomized rats that had estrogen supplements demonstrated the highest self-intake of drugs when compared to simply ovariectomized rats or compared to castrated males. A study run by Dluzen and Anderson (1997) showed that estradiol increased dopamine release in response to nicotine in female rats, implying that nicotine may be more rewarding when estradiol is high. In summary, whereas there are competing predictions based on the existing literature and evolutionary theorizing about humans, the non-human animal literature suggests that high

estrogen (which is associated with high fertility in both humans and non-humans) is associated with greater consumption of intoxicating substances. This meta-analysis aims to help identify associations between cycle phase and the use of drugs and alcohol in human females.

Prediction

The human and non-human literatures, taken together, revealed mixed results. On the one hand, the animal literature indicates that the mid-cycle phase will be associated with greater substance use due to higher concentration of estrogen at that time. Still, human data are unclear regarding whether the ovulatory or the early luteal phases increase or decrease alcohol and tobacco consumption. Therefore, there are competing predictions.

First, women may decrease drug and alcohol consumption at high fertility. This is possibly due to a selective pressure that makes women more attractive near ovulation. One of the possible by-product might be the enhance feeling of well-being and attractiveness at high fertility, which would decrease the craving or necessity of abusing such products.

Second, there could be an increase of drugs and alcohol consumption at menstrual and premenstrual phases because of lowered mood or increased discomfort due to premenstrual and menstrual symptoms. These two patterns – a decrease at high fertility and an increase premenstrually and menstrually – could lead to a cyclical change in alcohol and tobacco consumption.

Finally, an alternative hypothesis may come from the toxins avoidance pressure after ovulation, as progesterone rises. With a hormonal profile similar to pregnancy, counter-adaptation to toxic exposure could have led to decrease alcohol and tobacco consumption during the early luteal phase as compared to other phases except ovulation.

In summary, several different patterns are possible, a decrease in consumption at high

fertility, an increase premenstrually and menstrually, an increase at high fertility, and a decrease after ovulation as progesterone rises.

Sexual Behavior

Sexual contacts offer a variety of rewards (e.g., emotional and physical pleasure, relationship enhancement, and possible reproductive benefits) at the expense of an increased risk of incurring certain costs (e.g., pathogen exposure, possible reputational damage, viruses, etc.). Therefore, sexual behavior can be thought of as a form of health-related risk-taking or hazardous behavior¹. In our review and meta-analysis, we focus on frequency of allosexual activities specifically—rather than sexual desire or other forms of sexual behavior—because of clear and direct potential impacts on women’s health (STDs such as chlamydia, HIV, syphilis can also be transmitted during oral sex) and/or risk of conceiving. Allosexual behavior was operationalized as the frequency of intercourse, oral sex, or genital stimulation with a man or woman as those measures were most of the time mixed all together. We could not run analysis focusing specifically on frequency of heterosexual intercourses or unprotected sex, since not sufficient data were available.

State of the Evidence: Studies of Nonhuman Animals

Studies of nonhuman animals tend to find periods of sexual activity (estrous) clearly distinguishable from periods of sexual abstinence (diestrous; Balthazart, 2011; Thornhill & Gangestad, 2008; Pfaff & Joëls, 2017). Most mammals (dogs, rodents, etc.) and animals that possess estrus experience this increased sexuality at the only time conception can occur though

¹ One may criticize this standpoint as employing an overly broad definition of risk-taking. In general, sexual interactions that present potential risks is called “risky sex” and includes behavior that increase the likelihood of early sex initiation and pregnancy, multiple partners, unprotected sex, sex under the influence of alcohol or drugs (Donohew et al., 2000). Other distinctions include unsafe (having sex with a partner infected by STI without taking proper prevention measures) and hazardous sex (having unprotected sex with non-infected partner or having protected sex with infected individuals, see Slaymaker, Walker, Zaba & Collumbien, 2004). Since it is not possible to measure correctly those two latter categories, health experts usually use the “risky sex” definitions as a proxy.

the estrous cycle's length varies among species (4-5 days in rats or hamsters; 16 days in Guinea pigs; 28 days in rhesus macaques, see Brenner & Slayden, 2012). Behavioral estrus or heat can be defined as “a restricted period of proceptivity and receptivity characterized by mammalian females' behavioral readiness to mate, in addition to attractiveness to males, usually, though not invariably, coinciding with relatively high probability of conception” (Thornhill & Gangestad, 2008, p.184). Though usually described in mammals, a large portion of vertebrate taxa displayed hormonal, neural and physiological mechanisms that can be considered estrus, and phylogenetic analysis can help to clarify the origin of estrus. In female nonhuman Old World primates, mid-cycle patterns also appear to share similarities with estrus of other mammals (Dixon, 1998).

Nevertheless, some estrus-like patterns do not mean that females of all species will exhibit sexuality only during fertile phases and, on the contrary, some species do display extended female sexuality – having sex outside of the fertile period (Thornhill & Gangestad, 2008). Many species of birds (Birkhead & Møller, 1995) and nonprimate mammals (Fürstbauer, Heistermann, Schülke, & Ostner, 2011) copulate throughout the entire ovarian cycle. Many primate species, including humans, have extended sexuality and may engage in sexual intercourse on any day of the cycle (Pfaff & Joëls, 2017). However, women's extended sexuality is extreme: women are not only sexually proceptive and receptive throughout the cycle but also during other time points or conditions in which the conception is not possible, such as pregnancy, early lactation or anovulatory cycles (Grebe, Gangestad, Garver-Apgar & Thornhill, 2013).

State of the Evidence: Human Studies

In contrast with the nonhuman mammal literature, findings have been mixed regarding the existence and nature of shifts in women's sexual behavior across the menstrual cycle. Several studies have found an increase in women sexual activity during the high-fertility phase as

compared with the low-fertility remainder of the cycle (Adams, Gold, & Burt, 1978; Bullivant et al., 2004; Burleson, Trevathan & Gregory 2002; Harvey, 1984). However, patterns are not always consistent and this lack of stability could reflect the fact that sexuality is a complex social behavior, constrained and enabled by many factors, such as opportunities or leisure time (as revealed, for example, in the “weekend” effect, whereby people tend to have sex more on weekends as compared compare to week days, Ryan, Bernstein & Brown 2010). In sum, many social factors could moderate or obscure any effect of the menstrual cycle.

In addition, some studies reported an increase in sexual behavior at pre- and postmenstrual phases of the cycle; this pattern may reflect cultural taboos and restrictions on sexual activity during menses (Sanders & Bancroft, 1982). The increase in sexual behavior right before and after menses could reflect attempts to compensate for this reduction in sexual activity during menses.

Regarding the lack of a clear pattern in women’s sexual behavior across the cycle, individual studies may have lacked statistical power or used self-report measures of the menstrual phase (Adams, 1978; Bellis & Baker, 1990; Roney 2013). An evolutionary approach offers additional reasons why humans may differ from nonhuman mammals in patterns of sexual behavior across the cycle.

Insights from Evolutionary Theory

As discussed above, many primate species, including humans, have extended sexuality and engage in sexual intercourses on any day of the cycle (Gangestad & Haselton 2015; Thornhill & Gangestad, 2008; Pfaff & Joëls, 2017). Human female sexuality is relatively extreme among animals because they are receptive to sex (receptivity) and may actively seek sex (proceptivity) at any point within the menstrual cycle — even when they are not fertile. Scholars have proposed

several non-mutually exclusive explanations for why extended sexuality evolved in human females. For example, given an absence of obvious cues to ovulation (such as the bright red genital swellings that accompany the fertile window in nonhuman primates; Maestripieri & Roney, 2005), extended female sexual receptivity and proceptivity throughout the cycle may have made it difficult for males to discern when women were fertile. In turn, this may have enabled women to procure greater investment in offspring from putative fathers (e.g., if women have conceived with partners other than their primary social partner or through bi- or multiple-paternal care, see Gangestad and Thornhill, 2008; Hausfater & Hrdy, 1980; Hrdy, 1981; Rodríguez-Gironés & Enquist, 2001). Extended sexuality could also increase women's ability to choose long-term, investing partners, and decrease aggressiveness between males who might compete most aggressively for mating opportunities (Symons, 1979; for a brief summary of evolutionary explanations for extended sexuality in humans, see Haselton & Gildersleeve, 2011). Receptivity throughout the cycle could finally benefit women to promote investment from a pair-bonded mate and reduce polygyny, whereas selective proceptivity could favor conception with an extra-pair mate who possesses “good genes” that the main partner lacks (Gildersleeve, Haselton & Fales, 2014; Provots et al., 2008; Puts et al., 2012).

Importantly, extended sexuality does not necessarily imply no variation across the cycle in women's sexual desire or behavior. One of the most prominent and best-supported hypotheses regarding changes in women's sexuality across the menstrual cycle is the ovulatory shift hypothesis (Gildersleeve, Haselton, & Fales, 2014; Thornhill, & Gangestad 2008). This hypothesis proposes that, as heterosexual women get closer to ovulation (and their fertility rapidly peaks), they experience an increase in their sexual attraction to men who possess certain characteristics – namely, those characteristics that are thought to have historically reflected

beneficial heritable genetic qualities (e.g., good immune function). In other words, women experience an increase in sexual attraction to these men precisely when they are most likely to conceive and pass on the potential genetic benefits to their future offspring. Although the ovulatory shift hypothesis makes no predictions regarding general changes in women's sexual desire or behavior across the cycle, the proposed shift in women's mate preferences could produce a change in their overall frequency of sexual behavior depending on the social context. For example, women with access to sex partners possessing the characteristics they find particularly sexually attractive at high fertility might increase their sexual activity at this time.

Another hypothesis from an evolutionary perspective is that there will be a slight increase in sexual behavior at high- relative to low-fertility, *not necessarily because of an increase in women's desire*, but because of an increase in women's attractiveness. Evidence supports the existence of an ovulatory increase in women's attractiveness across multiple modalities (e.g., voice, appearance, movement, etc.), and both men and other women appear to be able to detect these "ovulation cues" and perceive them as attractive (Gildersleeve & Haselton, 2018).

Therefore, we might expect a slight increase in sexual behavior at high fertility because *women's partners might be more likely to initiate sexual behavior* at that time (Haselton & Gildersleeve, 2011).

Insights from Behavioral Neuroendocrinology

Because many brain regions involved in those sexual behaviors still present strong molecular and structural similitudes, phylogenetic inferences comparing different animal models can also help to make predictions for human beings. For instance, among ovariectomized rodents (rats, guinea pigs, hamsters and mice), although a treatment including only estradiol restore some part of female sexual behavior (Crowley, O'Donohue, & Jacobowitz, 1978; Mani, Blaustein, &

O'Malley, 1997), both estrogen and progesterone appeared necessary to restore the sexual behavior pattern that resemble the one observed during estrous (Beach, 1948; Edwards & Thompson, 1970). In most nonhuman primates (vervet monkeys, tamarins, and marmosets), females demonstrate sexual interest during the fertile phase (Gangestad & Thornhill, 2008). However, an extreme form of extended sexuality exist in blue monkeys, which have sex throughout the menstrual cycle well beyond the ovulatory period (Pazol, 2003).

Despite those behavioral differences, some structures play a key role in the regulation of female proceptivity and receptivity. The hypothalamic-pituitary axis, in particular, plays an active and retroactive role in many of these species. As a follicle matures during the first part of the cycle, it produces estrogen in greater quantity until a pulsatile surge in LH triggers ovulation. Estrogens surges right before ovulation has been regularly linked to lordosis in rodents via activation of several specific genes. More specifically, the preoptic area of the hypothalamus appeared to play a central role in the regulation of sexual behavior and sexual orientation (Balthazart, 2010; Dominguez, Gil, & Hull, 2006).

In sum, exploring the evolutionary history of estrus does lead to a clear picture of which pattern we should expect for women. Even though a vast majority of non-primate mammals' sexuality is related to estrogen fluctuations, the trend is more complicated for primates, with some species demonstrating dramatic extended sexuality, making it hard to predict an increase of heterosexual activity at mid-cycle.

Prediction: According to the literature above, we cannot with certainty predict a shift of women sexual activity at mid-cycle when compared to other phases. Extreme extended sexuality of women along with many confounding social effects (the weekend effect, the availability of the partners, religious beliefs, etc.) could weaken any existing effects. In particular, giving known

taboos about sexual intercourse during menstruation, we still expect to find an increase of sexual activity at mid-cycle as compared to menstrual days. Regarding the comparisons between the ovulatory phase and other phases (follicular and luteal), we expect a modest effects due to many confounding variables and external influences.

Risk Recognition and Avoidance

In addition to health-related risk-taking behaviors, a growing literature has examined variations across the menstrual cycle in women's ability to recognize cues of potential danger, emotion (fear and anger), as well as their tendency to avoid situations and people that could pose risks to their health. Given our objective of better understanding the role of the menstrual cycle in women's exposure to health-related risks, we included these studies in the meta-analysis.

State of the Evidence: Nonhuman Animal Models

While the nonhuman animals literature show that estrogen increases arousal in many circumstances, Morgan, Schulkin and Pfaff (2003) also revealed that under threatening environments, estrogen could similarly facilitate the increase of fear and avoidance responses. The non-human animal literature on this topic is inconsistent and complex (Pfaff, 2012). Animal models usually distinguish between active avoidance and passive avoidance. In active avoidance tasks, for example, rats avoided a mild presignaled shock by going into a secure location. In these tasks, females moved into the secure location more slowly on the days leading to ovulation (proestrus), indicating an impaired performance on associative learning or conditioning when estradiol levels are high (Diaz-Veliz et al., 1989). Moreover, in the same task and after ovariectomy, rats improved their avoidance response in laboratory whereas 17 β -estradiol injection damaged their performance (Alonso et al., 2006; Diaz-Veliz et al., 1989). In parallel, progesterone injections also slowed movement to the secure location in ovariectomized female

rats. In passive avoidance tasks, rats are trained to avoid a location where mild shock was experienced on a single training trial. Again, during estrous, females showed poorer performance with high level of estrogen and progesterone.

Other studies showed conflicting results with sometimes no effect of the cycle (Pfaff & Joëls, 2017). Morgan, Schulkin, & Pfaff (2004), on the other hand, found that mice treated with estradiol benzoate increase anxiety, fear learning and running wheel activity suggesting a general increase in arousal but depending on the environment. To go beyond those apparent inconsistencies, Morgan, Schulkin and Pfaff (2004) proposed a theoretical framework: the action of estrogens on motor activity and fear depend on context. While in a safe environment, estrogen would facilitate activity, in a threatening context, it will enhance fear, provoking a reduced activity. Estrogens effects would then depend on the environmental context during the behavioral tasks and would explain the apparent conflicting results in the literature. Thus, in safe context, estrogen would facilitate locomotor activity while under environmental threat, the same hormone would slow it down (Morgan, Schulkin & Pfaff, 2004). Second, the effect of estrogen would depend on the initial level of arousal and, according to Morgan and colleagues (2004), it must exist an optimal levels of arousal to facilitate courtship and mating responses in different context. Further studies are needed in that field to quantify this precise threshold.

State of the Evidence: Human Studies

In human females, several factors could lead to underestimating risks, including direct risk recognition, but also emotional recognition such as fear and anger that could lead to vital information pertinent to the survival of the individual (Bullivant, 2013; Derntl, Kryspin-Exner, Fernbach, Moser & Habel, 2008; Gasbarri et al., 2008; Sacher, Okon-Singer & Villringer, 2013). As in the non-human literature, inconsistencies are also present in the human literature: Pearson

and Lewis (2005), for instance, reported better fear recognition during high level of estrogen days and impaired judgment during menstruation when estrogen and progesterone levels are low. However, Guapo et al. (2009), reported, in contrast, that estrogen was negatively correlated with the accuracy of recognizing angry male faces, whereas Conway et al. (2007) found that progesterone levels were associated with greater precision at recognizing fearful and disgust faces. Concerning direct avoidance, a series of studies revealed that at high fertility, women evaluated men's sexual coerciveness (watching interview of men trying to attract other women) as more coercive than females in low-fertility days of the cycle (Garver-Apgar, Gangestad & Simpson 2007). Women in high-fertility phase were also more sensitive to snake detection (Masataka & Shibasaki, 2012), to sexual assault scenarios, measured by handgrip strength (Petrulia & Gallup, 2002), had lower risk-recognition latencies (Walsh & DiLillo, 2013), and perceived a violent criminal as larger and stronger as a non-violent criminal control (Fessler, Holbrook & Fleischman 2014).

There is debate about whether ovulating young women are underrepresented in sexual assaults (Morgan, 1981; Rogel, 1977; Thornhill & Palmer, 2000). Fessler (2003) suggested that earlier supported findings were flawed. According to Fessler (Fessler, 2003), the data in one study showed that frequency of rape among women is at chance on day 14 and above chance on days 12 and 13 (Rogel, 1977).

Insights from Evolutionary Theory

To the extent that such phenomenon is real, however, a possible explanation might be that a counter-adaptation to rape would have made women more sensitive at mid-cycle to specific threats, such as situations or cues associated with sexual coercion (Bröder & Hohmann, 2003; Chavanne & Gallup, 1998). Given women's heavy investment in offspring and limited number

of total offspring in a lifetime, women are selective in their choice of mates (Trivers, 1972; Buss & Schmitt, 1993). Therefore, one would expect that women might be especially selective in choosing sex partners and especially cautious about avoiding sexual coercion when they are most fertile within the cycle (Gildersleeve et al., 2014).

Insights from Neuroendocrinology

The amygdala is an important brain region involved in emotional recognition and known to be influenced by ovarian hormones both in women (Derntl et al., 2008) and in mammalian females (Adolphs, 2002). Derntl et al. (2008), for example, showed greater amygdala activation during follicular phase and better performance at recognizing emotions. Other studies demonstrated stronger activation of those zones during mid-cycle compared to menstruation when women were passively viewing ambiguous or angry faces (Sacher, Okan-Singer & Villringer, 2013). However, Van Wingen et al. (2008) showed that single injection of progesterone in healthy young women increased amygdala activation to angry and fearful faces while another study showed a decrease in responses to faces in amygdala after the same single administration of progesterone dose (Van Wingen et al., 2007).

Prediction: In general, one might expect an increase in risk avoidance and recognition, along with better specific emotion recognition (fear and anger) accuracy on the fertile days leading up to ovulation when compared to all the other phases.

Method

Research strategy. In order to gather as many studies as possible that meet our criteria, we contacted every researcher whose publications were available to obtain the necessary data to compute effect sizes and any unpublished work that may fit the inclusion criteria of our current meta-analysis. We also sent requests for manuscripts and data via the listservs of associations

such as the Society for Personality and Social Psychology (SPSP), Society for the Psychological Study of Social Issues (SPSSI), Society of Experimental Social Psychology (SESP) and the European Association of Social Psychology (EASP).

We conducted a search for published and unpublished studies that fit our inclusion criteria until November 2017 through a search of specific terms in a logic of mutual inclusion on the main psychological databases: PubMed, PsychInfo, ScienceDirect, Web of Science, GoogleScholar, EBSCO, Dissertation Abstracts Online and ProQuest Dissertations & Theses. We searched the databases of word associations linking terms related to ovulation as, for example, "ovulat*" or "hormonal cycle" or "menstrual cycle" or "midcycle" or "high-fertility" or "luteal" or "follicular" or "estrogen" or "progesterone" or "estradiol" or "LH" or "FSH" with terms for the various types of risky conduct discussed in our analysis as "risk-taking" or "health" or "alcohol" or "drugs" or "sexual activity" or "sexual behavior" or "intercourse" or "sex" or "tobacco" or "cigarettes" or "addiction" or "risk recognition" or "fear faces" or "angry faces" or "risk avoidance" or "emotion". We also wrote to all the first authors' private mails in order to get additional and/or unpublished data.

Inclusion criteria.

Criterion 1. The most important criterion was the fact that the study contained data from naturally cycling women. Specifically, the study participants should not use any form of hormonal contraception at the time of the study. The ovulatory phase in women implies many hormonal variations that could result in a change of influence on some brain areas (hypothalamic-pituitary-ovarian axis in particular) affecting cognition and decision making in different ways. Pregnant and post-menopausal women have also been excluded from the analysis.

Criterion 2. The study needed to determine precisely the point in the cycle in which the participant was at the time of the experiment. The study must be able to determine the fertile window of the participants (including the few days leading up to ovulation and the day of ovulation itself – see below for further details on how fertility is defined in analyses) or follicular (early or late) or luteal (early or late) or menses. This could be achieved using methods that aim to pinpoint the day of ovulation, such as measures of urinary LH, basal body temperature, or salivary progesterone and estradiol (Godbert, Miro, Shreeves, Gnoth & Johnson 2015), or by using counting methods that estimate current cycle position based on last/next menstrual onset and average cycle length. This criterion was essential to be able to sort the studies according to the different measurement methods (see Table 1-4 in Appendices for menstrual cycle days included in the different studies). In the present meta-analytical review, the papers varied widely in their definition of the phases and what we referred to as “ovulatory phase” covered from day 6 (Bellis & Baker, 1990) to day 23 (Dumas, Calliet, Tumbling, & King, 1984) in a normal 28-days menstrual cycle.

Criterion 3. To estimate the effect size, and in particular the Hedges’ g , we needed essential information such as variance and group averages. If the needed information was not available in the published report, we contacted the first authors to request that information. If we were unable to acquire the information, the study was excluded from our analysis ($K = 5$).

Computing Effect Sizes. The use of Hedges’s g was appropriate, given that the majority of studies in this literature have had small sample sizes and that Hedges’s g is a biased-corrected version of Cohen’s d (Borenstein, Hedges, Higgins, & Rothstein, 2009). The present meta-analysis compares different phases of the menstrual cycle through different types of risk-taking (alcohol and tobacco consumption, sexual activity, risk recognition and avoidance). Thus, g ’s

represent the standardized mean differences between two particular phases (e.g., ovulatory vs. follicular). If, for instance, one particular comparison came out positive with a value of 0.2 in the sexual activity category between the ovulatory and the follicular phase, this would indicate a slight increase of allosexual behavior during high-fertile days when compared to the follicular phase of the cycle. Similarly, to Cohen's d , while a g of 0.2 represent a small effect, 0.5 and 0.8 represent respectively a medium and strong effect (Cohen, 1988). In case of substantial heterogeneity ($I^2 > 75\%$), and following van Aert's recommendations (van Aert, Wicherts and van Assen, 2016), we created (when possible) homogenous subgroups based on theoretical assumptions to estimate and compare effect sizes of this subgroup with the overall analysis.

The hormonal profile characterization really depended on the type of study. Substance use studies (alcohol and tobacco consumption) tend to use more rigorous methods, including within-women design, thus increasing statistical power for tests of associations with different hormonal profiles. This polychotomous characterization of the hormonal profile (in comparisons to binary conceptualization of the cycle such as high vs. low fertility days) enabled us to analyze alcohol and cigarettes consumption through menstruation, follicular, ovulatory, early luteal and premenstrual phases. When it was not possible, as in the case of sexual behavior and risk recognition and avoidance for instance, we had to take a more restrictive approach including fewer phases. Finally, we systematically excluded studies that contained a high- vs low-fertilty comparisons since we could not compare them to more precise phase specifications (as for Adams, Gold and Burt, 1978; Bröder and Hohmann, 2003; Prokop, 2013).

Coding Study Characteristics. We coded study for different characteristic when data were available (and contacted respective first authors if not). This included 1) relationship context of the sample (single, in relationship, both or not specified), 2) mean age of the sample, 3)

dependence to the substance for the alcohol and tobacco category only: high (more than 10 cigarettes a day or more than one drink a day for women and two drinks for men) vs. low (10 cigarettes a day or less or up to 1 drink per day for women and 2 drinks for men, Boulos et al., 2009; CDC, 2016), 4) study design (within-participants vs. between-participants), 5) cycle position estimation method (forward counting method vs. reverse counting method vs. average from forward and reverse counting methods vs. luteinizing hormone tests to attest ovulation vs. salivary method to verify impending ovulation or estrogen/progesterone levels vs. basal body temperature (BBT), noting for studies that used counting methods whether the benchmark date of menstrual onset was verified). 6) Type of measure: self-reported (women indicated the length of their cycle and date of their past or next menstruation) vs. physiological (urinary, blood sample for BBT charts, saliva sample to assess cycle position). Two researchers independently coded each study and then crosschecked their codes. In the case of discrepancies (which were rare), the researchers referred back to the paper or contacted the authors to verify the correct code. Thus, all codes were verified as correct.

Analysis

The modeling approach, used for every analysis ran in this meta-analysis, gave us the ability to include non-independent effects from the same pool of participants in a single analysis. We then weighted each effect by its inverse variance to reduce imprecision in our estimate of the overall effect size (Borenstein, Hedges, Higgins, & Rothstein, 2009). We conducted all analyses in Comprehensive Meta-Analysis (version 3.3.070) because it includes the most complete set of analytical features (Bax, Yu, Ikeda & Moons, 2007; Borenstein, Hedges, Higgins & Rothstein, 2009).

Following van Aert, Wicherts, & Van Assen (2016), we ran both fixed- and random-

effect models for all the analysis included. While the former is used to make inferences based only on the actual studies, the later is generally applied to generalize the results for an entire population (Borenstein, Hedges, Higgins & Rothstein, 2009). However, under strong publication bias, random-effect models (REM) can result in overestimate effect sizes since studies with small sample sizes get more weight compared to fixed-effect analysis (the reason is that REM estimate a mean of distribution of effects and a small studies give information than other studies do not give and we cannot, in that extent, give it a smaller weight; see Borenstein, Hedges, Higgins & Rothstein, 2009).

We then conducted different type of analysis for each category. The alcohol and tobacco consumption category contains tobacco and alcohol consumption regularly notified in a daily diaries confirmed in some studies by physiological controls (e.g., carbon monoxide, blood alcohol level). The “sexual behavior” category included allosexual behavior (behavior involving another individual through sexual intercourse, genital simulation with other, foreplay). The “risk recognition and avoidance” category combined the level of accuracy to recognize emotions such as fear and anger (which might be cues to possible threats), on the one hand but also the capacity to recognize direct risk when reading sexual coercive scenario or when confronted to a doubtful individual (a strange confederate with a big facial scarce as in Guéguen, 2012)². Using meta-regression analysis (Borenstein, Hedges, Higgins, & Rothstein, 2009), we examined the following moderators: 1) whether the study used a self-report vs. physiological measure to assess cycle position or consumption markers (for all categories), 2) whether the sample came from dependent smokers or drinkers (in the alcohol and tobacco category), 3) the type of DV :self-reported vs. observed behavior (for the risk and recognition category), 4) the type of relationship:

² Despite not being a risk “per se”, those capacities to recognize emotional cues and dangerous situations (sexual or not) can lead women to take faster and more accurate decisions on signals that can indicate potential risks.

paired, single, both or no information (for the sexual activity category), and finally 5) the mean age of the sample (for all categories).

We computed numerous effect sizes that may be really dispersed and variable from one study to another. This inconsistency statistically refers to “heterogeneity” (Del Re, 2015; Higgins and Thompson 2002). For example, consider hypothetically that the effect of the fertile window compared to the follicular phase of the menstrual cycle on tobacco consumption is medium according to Cohen’s standards (Cohen, 1992) but there is high variability between and within study. It is plausible those women might differ quite dramatically from each other on their cigarettes smoke per day and that this variability could affect the true effect size. On the other hand, between-study variability may also account for variation among the effect sizes in the population.

When there is strong heterogeneity, it might be crucial to identify which moderators may account for this variability. This analysis can be run when there is a theoretical or empirical justification, thereby helping to avoid Type I errors (Hunter & Schmidt, 2004). We systematically applied fixed-effect and random-effects models (REM) to compare both results following the Meta-Analysis Reporting Standards (APA, 2008, 2010). In case of massive heterogeneity ($I^2 > 75\%$), we create subgroups of interests based on theoretical and methodological considerations and ran both types of models, including the 3 estimates of between-study variances in REM, namely I^2 , Q and t^2 (van Aert, Wicherts, & Van Assen, 2016).

Beyond heterogeneity, difficulties to correctly evaluate effect sizes with few studies in meta-analysis may be due to low statistical power or to publication bias (the so-called “file drawer problem”; Rosenthal, 1979). With the overrepresentation of significant effects published in the literature, true effect sizes can be largely overestimated (Rothstein, Sutton, & Borenstein,

2005). When significance was reached, we consistently reported funnel-plots and p-curve estimates in effort to isolate any particular publication bias or signs of p-hacking (Simonsohn, Nelson, & Simmons, 2014). Publication bias can artificially inflate the average effect size and reduce heterogeneity across studies. In the present meta-analysis, we intended to use as much cautions as possible so results could be interpreted more realistically giving the actual state of the publication bias debate in the literature.

Results

As explained in detail above, the menstrual shift hypothesis posits that women experience specific cycle change for every type of behavior analyzed (alcohol and cigarette consumption, sexual behavior, risk recognition and avoidance). Specifically, certain phases of the cycle are expected to exhibit shift such as increase of sexual activity and better risk accuracy recognition during the fertile window compared to the rest of the cycle. Moreover, alcohol and cigarette consumption are expected to decrease at mid-cycle and early-luteal phases compared to the rest of the cycle.

The analysis examined cycle shifts in risky behaviors from a broad set of measures. This global analysis included 79 effects (figure 2 in the following page) from 27 studies (total $N = 7,527$). Here, we present results category by category, because a global effect of such diverse types of risk-taking behaviors would not be appropriate, particularly given that there are different sets of predictions for each type of risk. We limited our analyses to effects for which there were reasonable predictions (e.g., a precedent in the literature, or reasoning we outlined in our introduction, such as that informed by evolutionary thinking).

	Ovulatory vs. Follicular	Ovulatory vs. Luteal	Ovulatory vs. Late Luteal	Ovulatory vs. Menstrual	Early Luteal vs. Follicular	Early Luteal vs. Late Luteal	Early Luteal vs. Menstrual
Alcohol and tobacco combined	$g = -0.07$ $95\% CI [-0.18; 0.04]$ $SE = .06$ $p = .19$ ($k = 6, N = 731$) $I^2/\tau^2 = 0, Q = 3.59,$ $p = .73$		$g = 0.01$ [-0.14; 0.16] $SE = .08$ $p = .86$ ($k = 7, N = 787$) $I^2 = 41.33,$ $\tau^2 = .02,$ $Q = 11.93,$ $p = .10$	$g = 0.01$ [-0.08; 0.09] $SE = .04$ $p = .87$ ($k = 7, N = 742$) $I^2 = 9.05, \tau^2 = .00,$ $Q = 7.70, p = .36$	$g = -0.15$ [-0.31; -0.00] $SE = .08$ $p = .048$ ($k = 4, N = 530$) $I^2/\tau^2 = 0, Q = 1.60,$ $p = .66$	$g = -0.09$ [-0.23; 0.04] $SE = .07$ $p = .19$ ($k = 5, N = 586$) $I^2/\tau^2 = 0, Q = 1.00,$ $p = .91$	$g = -0.02$ [-0.16; 0.13] $SE = .07$ $p = .83$ ($k = 5, N = 541$) $I^2/\tau^2 = 0, Q = .50,$ $p = .97$
Sexual activity	$g = 1.17$ [-0.02; 2.37] $SE = .61$ $p = .054$ ($k = 7, N = 2075$) $I^2 = 99.54,$ $\tau^2 = 3.31,$ $Q = 1731.00,$ $p < .001$	$g = 1.22$ [0.34; 2.09] $SE = .45$ $p = .006$ ($k = 9, N = 4753$) $I^2 = 99.48$ $\tau^2 = 2.37,$ $Q = 2123.06,$ $p < .001$		$g = 1.69$ [0.60; 2.78] $SE = .56$ $p = .002$ ($k = 6, N = 3306$) $I^2 = 99.57$ $\tau^2 = 2.75,$ $Q = 1837.34,$ $p < .001$			
Risk recognition and avoidance	$g = 0.28$ [-0.21; 0.78] $SE = .25$ $p = .26$ ($k = 8, N = 742$) $I^2 = 85.30,$ $\tau^2 = 0.38,$ $Q = 47.61,$ $p < .001$	$g = 0.40$ [0.06; 0.74] $SE = 0.17$ $p = .02$ ($k = 10, N = 917$) $I^2 = 76.63,$ $\tau^2 = 0.20,$ $Q = 38.51,$ $p < .001$		$g = 0.50,$ [-0.20; 1.21] $SE = 0.36$ $p = .16$ ($k = 5, N = 351$) $I^2 = 83.86,$ $\tau^2 = 0.51,$ $Q = 24.79,$ $p < .001$			

Figure 3. Table displaying all the main phases' comparisons for the three domains of health-related risks.

Alcohol and Tobacco consumption patterns. Ovulation vs. other phases.

We first analyzed the alcohol (ounces of alcohol per day) and tobacco consumption (number of cigarettes per day) throughout the ovulatory, the follicular, early luteal, late luteal and menstrual phases according to our theoretical framework.

Analysis comparing the *ovulatory* period to the *follicular* phase in REM revealed that the weighted mean g was null ($g = -0.07$, 95% $CI [-0.18; 0.04]$, $SE = .06$) and not statistically significant ($p = .19$) indicating no difference of alcohol and tobacco consumption between those two phases of the cycle. The data revealed low heterogeneity ($I^2 = 0$, $\tau^2 = 0$, $Q = 3.58$, $p = .73$). A strong pre-post correlation for within-study design ($r = 0.75$) led, on the contrary, to small significant effects in both fixed and random models indicating a small protective effect of the ovulatory phase, $g = -0.09$; $[-.17; -.00]$, $SE = .04$, $p = .047^3$ ($I^2 = 0$, $\tau^2 = 0$, $Q = 5.06$, $p = .54$). None of the moderator explained the effect ($Q = 3.13$, $p = .37$ for the full model including age, physiological control of the phases and dependent conditions – heavy smokers or alcoholics – of the participants).

When we compared the *ovulatory* period to the *late luteal period*, the REM analysis showed a null ($g = 0.01$, $[-0.14; 0.16]$ $SE = .08$) and not statistically significant effect ($p = .86$) without influence of the pre-post within-study correlation. The data revealed small to medium heterogeneity ($I^2 = 41.33$, $\tau^2 = .02$, $Q = 11.93$, $p = .10$).

We finally compared cigarette and alcohol consumption between the *ovulatory* phase and the *menstrual* phase. This category revealed that the weighted mean g was null ($g = 0.01$, $[-0.08; 0.09]$, $SE = .04$) and not statistically significant ($p = .87$) indicating no difference of consumption

³ No additional indications were inserted if the pre-post correlation threshold for within-study design ($r = 0.25$, 0.50 or 0.75) did not change the significance of the results.

between those phases. The data revealed low heterogeneity ($I^2 = 9.05$, $\tau^2 = .001$, $Q = 7.70$, $p = .36$).

Alcohol and Tobacco consumptions patterns. Early luteal vs. other phases.

We then compared this behavior within *early luteal* phase to the *follicular*, *late luteal* and *menstrual* phases according to our theoretical framework.

During the *early luteal* phase, women consumed significantly less alcohol and tobacco than during the *follicular* phase. This category revealed a *small significant* effect ($g = -0.15$, $[-0.31; -0.00]$, $SE = .08$, $p = .048$) with low heterogeneity ($I^2/\tau^2 = 0$, $Q = 1.60$, $p = .66$). Both fixed and random-effect models gave exactly the same results (see Appendices, Table 2 for menstrual cycle categorizations and figure A1 for funnel plots that revealed no apparent publication bias). A weak pre-post correlation of $r = 0.25$, revealed a marginal effect ($g = -0.15$, $[-.30; .01]$, $SE = .08$, $p = .07$) while a strong one (i.e., $r = 0.75$) revealed a significant effect ($g = -0.17$, $[-.30; -.03]$, $SE = .07$, $p = .01$) with very low heterogeneity in both cases ($I^2/\tau^2 = 0$).

Finally, the comparisons between the *early luteal* phase and the *late luteal* phase and between the *early luteal* phase and the *menstrual* phase revealed a null effect ($g = -0.09$, $[-0.23; 0.04]$, $SE = .07$ and $g = -0.02$, $[-0.16; 0.13]$, $SE = .07$, respectively) not statistically significant ($p = .19$ and $p = .83$) with low heterogeneity ($I^2/\tau^2 = 0$, $Q = 1.00$, $p = .91$ and $Q = .50$, $p = .97$, respectively). Due to the low number of studies for these comparisons, it was not possible to run any meta-regression including the covariates of interest or to compute p-curve because all tests included $p > .05$.

Sexuality pattern. Ovulation vs. other phases.

We analyzed the frequency of allosexual behavior to determine the difference between the *ovulatory* phase and the other phases of the menstrual cycle (see Table 4, in Appendices, for

the cycle days including in those phases).

The comparison between the *follicular* phase and the *ovulatory* period produced a weighted mean g that was large ($g = 1.17$, $[-.021; 2.37]$, $SE = .61$) but only marginally significant ($p = .05$). The fixed-effect model also displayed a significant result with a large effect ($g = 0.76$, $[-.69; .84]$, $SE = .04$, $p < .001$). However, the data revealed high heterogeneity ($I^2 = 99.54$, $\tau^2 = 3.31$, $Q = 1731$, $p < .001$) due to very strong effect sizes (from Caruso et al., 2014) that largely inflated the overall effect and produced publication bias (but no evidence of p-hacking, see figures S1a and P1a in Appendix). Not including them into the analysis produced a null and non-significant effect ($g = -0.04$, $[-0.22; .15]$, $SE = .09$, $p = .71$) with much lower heterogeneity compared to the full analysis ($I^2 = 70.09$, $\tau^2 = .04$, $Q = 20.06$, $p = .003$, see figure S1b in Appendix) leading to think that the true effect must be close to zero (the fixed-effect analysis even resulted in changing the direction of the effect, $g = -0.10$, $[-.18; -.004]$, $SE = .05$, $p = .04$).

We then compared data between the *ovulatory* and the *menstrual* phase and established that the weighted mean g was large ($g = 1.69$, $[-.60; 2.78]$, $SE = .56$) and statistically significant ($p = .002$) indicating more pronounced sexuality during the *ovulatory* phase when compared to the *menstruation*. The fixed-effect model also revealed a significant results with a medium to large effect ($g = 0.67$, $[-.60; .74]$, $SE = .04$, $p < .001$). The data again revealed very high heterogeneity ($I^2 = 99.57$, $\tau^2 = 2.75$, $Q = 1837.34$, $p < .001$) with apparent publication bias but no sign of p-hacking (see figures S3a and P1c in Appendix). Again, the data from Caruso et al. (2014) displaying abnormally high effect sizes, an analysis excluding those data were re-run leading to a small significant effect in both fixed- and random-effect models ($g = 0.17$, $[-.10; .24]$, $SE = .04$, $p < .001$) with no apparent heterogeneity ($I^2/\tau^2 = 0$, $Q = 5.50$, $p = .48$) or evidence of

publication bias (see figure S3b in Appendix).⁴

We finally compared the *ovulatory* period to the *luteal* phase and established that the weighted mean g was large ($g = 1.24$, $[0.32; 2.16]$, $SE = .47$) and statistically significant ($p = .008$) indicating higher frequency of sexual activity around *ovulation* when compared to the *luteal* phase (the fixed-effect model, however, revealed a more modest effect, $g = 0.33$, $[-.27; .39]$, $SE = .03$, $p < .001$). Since the heterogeneity was substantially high ($I^2 > 75\%$), we again ran an analysis excluded two inflated effects (from Caruso et al., 2014) and found no significant effect either in random-effect ($g = 0.06$, $[-.04; .16]$, $SE = .05$, $p = .27$) or fixed-effect model ($g = 0.005$, $[-.06; .06]$, $SE = .03$, $p = .88$) with a much lower level of heterogeneity ($I^2 = 50.04$, $\tau^2 = .01$, $Q = 16.01$, $p = .04$; see figures S2a, S2b and P1b for sign of publication bias and p-hacking analysis).

Risk recognition and avoidance pattern. Ovulation vs. other phases.

The third category of risks included sexual and non-sexual risk avoidance along with emotional cues that can lead to avoid potential risks (recognition of fear and anger). We first computed this risk recognition to compare the *ovulatory* and the *luteal* phase. Consistent with theorizing in this literature, this analysis revealed that the weighted mean g for the REM was small to moderate ($g = 0.40$, $[-.06; .74]$, $SE = .17$) and statistically significant ($p = .02$) indicating better risk recognition accuracy around *ovulation* when compared to the *luteal* phase of the cycle. The fixed-effect model also revealed a significant results ($g = 0.25$, $[-.11; .39]$, $SE = .07$, $p = .001$) with evidence of a small amount of publication bias, but no apparent indications of p-hacking (figure R3 and P2 respectively, in Appendix). Meta-regressions analysis did not reveal

⁴ There were not enough studies to run a meta-regression including the covariates of interest (age, relationship status and physiological controls). A weak pre-post correlation ($r = 0.25$) led to a significant results in both FEM and REM ($g = 0.17$, $[-.09; .25]$, $SE = .04$, $p < .001$) while a strong pre-post correlation ($r = 0.75$) led to a significant results of the same amplitude ($g = 0.18$, $[-.11; .25]$, $SE = .04$, $p < .001$).

any significant effects (the full model explaining 34% of the total between-study variance). Since the heterogeneity was still substantially high ($I^2 > 75\%$), we followed van Aert and colleagues' recommendations (2016) by analyzing subgroups of interest. The subgroup of interest, based on theoretical assumptions, were sexual risks (excluding emotion recognition studies) and revealed a small to large significant effect in both random-effects ($g = 0.55$, $SE = .27$, $[-.02; 1.08]$, $p = .04$) and a small effect in fixed-effect model ($g = 0.25$, $SE = .08$, $[-.09; .41]$, $p = .002$) still leading to non-trivial heterogeneity ($I^2 = 88.70\%$).

When we compared the *ovulatory* against the *follicular* phase, we found that the weighted mean g was small ($g = 0.28$, $SE = .25$, $[-.21; .78]$) but not statistically significant ($p = .26$) indicating no difference at risk recognition accuracy during the *ovulatory* compared to the *follicular* phase of the menstrual cycle (the fixed-effect model revealed a null effect, $g = -0.06$, $SE = .08$, $[-0.23; .10]$, $p = .44$). Large heterogeneity ($I^2 > 75\%$) led us to re-analyze our data based on sexual risk recognition studies and found no significant effect in both REM and FEM analysis ($g = 0.32$, $SE = .33$, $[-0.33; 0.97]$, $p = .34$ and $g = -0.10$, $SE = .09$, $[-0.27; .07]$, $p = .25$ respectively). This second analysis also led to substantial evidences of heterogeneity ($I^2 = 91.06$, $\tau^2 = 0.47$, $Q = 44.74$, $p < .001$).

We finally compared the *ovulatory* and the *menstrual* phases. This category revealed that the weighted mean g was moderate ($g = 0.50$, $SE = .36$, $[-.20; 1.21]$) but not statistically significant ($p = .16$) with high heterogeneity ($I^2 = 83.86$, $\tau^2 = 0.51$, $Q = 24.79$, $p < .001$). The fixed-effect model also yield a non-significant result ($g = 0.03$, $SE = .11$, $[-.18; .25]$, $p = .77$).

The funnel plots revealed that, while the alcohol and tobacco set of studies did not display any apparent bias, the other categories were inconsistent. In both risk-recognition and sexuality studies, there seemed to be an underrepresentation of studies in the lower part of the

plot (with smaller standard errors) and generally one or two studies outside the plot (with g 's > 1). According to Egger, Smith, Schneier, & Minder (1997), such apparent publications bias could be due to delayed publication or locations biases; selectively reported outcomes or analysis; fraud or simply chance. Sterne et al. (2011) later expressed some concerns over the direct association between funnel plot asymmetry and publications biases in particular when visually inspected funnel plots alone. Comparing fixed and random effect models is also a way to explore possible bias when funnel plots are asymmetrical in meta-analysis with substantial between-study heterogeneity. In both risk recognition and sexual activity studies, fixed effects models eventually revealing significant effects to the same extent of random-effect models.

In addition, while our set of alcohol and tobacco studies did not have enough significant studies to run adequate p -curves (a good sign of absence of p -hacking), the two others categories revealed no evidence of p -hacking with high power and good fit between expected and observed p -values (Simonsohn, Simmons & Nelson, 2015; see Appendices for details). Since data revealed moderate-to-large heterogeneity (for the risk recognition and sexual activity categories), we also followed van Aert and colleagues (2016) by doing subset analysis when possible. Approached based on selections methods, such as the one developed by Hedges (1992), presents less sensitivity to heterogeneity, and may lead us to extra-caution in interpreting results with moderate-to-large heterogeneity (McShane, Böckenholt & Hansen, 2016).

Discussion

Overview. This meta-analysis provides the first attempt to describe health-risks pattern across the ovulatory cycle. The three main categories of risk-taking behaviors assessed include alcohol and tobacco consumption, sexual behavior, and risk recognition and avoidance. The last one analyzed both the accuracy at recognizing emotions that could indicate threat (fear and

anger), as well as behavioral responses to potentially dangerous situations. All of those behaviors are of important concern for the health community. Understanding them, through different levels of organization (hormonal, social, and behavioral) represents both a scientific challenge and an important new way of thinking about women's health.

Surprisingly, the data revealed that the ovulatory phase was not associated with a reduction in alcohol and tobacco consumption when compared to the rest of the cycle. Those effects were close to null and the between-study variability due to heterogeneity rather than sampling error was null to medium ($0 < I^2 < 42$) due either to consistent measures and methods between studies and/or because our sample of studies was too small to estimate true heterogeneity. On the other hand, only the *early luteal* versus *follicular* comparison revealed a small reduction of consumption of these toxic substance during the post-ovulatory phase (women consuming less alcohol/tobacco at early luteal when compared to the follicular phase). Those general results may seem counterintuitive since the late luteal phase, in particular, is subject in some women to premenstrual syndrome, a common condition (involving depression, mood lability, abdominal pain, headache among others) that could lead to more alcohol and tobacco consumption (Dickerson, Mazyck & Hunter, 2003). Since our data did not reveal any relationship between the late luteal phase and substance use, this may indicate that as menstruation approached, withdrawal symptoms might increase but not necessary alcohol or tobacco consumption per se (see the meta-analysis by Weinberger et al., 2015).

The sexuality results did not match the same patterns observed in many non-human species. Despite an apparent conflicting literature and remaining debate and the evolution, existence, and function of estrus (Thornhill & Gangestad, 2008), the data revealed an increase in allosexuality around ovulation compared to the menstrual phase but the other comparisons did

not hold when excluding extreme effects (from Caruso et al., 2014). One possible confounding might be that sexual activity in general (masturbation, foreplay, etc.) varies across the cycle and that some specific behaviors (e.g., intercourses) weighted more than others did.

Another mediator that could partially explain the inconsistency observed in the allosexual behavior shift would be the increase in women's attractiveness. Gildersleeve & Haselton (2018), for instance, reviewed evidence for an ovulatory increase in the attractiveness of women's voices, appearance, and even body movements. As a result, women's partner might be more likely to initiate sexual activity at that time. It is unclear, however, whether women are driving this effect or if factors behind their control, such as partners' advances or availability play a role and to what extent. One thing to also consider is the target of women's attractions and sexuality. Past research has shown that increases in women's attraction to their own (primary) partners vs. other men is associated with the sexual attractiveness of their primary partners (reviewed in Larson, Pillsworth, & Haselton, 2012). Women partnered with less sexually attractive partners, on the other hand, tend to show increases in attraction to other men when fertile (see also Gangestad, Thornhill & Garver-Apgar, 2005; Thornhill & Gangestad, 2008). Controlling for the attractiveness perception of the participants and his/her partner could clarify this potential sexuality shift.

Another hypothesis that we did not investigate is the role of women's luteal phase in their sexual receptivity (i.e., acceptance of male sexual initiation) and proceptivity (i.e., women's initiation of sexual activity). Even though the luteal phase did not seem to display higher frequency of allosexual behavior than the ovulatory period, it's worth noting that recent data show an increase of sexual activity with primary partners when comparing the luteal phase to the follicular phases, particularly for women who feel that their partner's investment in the

relationship lags behind their own (Grebe, Gangestad, Garver-Apgar & Thornhill, 2013). This hypothesis (that extended sexuality promotes sexual activity in the luteal phase to encourage investment from male partners) is subject to controversy as recent works failed to replicate this effect (Roney & Simmons, 2016). In all, however, it remains plausible that women's sexual motivations are influenced by hormonal fluctuations (such as estrogen peak before and at ovulation) and that extended sexuality is influenced by social factors (such as week-end timing) that we did not assess in our present work (Roney & Simmons, 2016).

Along with the ovulatory shift in sexuality, researchers have predicted that a counter-risk mechanism may have evolved to protect women against environmental threats (including sexual assaults) specifically during the most fertile days. Whereas there is still an ongoing debate about whether women ovulating are underrepresented among victims of rape (Fessler, 2003), we found a shift on risk recognition when comparing the *ovulatory* and the *luteal* phases. However, the other phases comparisons did not reach significance. This could be due to a low statistical power or to the substantial between-study heterogeneity (concepts and methods use differed largely across studies). It is also possible that the risk recognition capacity encompasses larger skills sets toward at reducing risk of sexual coercion that the present studies did not include.

Limitations. The results of this meta-analysis presented somewhat mixed findings. On the one hand, there were some increases in sexual activity and risk recognition capacity during the ovulatory period as compared with other low-fertility phases (menstrual and luteal respectively). However, the alcohol and tobacco consumption analysis showed inconsistent results, which contrasted with results observed in the animal literature. Despite a relatively coherent methodology for the substance use portion of the analysis, with longitudinal design, physiological characterization of the menstrual cycle, low heterogeneity, only the analysis

comparing the early luteal versus the follicular phase displayed significant small effect.

Studies were methodologically heterogeneous. Therefore, all results should be cautiously interpreted. In the alcohol and tobacco category, data coming mostly from medical studies, represented high methodological standards with longitudinal studies design and LH measures. The very low heterogeneity and the good quality of measures would be optimal if there were not such small samples sizes and too many parameters (one or two independent variable with multiples modalities). Therefore, one should be cautious in interpretation these findings.

Sexual behavior also showed an increase during the fertile period when compare to other phases but only the ovulatory vs. menstrual comparison resisted the exclusions of the inflated effects (Caruso et al., 2014). This particular shift may be largely explained by the tendency to avoid sexual activity at menstruation because of physical discomfort or social taboos. It is also possible that male partners could be driving some of this effect because of their increase interest in women displaying estrus cues. The very few numbers of intercourses-only variable made impossible the analysis of that specific behavior. While the high vs. low fertility shift would include specifically higher frequency of sexual intercourses around ovulation, the shift might include a wider range of sexual activity when other phases are targeted. For instance, when comparing the luteal to the follicular phases, it might be plausible to see more non-reproductive sexuality at luteal phases (including masturbation, oral sex, etc.) when fertility in the lowest.

Along with sexual activities, some evolutionary theorists have argued that women will be better at recognizing emotions and cues of dangerous (sexually coercive) situations when fertile. Caution is again warranted in interpreting these findings. First, it is not clear that the emotion recognition is directly related to danger avoidance but we chose to include them because in an ancestral context, seeing anger or fear in someone else' face might be a cue to potential danger in

the near environment. Second, studies of reaction sensitivity to sexual assault scenario and threatening situations were highly heterogeneous. Finally, the only robust effect seemed to be the ovulatory vs. luteal comparisons with women participants more accurate at recognizing risk at high fertility compared to the luteal phase. One possible explanation is that our comparisons were too specific and a more general high vs. low fertility mechanism is at play. Again, those studies revealed large heterogeneity with or without subgroup analysis as illustrated by funnel plots (see Appendices).

A limitation of the funnel plot approach includes the fact that the shape of the funnel plot is largely determined by the way of building the plot. The other main problem with that technic is that publication bias, in both social and medical sciences, largely occur through significance and not effect sizes (Simonsohn, Nelson & Simmons, 2014). This can happen, in particular through p-hacking by data peeking, selectively reported DVs or excluding outliers (van Aert, Wicherts & van Assen, 2016). Since journals tend to report only significant findings, this can lead to largely inflate the effect sizes in the available literature (Ioannidis, 2005). Simonsohn and colleagues (2014) then decided to create p-curve stated that “because only true effects are expected to generate right-skewed p-curves — containing more low (.01s) than high (.04s) significant p values — only right-skewed p-curves are diagnostic of evidential value” (Simonsohn, Nelson & Simmons, 2014, p.534).

Contributions of the present research and directions for the future. This meta-analysis represent to our knowledge the first attempt to determine the combined effect of menstrual cycle on health-related risk-taking behavior for those specific categories of effects. Through 27 studies and 79 effects, we have been able to assess multiple analysis in an effort to examine risk behaviors across the cycle. We also used several procedures to determine whether observed

statistically significant cycle shifts appeared to result from bias in researchers' measurement of menstrual cycle phases (through meta-regressions) or variations across relationship context or physiological controls (but the lack of power make it hard to strongly based our analysis on such inferences).

In the future, researches should seek to identify the hormonal mechanisms underlying cycle shifts in women's risky behavior. Previous research has suggested several possible candidates for hormonal mediators of the cycle shifts observed in this meta-analysis. Estrogen seems to play a role in the regulation of dopamine during alcohol and tobacco use for instance. However, the exact pathway and the causal direction of this effect remains unknown and may contribute to make more systematic interdisciplinary projects leading to the evaluation of those biomechanics. Those biogenesis, proliferative, ovulatory, luteal and pre-menses) is the most appropriate experimentally.

Second, research in some area has focused on testing for the presence of cycle shifts in women's risky behavior primarily in Western samples of educated young women. That was the case of the risk and avoidance category mainly ran on psychological students. Those samples are usually overrepresented in psychological research and this bias is a real problem that need to be addressed (Henrich, Heine, & Norenzayan, 2010). However, the alcohol and tobacco dataset and the sexual behavior studies were largely run on non-undergraduate, community women allowing for conclusions that are more generalizable. Nonetheless, future research should consider varied samples of women to see if cultural context might affect cycle shifts. For example, menses is interpreted differently in non-Western societies and be more subject to taboo in certain part of the world. This could dramatically affect women's sexuality dynamic by either reducing even

more their activity at that time or promoting stronger effects when compared to other phases (Agyekum, 2002; Costos, Ackerman & Paradis, 2002).

Lastly, from a methodological standpoint, the study of menstrual cycle does not have yet a standard procedure across disciplines to precisely determine women's position on the cycle. In general, different methods with various reliability are available for that procedure. The strongest one consist at measuring the LH level of the women either in a cross-sectional design (between-study design) or along the cycle (within-study design or longitudinal). Other physiological tools permit to determine women's position cycle such as the BBT charts but many studies in psychology are still using self-report measures (backward and forward counting methods) that present weaknesses and imprecisions compared to the methods described above. It could be the case that medical studies, like those represented in the alcohol and tobacco category, have better measures of hormonal profiles and so lower heterogeneity as compared to psychological studies. In order to get an optimal understanding of those health-risk behaviors, inter-disciplinary studies and multi-methodology still represent the best option to understand risky behavior and provide insights into health applications and policy programs. On the other hand, we chose in this meta-analysis to make comparisons between different phases instead of using a dichotomous (high- vs low- fertility days). Future meta-analysis should also aim at analyzing high- vs. low- fertility on risky behaviors and compare it to phases analysis.

Table 1. Menstrual phases definitions for alcohol and tobacco studies (Ovulatory vs. Follicular/Late Luteal/Menstrual phases)⁵

☒ Menses (all bleeding days) and Follicular (end of menses to beginning of the ovulatory phase)

□ Ovulatory days

▨ Menses

■ Late Luteal

▤ Follicular

Study	Effect	Cycle days defined as “menses”, “follicular”, “ovulatory” and “late luteal”																												
		28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	← RCD
		FCD →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
DeBon et al. (1995)	Cig./phase																													
Roney & Simmons (2013)	% days alcohol consumed																													
Pomerleau et al. (1994)	Drinks and cig./day																													
Pomerleau et al. (2000)	Alcohol oz/day and cig/day																													
Dumas (1984)	Alcohol ounces/day																													
Charette (1989)	Alcohol ounces/day																													
Harvey (1984)	Alcohol ounces/day																													

⁵ We assumed a 28-day cycle length to compare the different methods (forward and backward counting methods, BBT chart, etc.) with ovulation occurring on day 14 for FCD and 15 for RCD. Light blue boxes indicate studies that only used physiological measures and cannot be framed as FCT or BCT.

Menses (all bleeding days) and Follicular (end of menses to beginning of the ovulatory phase)
 Early luteal
 Late Luteal

Menses
 Follicular

Study	Effect	Cycle days defined as “menses”, “follicular”, “ovulatory” and “late luteal”																												
		28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	← RCD
		FCD →																												
DeBon et al. (1995)	Cig./phase																													
Roney & Simmons (2003)	% days																													
	alcohol																													
	consumed																													
Pomerleau et al. (1994)	Drinks and cig./day																													
Pomerleau et al. (2000)	Alcohol																													
	oz/day and																													
	cig/day																													
Dumas (1984)	Alcohol ounces/day																													

Ovulation Luteal

Menses Follicular

Menses (all bleeding days) and Follicular (end of menses to beginning of the ovulatory phase)

Study	Effect	Cycle days defined as “menses”, “follicular”, “ovulatory” and “late luteal”
		28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 ← RCD
	FCD →	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

Pearson & Lewis (2005)	Face recognition accuracy	
Petralia & Gallup (2002)	Sexual assault scenario on handgrip strength	
Guapo et al. (2009)	Accuracy in emotion recognition	
Guéguen (2012)	Interaction with a threatening confederate	
Walsh & DiLillo (2013)	Risk recognition latency	
Fessler (2014)	Fear of crime, sexual assaults. Score difference in envisioned physical formidability	
Maner & Miller	Facial expression	

(2014)	identification	
Bullivant (2013)	Perception of intensity of emotions
Chavanne & Gallup (1998)	Risk-taking scores

Table 4. Menstrual phase definitions for Sexual Activity studies (Ovulation vs. Follicular/Luteal/Menstrual)

- ☐ Ovulation
 ☐ Luteal
☒ Menses
 ☒ Follicular
☒ Menses (all bleeding days) and Follicular (end of menses to beginning of the ovulatory phase)

Study	Effect	Cycle days defined as “menses”, “follicular”, “ovulatory” and “late luteal”																												
		28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	← RCD
		FCD →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Bellis & Baker (1990)	Frequency of sexual activity/day
Caruso et al. (1994)	% sexual activity/day
Morotti (2013)	Number of intercourses/week.

Appendix

A1. Alcohol/Tobacco (Early luteal vs. Follicular)

R2. Risk recognition and avoidance (Ovulation vs. Follicular)

R3. Risk recognition and avoidance (Ovulation vs. Luteal)

R4. Risk recognition and avoidance (Ovulation vs. Menstrual)

S1a. Sexual activity (Ovulation vs. Follicular with Caruso et al., 2014)

S1b. Sexual activity (Ovulation vs. Follicular, without Caruso et al., 2014)

S2a. Sexual activity (Ovulation vs. Luteal with Caruso et al., 2014)

S2b. Sexual activity (Ovulation vs. Luteal without Caruso et al., 2014)

S3a. Sexual activity (Ovulation vs. Menstrual, with Caruso et al., 2014)

S3b. Sexual activity (Ovulation vs. Menstrual, without Caruso et al., 2014)

P1a. Sexuality, ovulatory vs. follicular

Note: The observed p -curve includes 20 statistically significant ($p < .05$) results, of which 17 are $p < .025$. There were no non-significant results entered.

P1b. Sexuality, ovulatory vs. luteal

Note: The observed p -curve includes 22 statistically significant ($p < .05$) results, of which 20 are $p < .025$. There were no non-significant results entered.

P1c. Sexuality, ovulatory vs. menstrual

P2. Risk-recognition (ovulation vs. luteal phase)

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