Arch Sex Behav
DOI 10.1007/s10508-007-9219-7

ORIGINAL PAPER

Differences in Gait Across the Menstrual Cycle and Their Attractiveness to Men

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Received: 23 December 2005 / Revised: 27 December 2006 / Accepted: 8 April 2007

Abstract We investigated variations in gait between women at high and at low conception probability, and how men rated those variations. Women participated in a motion capture study where we recorded the kinematics of their walking patterns. Women who were not using hormonal contraception (n = 19) repeated the study during the late follicular stage and the luteal stage of their menstrual cycle. Using a discriminant function analysis, we found signiÞcant differences in walking behavior between naturally cycling women at their follicular and luteal phases, with 71% of the walks classiÞed correctly. However, there was no difference between walks of women in their follicular stage and women using hormonal birth control (n = 23). We compared structural and kinematic characteristics of the womenÕs walking patterns that appeared to be characteristic of women in the speciÞc conception risk groups, but found no significant differences. In a second study, 35 men rated the walks of women not using hormonal contraception as slightly more attractive during the luteal stage of the cycle compared to the late follicular stage. Thus, for women not using hormonal birth control, it would appear that some information regarding female fertility appears to be encoded in gait.

Keywords Unadvertised ovulation · Motion capture · Gait · Biological motion · Attractiveness

Introduction

Scientists have traditionally described a womanÕs ovulation as concealed because, unlike most non-human primates, women do not appear to have demonstrably visible signs of fertility (Badcock, 1991). The theories explaining why women have concealed ovulation are numerous, but most theorists assume it results from sexual selection. SpeciÞcally, concealed ovulation could be a method to increase paternal parental care (see, e.g., Freeman & Wong, 1995; Strassmann, 1981) or limit knowledge regarding time of conception from a woman herself in order for her to better convince her partner that he is the father when, in fact, he may not be (Schröder, 1993).

In contrast to these theories, studies have demonstrated that ÔÔunadvertised,ÕÕ rather than ÔÔconcealed,ÕÕ may be a more appropriate term for human ovulation. Doty, Ford, Preti, and Huggins (1975) showed that womenÕs vaginal secretions smell differently across the menstrual cycle, with the secretions being perceived to smell the most pleasant during the time of ovulation. Roberts et al. (2004) found that both women and men judged womenÕs faces to be more attractive during ovulation than during other stages of the cycle. Morris and Udry (1970) found that women were more active (that is, when walking or running, they tended to take more steps in a given amount of time) during the stage of peak fertility compared to other stages of the menstrual cycle. Grammer, Filova, and Fieder (1997) recorded videos of women turning around in the presence of either a male or female researcher, and analyzed the aspects involved in the movement, such as duration, the number of basic movement units, the complexity of the movement, and the maximum speed of the turn. They found that there were signiÞcant correlations (with r^2 ranging from .20 to .27) between aspects of the turn and fertility status (parameterized by estrogen level), but only in the presence of the male researcher. A trained artiÞcial neural network (a computer system designed to emulate neural connections of the brain) was also able to accurately classify the videos with regard to whether the women were fertile or not.

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Though these studies show that ovulation is not concealed, most do not demonstrate if any information regarding a woman's fertility status is available without familiarity with the woman. That is, the majority of the differences necessitate knowing a woman across at least one menstrual cycle to track the changes. As well, information from these differences may be too difficult to detect from a distance, or the difference itself is found in something so specific (e.g., turning movements) that the opportunity to observe the difference is limited. However, because differences around the time of peak fertility (late follicular stage of the menstrual cycle) have been demonstrated in numerous facets of human appearance and behavior, including some aspects of movement, it is possible that it may also affect characteristics of the most accessible and common movement in humans, namely walking.

Walking motions contain a lot of information about the walker. An experimental approach to uncouple biological motion information from other, non-dynamic sources of information is to represent the main joints of a person's body by bright dots against a dark background (Johansson, 1973). Employing this point-light display technique, observers can easily recognize a human walker, determine his or her sex (Barclay, Cutting, & Kozlowski, 1978; Cutting, 1978; Kozlowski & Cutting, 1977; Mather & Murdoch, 1994; Troje, 2002a), recognize various action patterns (Dittrich, 1993), identify individual persons (Cutting & Kozlowski, 1977; Troje, Westhoff, & Lavrov, 2005), identify the mood of the walker (Troje, 2002b) and even recognize themselves (Beardsworth & Buckner, 1981). Using sex classification as an example, Troje (2002a) used discriminant function analysis to model a human observer's ability to distinguish male and female walking patterns. Visualizing the discriminant function, the characteristics that discriminated the walker as either male or female were extrapolated and amplified. Troje found that men have a wider stance than women, with elbows out to the side, and a larger lateral body sway, whereas women have more exaggerated hip movement.[1] However, research has not investigated the association of specific walking patterns with ovulation.

In the first of the studies presented here, we used a similar procedure to investigate differences in the walking patterns of women at different stages of their menstrual cycle, particularly at times of peak fertility and low fertility risk. In the second study, we investigated how others perceive the information encoded in gait by asking men to rate the walks of the women on attractiveness. If ovulation is concealed, walking patterns of women at times of peak fertility should be similar to those of women at times of low fertility risk (i.e., not in the late follicular stage or on hormonal birth control). However, if the time of peak fertility is not hidden, one should be able to discriminate between walking patterns of women at high conception risk versus those at low conception risk.

[1] Please see http://www.biomotionlab.ca/Demos/BMLgender.html for a demonstration.

Study 1

The objective of this study was to investigate differences in women's gait across the menstrual cycle.

Method

Participants

Women not using hormonal birth control (NHBC; $n = 36$) and women using hormonal birth control (HBC; $n = 23$) participated in this study. The self-reported menstrual cycle stage of five NHBC women was not confirmed with ferning patterns in their dried saliva (see below), so these women were not used in the analyses. In addition, seven NHBC women (one in the late follicular phase, and six in the luteal phase) did not attend both sessions, so their data were not used in the repeated measures analysis. Finally, due to technical issues when collecting the data (described below), eight walkers had to be removed from the analyses (four NHBC and three HBC). Thus, walks from a total of 19 NHBC women (M age = 22.1 years, SD = 4.1) were used in the repeated measures study, and those from 20 NHBC women (M age = 21.8 years, SD = 4.3) were used to compare with walks from 20 HBC women (M age = 18.5 years, SD = 1.2).

Procedure

We recruited women from the community and first year undergraduates to participate in the study. A female researcher met the participants, informed them that the study was investigating motion across the menstrual cycle, and obtained their informed consent. The women then answered a brief questionnaire, including questions regarding their use of birth control, the length of their menstrual cycle, the day of their last period, and the regularity of their cycle in order to estimate cycle stage. Women who were unsure of their last period, had menstrual cycles shorter than 21 days or longer than 35 days, and those who had irregular cycles did not participate. NHBC women participated during the late follicular phase (high fertility phase; 14–16 days before their next period) or the luteal phase (low fertility phase; 5–7 days before their next period, to limit the influence of premenstrual symptoms). Cycle stage was confirmed using salivary ferning. At the time of peak fertility, an increase of 17-beta estradiol increases the amount of electrolytes in a womanÕs endocrine system, and one speciÞc electrolyte, sodium chloride, causes a ferning pattern in dried saliva (Guida, Barbato, Bruno, Lauro, & Lampariello, 1993) and cervical mucus (MacDonald, 1969; Salvatore, 1961) when observed under a microscope. Guida et al. (1999) found that 78% of their participants showed salivary ferning at the time of peak fertility (with ovulation measured by pelvic ultrasonography). If NHBC women were in one of the correct menstrual cycle stages, they participated that day; otherwise, we made an appointment for their return to the laboratory at the correct stage of their menstrual cycle. HBC women all participated on the day they came into the laboratory.

All women changed into a supplied ballet suit, slippers, and hat attached with reßecting markers. We also placed additional markers (for a total of 41) directly on their skin, using a modiÞed version of the Helen Hayes marker set (Davis, Ounpuu, Tyburski, & Gage, 1991). A motion capture system (Vicon, Oxford Metrics, Oxford, UK) with 12 CCD-cameras recorded participants performing a series of movements to both calibrate the motion capture system and to initialize the biomechanical model used for subsequent modelling. Then, the participants were asked to walk back and forth across the Þeld of capture (approximately 6 m) until we asked them to stop. In order for the participants to become comfortable with the experimental setup and to make sure they behaved as normally as possible, participants walked across the Þeld of capture at least three times before the researcher recorded the Þrst walk. While participants were walking, we covertly collected four recordings of their walks (two in each direction). In total, participants walked for approximately 5 min. We then made appointments for NHBC women to return if necessary, where the procedure was repeated, minus the questionnaire.

Data Analysis

The trajectories (3D Cartesian coordinates as a function of time) of 15 virtual markers corresponding to the major joints in the body were calculated from the original 41 using commercially available software for biomechanical modeling (Bodybuilder, Oxford Metrics). At this stage, some trials had to be excluded from the Þnal analysis because one of the original markers had fallen off and the computation of the virtual markers was not possible. To reduce the dimensionality of the data, the time series of the virtual markers were decomposed into a Fourier series, and then a principal components analysis was applied to the resulting Fourier representation. This process effectively calculates the omnibus relationship between the location and movement of each marker with respect to the other markers for each person (for a detailed description of the calculations used to model the walkers, see Troje, 2002b). We then computed a discriminant function in a space spanned by the Þrst 12 principal components. The discriminant function separates walkers into categories based on the calculation of the overall relationship between their markers, resulting in less variance among the group than between the groups on these omnibus correlations. This procedure was used for two classiÞcations: NHBC women (n = 19) during the late follicular phase versus the luteal phase; and NHBC women (n = 20) during the late follicular phase versus HBC women (n = 20). We evaluated the classiÞcation performance of the linear discriminant function using a cross validation procedure. This procedure was slightly different for the repeated measures classiÞcation (i.e., NHBC women) and the between subjects classiÞcation (i.e., NHBC versus HBC women). For NHBC women, we removed both walks (i.e., in the late follicular and luteal phases of the menstrual cycle) of a given participant, calculated the discriminant function based on the remaining walkers, and then the two walks were classiÞed independently by projecting them on the discriminant function. Walkers in the second comparison were independent so each was removed one at a time, a new function was calculated based on the remaining walkers, and then the single walker was classiÞed with the resulting discriminant function. The output of these procedures was the proportion of misclassiÞed original walkers. We then used a z-test to evaluate the difference of a proportion from the null hypothesis, which assumed a population proportion of 0.5.

Results

The linear discriminant function for NHBC women significantly discriminated women at peak fertility from women in the luteal phase (z = 2.59, p < .01, n = 38). A total of 71% of the walkers were classiÞed correctly.[2] 79% of the ovulation phase walks were classiÞed correctly (four women were misclassiÞed), and 63% of the luteal phase walks were classiÞed correctly (seven women were misclassiÞed). Only one woman was misclassiÞed in both stages. The linear discriminant function for HBC women and NHBC women in the late follicular phase did not signiÞcantly discriminate women of peak fertility from women using hormonal birth control (z = 1.26, p > .05, n = 40), with 40% of women classiÞed correctly with this linear discriminant function.

To explore further the differences between motion patterns in women in the late follicular phase versus women in the luteal phase, we examined where they were most disparate. First, we calculated the overall average walker (i.e.,

[2] To see demonstrations of these differences, please see http://www.biomotionlab.ca/Demos/BMLmenstrual.html.

the single walker resulting from averaging all walkers of the two menstrual cycle stages), and a hypothetical extreme walker of each stage, calculating the walkers at ±3 SD away from the average in both directions along the discriminant function. Upon visually observing these two walkers, the lateral distance between the knee and ankle joints and the hip movement appeared to be the major differences between fertile and non-fertile women. Since the positions of the markers are stored as data during the modeling procedure, we were able to calculate the distance between the aforementioned joints. We parameterized hip movement by calculating the amplitude of vertical hip joint displacement, taking the average amplitude of the two hips joints for each cycle stage (see Table 1). We then compared these characteristics using a repeated measures MANOVA. The repeated factor was fertility stage (late follicular versus luteal), and the measures were the three body measurements (ankle, knee, and hip). However, these distances were not statistically different between the two cycle stages of NHBC women, $F(3, 16) = 2.38$, $p > .05$.

Discussion

Our results demonstrated that there were signiÞcant differences in gait between women who were at high fertility risk (i.e., naturally cycling and in the late follicular stage of their menstrual cycle) and naturally cycling women at low fertility risk. Because walks given by each woman were independently classiÞed into the fertile and non-fertile group without their other walk entered into the discriminant function, the differences between walking patterns during peak and low conception probability were not dependent on familiarity with the walker. Though some differences in the body kinematics and dynamics of NHBC women were visible in a demonstration of the mathematically extreme walker, they were not statistically reliable. It is possible that we did not focus on the correct characteristics to examine the exact differences, but that is unlikely given our methodology. Instead, it is probable that the cyclic hormonal differences may be more ubiquitous in womenÕs walking patterns, and it is more efÞcient to discriminate the groups using walkers as complete units rather than by concentrating on local joint positions or movements.

Table 1 Distance between ankle and knee joint, and average vertical displacement of hips between cycle stage (in mm)

Body joint	M	SD
Ankle		
Late follicular	85.81	15.31
Luteal	85.79	10.97
Knee		
Late follicular	87.30	20.54
Luteal	92.94	19.83
Hip		
Late follicular	89.90	21.85
Luteal	94.54	15.98

In addition, there did not appear to be a signiÞcant difference between women at high fertility risk and women using hormonal birth control. It is possible that this result was due to ßuctuations in personality dimensions of women not using hormonal birth control. For example, women using hormonal birth control may differ from NHBC women on some dimension that ßuctuates in NHBC women (e.g., perhaps HBC in comparison to NHBC women are more extroverted or agreeable in general, so their gait reßects such traits at all times, but such extroversion or agreeableness is pronounced in NHBC women only during times of peak fertility). It is also possible that similarities in sexual openness or interest is related to the inability of NHBC women in the late follicular phase and HBC women to be classiÞed by their walks. It is reasonable to assume that HBC women, in contrast to NHBC women in general, are more open to engaging in sexual relations. However, research demonstrates that NHBC women at peak fertility are more interested in sexual activity, especially with extra-pair partners (Gangestad, Thornhill, & Garver, 2002). Thus, walking patterns may be similar because of the interest in sexual activity of NHBC women at peak fertility and HBC women. This explanation seems unlikely because participants only interacted with a female researcher, but it can be tested by investigating the interaction between cycle stage and sex of researcher on walking patterns. However, it may simply be that hormonal levels in HBC women may affect their walk so that they are indistinguishable from NHBC women at peak fertility. Women using hormonal birth control have more circulating sex hormones than NHBC women in their luteal phase, when estrogen begins to drop. These extra-elevated levels of estrogen may affect the muscles and ligaments of the body, and thus womenÕs gaits (see Hewett, 2000). Thus, larger amounts of estrogen in women using HBC may make their walks more similar to women at times of peak fertility. Any personality or behavioral differences may be the root cause, but the precipitating cause would be hormone levels. Further studies are needed to discriminate among these possible explanations.

Additionally, these results do not determine if ovulation was imperfectly concealed or if there is a purpose for the difference in walking patterns. If the walk of a woman at high conception risk is similar to an attractive female walk, then it is possible the walk could be a tool to attract a mate. Alternatively, if the walk characteristic of a woman at high conception risk is different from a characteristically attractive female walk, the walking pattern may be a protective mechanism for the woman to avoid unwanted attention at the time of peak fertility. We preformed a second study to investigate how men rated the attractiveness of the walks.

Study 2

The purpose of this study was to determine if men rated the attractiveness of NHBC women differently across the menstrual cycle.

Method

Participants

A total of 43 men in an introductory psychology course participated in this study for course credit. Four men were removed from the analysis because they indicated scores higher than two on the Kinsey scale, indicating either a preference for, or a behavioral tendency towards, non-heterosexual sexual activity (Kinsey, Pomeroy, & Martin, 1948) and a further four were removed because they did not supply complete information or had response times of <1 second per stimulus. Thus, 35 men were included in the Þnal analysis (M age = 18.8 years, SD = 1.9). The majority of the participants were white (66%), or Asian (29%), with the rest of the participants being of mixed heritage.

Stimuli

The models of each walker were rendered as point-light displays using the 15 virtual markers described in Study 1. The height of the walker subtended about 20° of visual angle.

Procedure

We informed men that they would be participating in a study on attractiveness; however, we did not inform them of the different hormonal states of the women. We told the participants that they would see point-light walkers of women on the screen, and their task would be to rate the attractiveness of the walkers on a 6-point Likert-like scale provided (ranging from ÔÔVery attractiveÕÕ to ÔÔVery unattractiveÕÕ; high scores represented low-levels of attractiveness). Participants saw the walkers in random order.

Results

Late follicular walks had a similar attractiveness level (M = 3.66, SD = .5) as walks recorded in the luteal phase of the menstrual cycle (M = 3.56, SD = .5) when compared with a paired t-test, $t(18) < 1$. However, using a paired t-test with these data had two major issues. First, the classiÞer allows an empirical value to be assigned to each walk to determine its location along the continuum created by the classiÞer. In addition, collapsing across these data into the two groups resulted in a lack of power. We thus followed these analyses with an analysis that incorporated the location of each walk along the continuum.

The walks were projected onto the discriminant classiÞcation function to calculate in z-scores how far each was from the average walker, with positive z-scores representing the late follicular stage, and negative scores representing the luteal stage. We used these z-scores to operationalize menstrual cycle stage as a continuous variable. We also transformed the attractiveness ratings into z-scores between participants to ease interpretation of the results. We then used hierarchical linear modeling (HLM, Raudenbush, Bryk, & Congdon, 2005) to model the effect of menstrual cycle stage z-score (MCSz) on the attractiveness rating z-score, similar to a repeated measures regression, because HLM accounts for the repeated aspects of both the walkers and the raters in its analysis. We modeled the Þrst level as: attractiveness z-score = $\beta_0 + \beta_1$(MCSz) + r, and the level 2 models were $\beta_0 = \gamma_{00} + u_0$ and $\beta_1 = \gamma_{10} + u_1$; thus, we modeled the intercept (β_0) and slope (β_1) of the linear relation between MCSz and z-scores of attractiveness obtained by each observer.

In the original model, we modeled the group mean of the fertility slope, and did not Þx the variance. The reliability estimate of the intercept was acceptable (.81); however, the reliability for MCSz was too low (.04). By convention, we Þxed the variance of the MCSz and modeled the grand mean of MCSz, resulting in Þnal level 2 models of $\beta_0 = \gamma_{00} + u_0$ and $\beta_1 = \gamma_{10}$. Fixing the variance of the variable means that there is no variation in response due to female fertility status between individual male raters, and thus each rating was treated as an independent rating. As a consequence, the critical value of the t statistic for the coefÞcient changes, thus not changing the effect of the target variable (i.e., fertility status), even with the increase in df. Attractiveness scores were related to menstrual cycle stage, $\beta = 0.08$, $t(1258) = 3.0$, $p < .01$, with men giving lower scores (indicating higher attractiveness) to women in the luteal phase of their menstrual cycle (results were similar when the variance of the slope was free, $\beta = 0.08$, $t(34) = 3.0$, $p < .01$). Each SD of menstrual cycle score increase resulted in a 0.08 increase in the z-score of attractiveness rating, meaning lower perceived attractiveness. Raters and menstrual cycle phase accounted for a total of 11.3% of the variance.

Discussion

In this study, we found that men responded to the changes in gait women demonstrate across the menstrual cycle.

Without knowing the differences between the women they were rating, men were signiÞcantly more likely to rate women walkers in their luteal phase as more attractive. This Þnding contradicts research in face research, where men judge women to be more attractive at times of peak fertility (Roberts et al., 2004). It is possible that faces and gait present different information because of the intimacy with which the stimulus is viewed. For example, faces can only be seen in a fairly close encounter, whereas gait patterns can be seen from a large distance. If women are trying to protect themselves from sexual assault at times of peak fertility, it would make sense for them to advertise attractiveness on a broad scale when they are not fertile, yet still being attractive to people they choose to be with (i.e., during face-to-face interactions). Thus, it is necessary to investigate how men prone to using sexual violence view the walking stimuli, as well as to test the use of sexual coercion both in and outside of couples across the menstrual cycle, to investigate if unadvertised ovulation is adequately protecting a womanÕs reproductive Þtness interests.

General Discussion

These studies add further evidence to the position that ovulation is unadvertised, not concealed. They demonstrate that there are changes in gait among naturally cycling women across the menstrual cycle, and that men are attuned to differences across the cycle at some level. However, it appears that men judge naturally cycling women to be more attractive at a stage of low pregnancy probability than when they are most fertile. Prior research on physical changes across the menstrual cycle have demonstrated a different effect, specifically high levels of attractiveness during peak fertility, but these changes (body odor, facial attractiveness, etc.) are all cues that are less broadly displayed than walking pattern. Further research is necessary to investigate further cues of female fertility state and if the broadness of the signal inßuences how men respond to them.

Acknowledgments The authors would like to thank A. Olmos, T. Otto, D. Saunders, and C. Westhoff for their assistance with the motion capture technology and computer programming. We would like to thank Dr. S. Fergus for his assistance with HLM. We would also like to thank the Editor and two anonymous reviewers for their helpful comments on an earlier draft of this article. We would also like to acknowledge the support of a SSHRC scholarship to MPB, and a grants from CFI and OIT to NFT.

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