1. Introduction

Every living animal species, including humans, has a biological clock that responds to environmental cues like light/dark cycles. This property is called ‘chronobiosis’ and regulates the secretion of the hormone melatonin from the pineal gland. Melatonin is a hormone secreted mainly at night and it reaches its nadir in the early morning. The circadian pacemaker, is contained in the suprachiasmatic nucleus (SCN). Sunlight enters the eyes, strikes the retina and ultimately reaches the SCN via the retinohypothalamic pathway or the RHT. The SCN sends signals via a series of nerve fibers in the hypothalamus, up to the pineal gland to stimulate melatonin secretion, which in turn, induces sleep (Gibb 2007).

Human sleep patterns differ across age groups and between males and females, and their association with age and gender suggest that they might have been the target of sexual selection during human evolutionary history. Indeed, sexual selection (Darwin, 1871) is the primary evolutionary cause of sex differences. The most likely way in which sexual selection could have acted on human sleep patterns is through a lek-display system, taking place at night, when people were free from foraging activities or other tasks and stayed closer to each other in order to defend themselves from predators. In many birds, insects and mammals, males (two or more) use a communal area in which they perform courtship displays, usually by dancing or fighting with other males. Females are attracted by concentrations of males. In the black grouse, for example, ' males gather on traditional display grounds in the early morning and spend a good part of each day on breeding territories within which they do not feed but attempt to attract females for purposes of mating' (Trivers 1985). In these species, females have been shown to exercise mate choice, preferring males with specific characters (Andersson 1994).

In the same way, most social activities have always taken place at night, from the dances of hunter gatherer groups to the bars, pubs and clubs of contemporary societies. The evening is therefore a ‘’temporal lekking ground’’, or the part of the day when men ‘perform courtship displays, usually by dancing (and fighting?)’ in a communal area and women choose the most attractive males. Among the Wadabe of Niger, for example, the men prepare their clothing and their makeup. They then line up and chant and step forward opening their eyes really wide and grimacing to show their pretty teeth to the crowd of women before them. They dance vigorously for seven full nights and at the end of the ceremony each woman chooses the man that she finds most attractive and she invites him for a sexual encounter. Usually Wadabe women prefer the tallest men with the whitest teeth, the largest eyes, the straightest nose, the most elaborate body-painting and the most creative ornamentation (Miller 2000).

According to my hypothesis, evening-oriented males had an higher reproductive success than morning-oriented males and therefore they left more descendants carrying the genes for eveningness (evening preference). However, since eveningness increased the fitness of males more than the fitness of females, eveningness became a sexually dimorphic trait, more pronounced in males than in females. The reason why eveningness is more favourable to males than to females is because, according to the moderately polygamous nature of humans, male differential reproductive success (RS) is higher than female differential RS, so although women also had to be awake relatively late in order for men to mate with them, the benefit (in terms of darwinian fitness) to a man of staying up late (thus having access to an increased number of women) was higher than the benefit to a woman. This type of selection is intra-sexual, because it does not involve female choice for the eveningness trait, but rather competition between males over who is able to stay up late enough to mate with the women.

Fisher's (1930) runaway sexual selection is another possible process through which the sexual dimorphism in circadian preference could be accounted for. This is a two-step process. Females who choose males that carry a genetic variation responsible for a trait that has initially a slight survival advantage bear sons with high survival. Hence alleles that code for that particular trait in males will spread, together with alleles which make females prefer that trait, as the two types of alleles become associated in their offspring. When this process continues, a new effect grows in importance: males with the trait that initially conferred high survival are favoured not only by better survival, but also by higher mating success as the preference for that trait spreads among females. This makes the associated alleles for the trait and the female preference increase to yet a higher frequency, and a feedback 'runaway process' develops at an accelerating pace (Andersson 1994). Although theoretically possible, we need to hypothesise how the E-trait might have conferred a benefit to the initial carriers of that trait, thus kick-starting the Fisherian runaway selection process. The only problem with this theory is that it is difficult to imagine how evening preference in men could have initially increased their survival, and it's difficult to test any hypothesis about it without incurring the risk of telling "just-so" evolutionary stories.

Another possible kind of sexual selection at work might be handicap signalling (Zahavi 1975). Handicap signalling was presented by Zahavi (1975) as an alternative to Fisherian sexual selection by self-reinforcing mating advantages. According to this hypothesis, traits which are expensive for the individual to carry make those traits reliable as indicators of fitness. For example, peacock tails are costly in terms of the energy required to grow, to preen and to carry around, so that unhealthy, unfit peacocks cannot afford big, bright tails (Miller 2000).

Although people who go to bed later also tend to wake up later, therefore getting the same amount of sleep as people who go to bed earlier, social and survival needs(e.g. work) often require people to wake up earlier even after a late night, causing sleep deprivation. Evening people report lower sleep quality and shorter time in bed during the week and greater consumption of caffeine-containing beverages and substances to promote sleep (Giannotti et al. 2003).

Sleep deprivation is associated with a variety of health problems (heart conditions, depressed immune system, increased risk of cancer, etc.) and only people with good health can afford to stay up all night and work the day after. The morningness versus eveningness dimension can be viewed as part of the Cad versus Dad strategy, where Dads are represented by morning types, and where Cads are represented by evening types. Other traits, such as extraversion, are associated with an higher number of sexual partners but also with higher risk of injuries and lower life expectancy compared to introversion. In the same way, evening types (E-types) tend to use alcohol, tobacco and other caffeine-containing beverages more frequently. E-types also report more injuries and poorer performance in school (Giannotti et al. 2001).

Thus, Eveningness might be a trait that favours reproductive effort over somatic growth. The increase in reproductive success of the individuals who carry the Eveningness trait might compensate for the costs to their health, allowing its persistence in the human population through the generations.

In this study I test the hypothesis that sexual selection accounts for the observed differences in sleep patterns between males and females. My study is the first to date that tests the hypothesis of sexual selection on sleep patterns in humans.

Sexual dimorphism (the systematic difference in form between individuals of different sexes in the same species) is due to the differential effects of sexual selection on the two sexes and therefore sexual selection is thought to account for many sexual dimorphic traits. For example, body size is sexually dimorphic in most species, where the male is usually larger than the female. Bright plumage in birds is attractive to females, and males usually have brighter colours than females. Large horns in some species aid the males in the competition for females, allowing the male to engage in combat with other males more effectively.

I will test the hypothesis that eveningness is a sexually selected trait by analysing the relationship between a measure of reproductive success (number of sexual partners) and eveningness. I predict a negative relationship, with male evening types (low score on the Morningness/Eveningness questionnaire) reporting an higher number of sexual partners. On the other hand, I predict no relationship between Eveningness and number of sexual partners among women. Relating a secondary sex trait to mating success is the standard method used in studies of sexual selection in animals (Andersson 1994).

Sleep patterns show marked sex differences and change with age.

Traits that are a result of sexual selection usually grow only after puberty, because courtship is restricted to sexual maturity. For example, male beards and other body hair, male upper body musculature, male penises and deep voice begin to develop during puberty.

Studies of teenagers show the occurrence of many shifts in sleep/wake patterns, particularly during the transition from childhood to adolescence. Older boys tend to have a more irregular sleep schedule, and they also tend to go to bed later. In a study of Finnish children (Tynjala and Kannas 1993) the proportion of those children who went to bed after 11 pm increased from about 5% for 11-year-old boys to about 30% for 15-year-old boys. Later bedtime was more common for boys than for girls. Similar results are reported by a study (Giannotti et al. 2002) of Italian high-school students, based on answers to a comprehensive questionnaire including items regarding circadian preference, sleep and daytime behaviour. This study found no significant sex differences in morningness/eveningness preference, but males had later bedtimes and rise times in the two age groups (younger aged 14.1-16 years and older aged 16.1-18.6 years). A tendency to go to bed later with age, both during school nights and particularly weekends, was confirmed by this study. A study (Tsai and Li 2003) of Chinese college students (aged 18-24) showed the same gender differences. Women went to bed earlier and woke up earlier than men, but they also had longer sleep latency, more awakenings during night sleep, and lower ratings on sleep quality. Contrary to other studies, this one did not show significant gender differences in bedtime or rise time regularity.

Gibertini et al. (1999) found sex differences in melatonin secretion patterns. Males on average had peak melatonin levels somewhat later than females and females were significantly phase-advanced compared to men. Melatonin acrophase was also related to self-reported circadian type, suggesting that morningness-eveningness questionnaires are reliable indicators of circadian type. The same study found an age effect on circadian types, with morning types somewhat older than afternoon or evening types.

Moe et al. (1991) reported differences between men and women in core body temperature and acrophase (advanced for women by an average of 49 minutes), and women retired and rose earlier than men. Similar findings were reported by Wilson (1990), Baehr et al. (2000) and Buela-Casal (1999). Tankova et al. (1994) did a meta-analysis which showed that women were phase advanced compared to men, although by only one hour. This difference was too small to be reflected in the scores on morningness-eveningness questionnaires.

A study on a large university population (n= 2135) found significant gender differences in the mean score and in the circadian typologies between men and women (Adan and Natale 2002).

A meta-analysis of 52 studies which used self-report questionnaires, found a weak but significant effect of gender on morningness, with girls and women being significantly more morning oriented than boys and men (overall effect size E = 0.097 under a fixed effects model and E = 0.0845 under a random effects model) (Randler 2007).

A Japanese study (Park et al. 2001) analyzed the habitual sleep-wake rhythm of a large sample divided into 21 age groups (aged 6-89 years), with the same number of males and females. The delay in bedtime started from 6-7 years in both genders and continued to 22-24 years in males, 16-17 in females; then after those ages both genders exhibited an earlier bedtime. Sleep length decreased rapidly from 6-7 to about 20 years, and then it showed the opposite trend. This study is unique in that it covers almost the entire lifespan of individuals and it shows a progressive delay of bedtimes during (and partly before) the reproductive years, reaching the peak around 22-24 years, then advancing to earlier times with increasing age. This trend is similar to those observed for other behaviours (e.g. male homicide rates) related to reproductive success. It supports the view that eveningness is a trait selected because it increased the reproductive success of its carriers.

Not surprisingly, another Japanese study (Fukuda and Ishihara 2001) shows that bedtime linearly delayed with age throughout adolescence, while rise time didn't change until the beginning of university age, when it started to decrease gradually (thus, in this study the decrease in bedtime and rise time starts at a younger age (20 years) than in the Fukuda and Ishihara's study).

The interindividual differences in preferred timing of behaviour are described by the morningness/eveningness scale. M-types are those individuals who prefer going to bed and waking up early, whereas E-types tend to sleep at later hours and find it more difficult to get up in the morning. They have been shown to differ across a wide range of behavioural variables, with E-types reporting shorter total sleep time, longer weekend time in bed, less regular sleep-wake schedule, subjective poor sleep, attention problems, lower school achievement and emotional problems (Giannotti et al. 2002). The contribution of the endogenous circadian oscillator to morningness/eveningness has been showed by studying individuals during laboratory-based constant-routine procedures, in order to expose the unmasked (free of external or social influences) phase of the circadian oscillator. Circadian phase markers such as minimum body temperature and maximum subjective alertness differed by 2.12 and 4.28 h, respectively, between two groups of E-types and M-types (Kerkhof and Van Dongen 1996). Dim light salivary melatonin onset (DLSMO) is another phase marker, which is correlated to other phase markers, such as sleep onset and sleep offset (Carskadon et al. 1997). Carskadon et al. (1997) showed that, during a constant-routine procedure, the offset phase of melatonin secretion was significantly correlated with age and Tanner stage. This study shows that adolescent maturation in humans is associated not only to changing sleep patterns, but also with a circadian phase delay. This finding undermines the hypothesis that changes in sleep patterns during adolescence are solely due to changing social or familiar demands.

Assortative mating for eveningness was found by Hur et al. (1998) to have a correlation of 0.25. If assortative mating for eveningness exists, eveningness is a trait that people use when choosing a potential partner and this suggests the possibility that eveningness is a trait preferred by female choice.

Sexual selection probably accounts for the sex differences in sleep patterns, as well as for the changes in sleep patterns across age groups. One possible mode of selection is inter-sexual selection by female choice. However, this study does not test the hypothesis that females prefer evening-oriented males.

The intra-sexual mode of selection, on the other hand, involves a competition between males to stay up late in order to mate with the women who are awake. Thus, men who cannot afford to stay up late have less possibilities of mating.

One could argue that, in order for evening-oriented men to mate with women, women also have to stay up late, therefore the selection for eveningness would be as strong for females as it is for males. But the reproductive success of females is not as dependent on the number of sexual partners as is the reproductive success of males, because a woman can have only a limited number of offspring, whereas there is no limit to the number of offspring that can be sired by a male.

2. Methods

2.1. Sample

Participants were recruited at the mall and (mostly) at the beach in the province of Massa Carrara (northern Tuscany) and of Ravenna (north-eastern Italy) and an Italian translation (made by the author, and composed of 7 items instead of the original 19), of the Horne and Ostberg MEQ (Morningness/Eveningness) was given to them. The short version was preferred due to practical reasons, as the standard version can be considered too lengthy by many respondents.

The sample was comprised of 140 Caucasian Italian females (coming from different parts of Italy and from a heterogeneous educational/social background) aged18-30(mean=22.8, SD=3.1 and 134 Caucasian Italian males aged 18-38(mean=22.2; SD= 3)). Participants were informed about the content of the questionnaires and were told that they could refuse to answer any questions. They were also told that the purpose of the research was the study of the biological evolution of sleep patterns. All participants gave their informed consent prior to their inclusion in the study. The study was approved by the Anthropology Department Research Ethics and Data Protection Committee of Durham University.

Each copy of the questionnaire had a randomly assigned anonymous code. After the participants had completed the questionnaire, they were given another questionnaire on sexual behaviour, on which they were asked to copy the anonymous code. Participants then folded the completed questionnaire on sexual behaviour and put it in an envelope. The questionnaire on sexual behaviour asked “How many sexual partners of the opposite sex (excluding prostitutes) have you had?”; “How many of those were foreign?”; “In what part of the day have you met your current girlfriend/boyfriend (or wife/husband or fiancée/fiance)? Otherwise, if you are single, in what part of the day have you met your last girlfriend/boyfriend (or wife/husband or fiancée/fiance)?”.

Male participants were then instructed to have their voices recorded using a laptop computer with a microphone onto the free software Praat (Boersma & Weenik, www.praat.org), which was then used for vocal analysis. They were instructed to pronounce the vowel /a/ for about 5 seconds. The mean fundamental frequency of the vocal sample was calculated using the autocorrelation method (with standard analysis parameters – minimum pitch 75Hz/maximum pitch 500Hz) and it was written on the copy of the MEQ questionnaire. Vocal recordings of the first 39 subjects were not taken because I did not consider including measures of voice pitch in the initial design of the experiment, which instead included hand grip strength measures. Voice pitch recordings from 87 subjects were taken.

The data were analysed using Excel and the tests carried out were two-tailed.

3. Results

3.1. Relationship between MEQ score and number of sexual partners (excluding prostitutes)

MEQ scores from 133 (one questionnaire had to be discarded because it was not completed) different males and 140 females were collected . Morningness is reflected by a high MEQ score whereas eveningness is represented by a low MEQ score. ‘Neither types’ have an intermediate score.

There were 118 out of 134 male subjects and 130 out of 140 female subjects who completed the questionnaire on sexual behaviour refused to do so. They were asked how many sexual partners of the opposite sex they had. Males were asked to exclude prostitutes from the count because sex with prostitutes does not reflect actual mating success due to intrinsic qualities of the male. Even if contraception didn’t exist, the likelihood of siring any offspring would be low, because sperm competition from other men would drastically reduce the probability of fertilising the female egg.

The mean number of sexual partners was 5.4 (SD=7.21) for females and 6.89 (SD= 8.24) for males. However, the sample was composed of two males whose self reported number of sexual partners was 50, that is 5.2 SDs above average. I decided to leave them out, as they would have affected the correlations. After taking the two outliers out, the mean number of sexual partners is slightly lower, that is 6.15. The median number of sexual partners for males was 4, indicating that potential reproductive success was biased towards a minority who enjoyed a very high number of sexual partners, whereas the majority of individuals enjoyed a lower potential reproductive success.

I had predicted a negative correlation among males between MEQ score and a measure of reproductive success: self reported number of sexual partners(Italian and foreign) of the opposite sex, excluding prostitutes and therefore, only due to female choice or increased opportunities for encounters with the opposite sex. A negative correlation means that nocturnal types (low MEQ scorers) have an higher number of sexual partners. A significant negative correlation (r= - 0.182; N=117; p=0.049) was found between MEQ score and the self reported number of sexual partners (excluding prostitutes). However, after leaving the two outliers out (whose self-reported number of sexual partners was 50, that is 5.2 SDs above average), the correlation between MEQ score and the self reported number of sexual partners is r= –0.256 (N=115; p=0.005).

The correlation between MEQ score and number of foreign sexual partners is also negative (N= 114; r=-0.168) but not statistically significant (p=0.074). It is also slightly weaker than either the correlation between MEQ score and the number of Italian sexual partners (r= -0.185; N=114; p= 0.048) or between MEQ score and total number of sexual partners (r= - 0.256 ; N=115; p= 0.005).

On the other hand, I had predicted no correlation between MEQ score and number of sexual partners among females. Indeed, no significant correlation was found between these two variables among females ($r= 0.012$; $N=130$; $p=0.89$).

As expected, among males, age had a statistically significant positive correlation with number of sexual partners ($r=0.26$; $N=115$; $p=0.005$) but it had no statistically significant correlation with MEQ ($r=- 0.019$; $N=131$; $p=0.82$), therefore age cannot account for the higher number of sexual partners reported by male evening types. This result implies also that men aged 18-30 are homogeneous in their circadian preferences and that a phase advance is likely to occur after the age of 30. All the subjects had the same nationality (Italian) and belonged to the same race (Caucasian) therefore race and nationality could not act as confounds.

Mean number of sexual partners for male morning types (whose score was approximately 1.5 SDs above average or higher) was 3.6 and for evening types (whose score was approximately 1.5 SDs below average or lower) was 16.3. This means that evening types have about four times as many sexual partners as morning types, thus showing the positive effect of eveningness on reproductive success.

MEQ score was a significant predictor of the part of the day when people had met their current or their last partner of the opposite sex. Indeed, a significant negative relationship ($r=-0.305$; $N=270$; $p<0.001$) was found between MEQ score and part of the day (the four options in the questionnaire from which the participants could choose were morning, afternoon, evening, night) when the current or last long-term partner of the opposite sex was met, with evening types more likely to have met their partners at night or in the evening compared to morning types, suggesting, as predicted by my hypothesis, that circadian preference has an effect on mating patterns in humans. This correlation was similar among males ($r=-0.299$; $N=131$; $p<0.001$) and females ($r=-0.310$; $N= 139$; $p<0.001$).

In particular, among morning types (scoring over 20) 38% had met their current or previous partner in the morning, 33% in the afternoon, about 20% in the evening, and about 5.5% at night ($\chi2= 29.57$; $p<0.005$).

On the other hand, 0% of the evening types(scoring below 12) had met their current or last partner in the morning, 28% in the afternoon, 44% in the evening and 28% at night ($\chi2= 40.16$; $p<0.005$).

E-types are more active at night and their courtship behaviour follows their circadian pattern because they are more prone to meet new people of the oppoiste sex at night.

This result also supports the validity of the M/E questionnaire which I've used, showing that it's a reliable indicator of daily activity patterns.

Among men, a significant positive correlation ($r= 0.29$; $N=115$; $p=0.001$) was found between number of sexual partners and part of the day when last partner was met and this implies that men can meet more women at night than during the day. Such a correlation was not found among women.

Contrary to what might be believed, eveningness is not correlated to extraversion (Horne and Ostberg 1977; Matthews 1988), therefore it is very likely that extraversion does not account for the higher number of sexual partners reported by evening-oriented males. Instead, people appear to meet their partners of the opposite sex mainly in the evening and less in the morning or in the afternoon, and this gives an advantage to evening types (compared to morning types) who are more active in the evening and therefore are more prone to engage in courtship behaviour. Contrary to what some readers might believe, eveningness is not a direct measure of how often a person goes out to bars or discos. An evening oriented person could, for example, spend the night at home, watching TV or surfing the internet, although it is likely that evening types go out at night more often than morning types. This must be kept in mind because social factors such as money or attractiveness, whereas they might predispose people to entertain in the night more, they are unlikely to have an effect on the circadian typology that is measured by the MEQ questionnaire. The MEQ questionnaire does not ask people how often they go to bars or discos but it refers to more basic psychological or physiological traits, such as preferred bed time and wake up time, or preferred time for physical or mental activities. Indeed, Paine et al. (2006) noticed that Morningness-Eveningness preference was independent of ethnicity, and socioeconomic position, supporting the view that it is a characteristic that may be better explained by endogenous factors. Thus, it's unlikely that socioeconomic status could account for the correlation between Eveningness and the number of sexual partners.

I included a measure of voice pitch as a proxy for men's physical attractiveness because it is strongly correlated to testosterone and other physical traits, such as shoulder circumference, chest circumference and shoulder-hip ratio (Evans et al. 2006; Evans et al. 2008). A study linking voice pitch to RS was done by Coren Apicella et al. among Hadza foragers, where males with lower voice pitch were found to have fathered more children and therefore had more surviving children.

In my study, voice pitch has a non significant correlation with the number of sexual partners (r=0.18; N=76; p= 0.11). However, when the two outliers were included, voice pitch had a highly statistically significant correlation with the number of sexual partners (r=-0.273; N=78; p=0.015), with lower pitched individuals reporting an higher number of sexual partners. This supports the hypothesis that voice pitch is a secondary sexual trait, favoured by female choice.

No correlation was found between voice pitch and MEQ score ($r = -0.08$; $N=86$; $p = 0.46$). This implies that voice pitch is not a confounding variable and it suggests that the higher number of sexual partners reported by male E-types is not due to their higher physical attractiveness or their attractive voice.

Discussion

My study on sleep patterns suggests that a phase delayed circadian type and eveningness are sexually selected traits and that sexual selection accounts for at least part of the sex differences in circadian preference between men and women. Indeed, a statistically significant relationship between eveningness and a measure of mating success (number of sexual partners) was found, even after a proxy for physical attractiveness (fundamental frequency) was controlled for. Evening types have about four times as many sexual partners as morning types, thus showing the positive effect of eveningness on reproductive success. Female E-types, on the other hand, did not report more sexual partners than M-types.

This is in accord with the sexual selection hypothesis of sleep patterns, although it doesn't discriminate between the handicap signalling hypothesis and the lek-display hypothesis. Indeed, the increased reproductive success enjoyed by E-types could be due both to female preference for E-types or to increased opportunities of encounters with the opoposite sex due to the fact that E-types tend to go out at night more often (an assumption which has not been tested by this study) and therefore meet more women . My finding is that most people in this sample had met their current or previous long-term partner of the opposite sex in the evening (45%), whereas 27 % met their partner in the afternoon, 17% in the morning and 11% at night. This finding provides evidence for my hypothesis that the evening is a 'temporal lekking ground' where most encounters with the opposite sex happen and therefore, according to the intra-sexual selection hypothesis, evening preference provides an aid to human males in the competition for females.

Indeed, circadian preference is associated with higher potential reproductive success. In Malte Andersson's book 'Sexual selection' (1994) the criteria for inclusion of a study are that 'it demonstrates a statistically significant relationship between some character and mating success, and that it identifies a mechanism of sexual selection'.

Following reproductive success from mating success in a modern western society is very difficult because contraception cancels any relationship between the two variables, therefore it is unlikely that eveningness still exerts a strong effect on reproductive success, but it might have done so during human evolution and it might continue to do so in non-western societies where contraception is not very common.

My findings do not exclude the possibility that female preference for eveningness (possibly due to a Fisherian selection process or even an arbitrary preference) could exist. Other studies will be needed to test this last hypothesis. The simplest and most likely explanation is that evening types have increased mating opportunities because they are more active in the evening when it's easier to meet people of the opposite sex.

The correlation between Eveningness score and the number of sexual partners persists even in an international mating contest, not only limited to Italian women. However, the correlation between MEQ score and number of foreign sexual partners (r=-0.168) is negative but weaker than either the correlation between MEQ score and the number of Italian sexual partners (r= -0.185; N=114; p= 0.048) or between MEQ score and total number of sexual partners (r= - 0.256 ; N=115; p= 0.005). Thus, morning types tend to have more foreign sexual partners than E-types. A possible interpretation is that M-types date foreign women because they have reduced access to women of the same nationality. This interpretation is supported by the finding that the correlation between male voice pitch and the number of foreign sexual partners is lower (r= -0.142) than the correlation between voice pitch and total number of sexual partners (r=-0.18; p<0.11). Another possible(but in my opinion less likely) interpretation is that Italian women pay more attention to voice pitch when choosing a man and that eveningness in the Italian culture is a better predictor of reproductive success compared to other cultures. It is also possible that people are more accurate when answering the question relative to the total number of sexual partners and that they do not accurately remember the nationality of their past partners. This imprecision might result in weaker correlations. Indeed, imperfect or imprecise measures often lead to weaker correlations as the chance factor plays a more important role.

The finding that the MEQ score of males but not of females is correlated to their potential reproductive success might account for the sex differences in sleep patterns, that is males have a later circadian phase than females.

This study focus on a population from a single culture, thus potential confounding variables related to the particular culture might not be accounted for. It would be interesting to repeat the same experiment in a different country (for example, Northern vs. Southern Europe, or Western vs. non-Western countries) and see if the relationship between the MEQ score and number of sexual partners persists. Studies on sex differences in sleep patterns come from a wide variety of countries, and show similar results across continents and racial groups. Sex differences in sleep patterns have been measured using both self report questionnaires(M/E) and physiological variables related to the circadian clock (internal body temperature, melatonin onset and offset, etc.) and are likely to be based on universal features of the human genome, which have not yet been explored.

Hopefully other studies will repeat the results presented in this dissertation and they will also study the correlation between circadian preference and actual reproductive success in a society(like the Hadza) where contraception does not obscure its relationship with mating success and they will try to see if reproductive success is related to circadian preference also in Western societies. Moreover, they will have to determine if sexual selection was powerful enough to have accounted for at least part of the differences in circadian preference between the sexes.

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References:

Adan, A., Natale, V. (2002). Gender differences in morningness-eveningness preference, *Chronobiol. Int.* ,19, 709-720.

Andersson, M. (1994). Sexual selection. Princeton University Press. Princeton, NJ.

Baehr, E.K., Revelle W., Eastman, C.I. (2000). Individual differences in the phase and amplitude of the human circadian temperature rhythm: With an emphasis on morningness–eveningness, *Journal of Sleep Research*, 9,117–127.

Carskadon M. A., Acebo C., Richardson G. S., Tate B. A. and Seifer R. (1997) .An approach to studying circadian rhythms of adolescent humans. *J. Biol. Rhythms*, 12, 278–289.

Darwin, C. (1871) The Descent of Man, and Selection in Relation to Sex.

Murrary, London.

Evans, S. Neave, N. Wakelin, D. (2006). Relationship between vocal characteristics and body size and shape in human males: An evolutionary explanation for a deep male voice. *Biological Psychology* , 72: 160-163.

Evans, S. Neave, N. Wakelin, D. Hamilton, C. (2008). The relationship between testosterone and vocal frequencies in human males. *Physiology and Behaviour*, 93, 783-788.

Fukuda K., Ishihara, K. (2001). Age-related changes of sleeping pattern during adolescence. *Psychiatry and clinical neurosciences*, 55, 231-232.

Giannotti F, Cortesi F, Sebastiani T, Ottaviano S. (2002). Circadian preference, sleep and daytime behaviour in adolescence. *Journal of Sleep Research* ,11, 191-199.

Gibb J.B. (2007). The rough guide to the brain. Rough guides, London.

Gibertini M., Graham C., Cook R.M. (1999). Self-report of circadian type reflects the phase of the melatonin rhythm. *Biological Psychology*, 50, 19-33.

Horne, J.A., Ostberg, O. (1977). Individual differences in human circadian rhythms. *Biological psychology* , 5, 179-190.

Kerkhof G.A., Van Dogen H.P.A.(1996). Morning-type and evening-type individuals differ in the phase position of their endogenous circadian oscillator. *Neuroscience Letters*, 218: 153-156.

Matthews, G. (1988). Morningness-eveningness as a dimension of personality: trait, state and psychophysiological correlates. *European Journal of Personality*, 2: 277-293.

Miller, G. (2001). The mating mind. How sexual choice shaped the evolution of human nature. Anchor Books, New York.

Moe, K.E., Prinz, P.E., Vitiello,M.V., Marks, A.L. and Larsen, L.H. (1991). Healthy elderly women and men have different entrained circadian temperature rhythm. *Journal of the American Geriatrics Society,* 39,383–387.

Paine, S.J., Gander, P.H., Travier, N. (2006). The epidemiology of Morningness-eveningness: Influence of age, gender, ethnicity, and socioeconomic factors in adults (30-49 years). *Journal of Biological Rhythms,* 41, 68-76.

Park Y.M., Matsumoto K, Shinkoda H., Nagashuma H., Kang M.J., Seo A.Y.J. (2001). Age and gender difference in habitual sleep-wake rhythm. *Psychiatry and Clinical Neurosciences*, 55, 201-202.

Randler C. (2007). Gender differences in morningness–eveningness assessed by self-report questionnaires: A meta-analysis. *Personality and individual differences*,40, 1667-1675.

Rahman, Q. Wilson, G.D. Born Gay? (2003). The psychobiology of human sexual orientation, *Personality and Individual Differences*, 34, 1337–1382

Tankova,I. Adan, A. and Buela-Casal, G.. (1994). Circadian typology and individual differences: a review, *Personality and Individual Differences*, 16, 671–684

Trivers, R. (1985). Social Evolution. Benjamin/Cummings Publishing Company.

Tsai L., Li S. (2004). Sleep patterns in college students. Gender and grade differences. Journal of *Psychosomatic Research*, 56, 231-237.

Tynjala J., Kannas L. (1993). Sleep habits of Finnish school children by sociodemographic background. *Health Promotion International* ,8, 281-289.

Wilson, G.D. (1990). Personality, time of day and arousal, *Personality and Individual Differences*, 11, 153–168.

Zahavi, A. (1975). Mate selection- a selection for a handicap. *J.Hum.Biol.*, 53, 205-214.