POSTURAL STABILITY AND GAIT DURING MENSTRUAL CYCLE

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Content

Abbreviations

ANOVA	analysis of variance
BC	before Christ
BMI	body mass index
CoP	center of pressure
CTSIB	clinical test of sensory interaction on balance
FSH	follicle-stimulating hormone
GnRH	gonadotropin-realising hormone
IQR	interquartile range
LH	luteinizing hormone
LoS	limits of stability
NaCl	sodium chloride
OSI	overall stability index
PRISMA	preferred reporting items for systematic reviews and meta-analyses
RQ	research question
TUG	timed up and go test
x25	lower quartile
x75	upper quartile

Introduction

The representation of women in research studies in the field of sports and sports medicine remains significantly lower compared to men. The main obstacle to including women in these studies is the menstrual cycle and its cyclical changes (Bruinvels et al., 2017; Cowley et al., 2021; Meignié et al., 2021). For this reason, more profound knowledge about the impact of different menstrual cycle phases and associated hormone variations on fundamental movement skills and athletic performance is a very current topic, allowing the narrowing of the gender gap in sport-related research.

A previous study exploring the gender gap in sport and exercise-related research reported that 6% of published articles from 2014–2020 focused only on female participants (Cowley et al., 2021). Further evaluation of these studies shows a higher quality of the research design when a female author(s) led the study, as female researchers seem more aware of female-specific factors such as considering the reproductive hormone profile of participants (Cowley et al., 2024). Future research should address this ongoing gender gap, which might also be related to the gender distribution of senior academics and editorial boards (Cowley et al., 2021; Cowley et al., 2024).

The menstrual cycle is becoming a widely discussed topic in sports environments. Up to 41.7% of female athletes state that menstruation hurts their training and performance, but the specific reasons are not yet sufficiently researched (Bruinvels et al., 2016). Previous studies systematically reviewing the effect of menstrual cycle phases on exercise performance showed a reduced performance during menstruation and late luteal phases of the cycle (Carmichael et al., 2021; McNulty et al., 2020) or their results are inconclusive, suggesting a variable association between menstrual cycle phase and endurance, power resistance, decision-making skills, level of perceived exertion or competitiveness (Carmichael et al., 2021; Meignié et al., 2021; Paludo et al., 2022).

To increase the knowledge about the effect of different menstrual cycle phases on physical performance, two fundamental elements of human movement – postural stability, as a critical factor for balance, risk for falls and consequent risk of injuries, and gait, as the basic locomotor pattern in humans, were analyzed in this book. Reproductive hormone levels fluctuate throughout the menstrual cycle, impacting the musculoskeletal system by enhancing bone and muscle mass, reducing stiffness in tendons and ligaments, and influencing the central nervous system, which can affect postural stability and gait (Chidi-Ogbolu and Baar, 2019; N-Wihlbäck et al., 2006;

Taraborrelli, 2015). The contradictory results of the previous studies highlight the need for a systematic synthesis of the available literature and elaborating their results in novel original studies. The following research questions (RQ) were analyzed in this book.

RQ1: How do different menstrual cycle phases affect postural stability parameters?
RQ2: How do different menstrual cycle phases affect postural stability parameters in situation with dual-task?
RQ3: How does the age at menarche influence postural stability parameters in adult women?
RQ4: How do different menstrual cycle phases affect spatiotemporal and dynamic gait parameters?
RQ5: How do different menstrual cycle phases affect spatiotemporal and dynamic gait parameters in situation with dual-task?
RQ6: How does the age at menarche influence spatiotemporal and dynamic gait parameters in adult women?

The first chapter of this book provides the necessary insight into the menstrual cycle, its endocrine regulation, methods used for menstrual cycle monitoring, and an introduction to postural stability assessment and gait analysis. The second chapter focuses on the menstrual cycle's influence on postural stability. It starts with a systematic review summarising the results of the previous scientific studies on this topic. It continues with novel research focused on the effect of different menstrual cycle phases on postural stability in situations with and without dual-task. The second chapter ends with presenting a feasibility study on the impact of age at menarche on postural stability. The second chapter's conclusions answer the RQ1, RQ2, and RQ3. The third chapter is dedicated to the influence of the menstrual cycle on gait. Similar to the second chapter, it starts with a systematic review summarizing previous studies' results about the menstrual cycle's influence on gait. This chapter continues with original research on the effect of different menstrual cycle phases on gait in situations with and without dual-task. It ends with a feasibility study on the impact of age at menarche on gait. The third chapter's conclusions answer the RQ4, RQ5, and RQ6. The rigorous standards of academic work required in scientific journals were followed when presenting data in Chapters 2 and 3.

This book aimed to summarize the current knowledge about the effect of menstrual cycle phases on postural stability and gait and present possible directions for future research in this field. Increasing the knowledge about the underlying mechanisms that link female physiology to movement biomechanics and performance holds implications for research and practical applications in the health sciences and sports.

Chapter 1. A brief introduction to the menstrual cycle, postural stability, and gait

Chapter summary

This chapter aimed to provide the necessary background for the research focused on the effect of the menstrual cycle on postural stability and gait. The female reproductive system includes two regular cycles, the ovarian cycle and the menstrual cycle, which are interconnected. These cycles are controlled by the hormone interaction of gonadotropin-releasing hormone, follicle-stimulating hormone, luteinizing hormone, estrogen, and progesterone. Besides controlling the reproductive system, these hormones affect the musculoskeletal, and central nervous systems which can influence postural stability and gait.

During a quiet stance, postural stability is the ability to control and maintain a static upright body balance by integrating visual, vestibular, and somatosensory inputs. Postural stability is usually measured for research purposes by force platforms that enable the calculation of the movement of the center of pressure. The gait cycle can be divided into the stance phase when the foot is in contact with the ground, and the swing phase, when the limb moves forward without contact with the ground. Kinematic and dynamic gait analyses are the most common in research. Additionally, spatiotemporal gait parameters are essential for gait description and are used in clinical practice. During the postural stability and gait, cognition and motor control interact, and testing the cognitive-motor interference with a dual-task provides important knowledge about the cognitive involvement in gait and postural stability control.

Menstrual cycle

The female reproductive system enables the production of female sex hormones, formation and development of eggs (oocytes), their fertilization, and gestation, i.e., the development of the fertilized egg, embryo, and fetus in the woman's uterus during pregnancy, and subsequent delivery, or shedding of the endometrial lining if the fertilization does not occur. The female reproductive system includes two regular cycles: the ovarian cycle (cycle of the ovaries) and the menstrual cycle (cycle of the uterus), which are interconnected and reoccur approximately every 28 days from menarche, the first menstrual bleeding, to menopause, the last menstrual bleeding. These cycles are controlled by the hormones of the hypothalamus and pituitary gland (Constanzo, 2014; Preston and Wilson, 2012).

In this subchapter, the ovarian and menstrual cycle were briefly described. This subchapter also described the endocrine regulation of the menstrual cycle and methods used for monitoring the menstrual cycle. This subchapter aimed to provide the necessary background for the kinanthropological research related to the menstrual cycle.

Ovarian cycle

Oocytes are stored in follicles in the cortex of the ovary. Primary follicles are established before birth, ranging from 700,000 to 2 million. Maturing secondary follicles and mature Graafian follicles mature between menarche and menopause. During the fertile period of a woman's life, approximately 400 eggs will mature. It takes more than 120 days for a primary follicle to transform into a secondary follicle and another 85 days for a secondary follicle to transform into a Graafian follicle and ovulation to occur. Thus, the entire period of follicle growth is more than 220 days, or approximately 8 menstrual cycles (McGee and Hsueh, 2000).

The approximately 28-day-long ovarian cycle consists of three phases: (i) the follicular phase, when follicles mature, estrogen level gradually increases and the high levels of estrogen cause proliferation of the endometrial lining of the uterus. Additionally, follicular phase can be subdivided into early follicular phase, which often coincides with menstrual bleeding and is characterised by low sex hormone concentrations, mid-follicular phase, when estrogen concentration increases, and late follicular phase, when estrogen levels peak; (ii) ovulation, when the egg is released from the Graafian follicle. Ovulation is the most fertile phase of the cycle and occurs approximately 14 days before the next menstruation; (iii) the luteal phase, when the empty Graafian follicle transforms into a corpus luteum. The corpus luteum is hormonally active, producing progesterone and estrogens. If the egg is not fertilized, the corpus luteum disappears after 10 to 12 days, and only a small scar remains. During fertilization, the corpus luteum remains active until the 4th month of pregnancy, when its function is taken over by the placenta. Similar to follicular phase, luteal phase can be subdivided into early luteal phase, when progesterone levels increase, mid-luteal phase, when progesterone levels peak, and late luteal phase, when sex hormone levels decrease (Constanzo, 2014; Elliott-Sale et al., 2021; Preston and Wilson, 2012).

Menstrual cycle

The endometrium of the uterus undergoes cyclical changes known as the menstrual cycle, in which we recognize the following phases: (i) menstrual phase (1st to 4th day), when the functional layer of the endometrium is lost together with menstrual blood (35 to 80 ml); (ii) regenerative phase (5th day); (iii) the proliferative phase (6th to 14th day), when a new functional layer of the endometrium grows, the endometrial thickness increases from 1–2 mm to 8–10 mm; (iv) the secretory phase (15th to 27th day), when the blood supply to the endometrium increases, the endometrial glands produce polysaccharide-rich mucus, the endometrium is prepared to receive a fertilized egg during this phase of menstrual cycle; and (v) the ischemic phase (28th day), when the spiral arteries supplying the endometrium are constricted and the functional layer of endometrium breaks down (Preston and Wilson, 2012).

Anovulatory cycle

During the anovulatory cycle, ovulation does not occur. It is only a prolonged follicular phase when the endometrium's functional layer increases and subsequent bleeding occurs. Thus, during the anovulatory cycle, no luteal phase is associated with an increase in progesterone (Briden, 2015). Chronic anovulatory cycles are a cause of infertility and can be caused by polycystic ovary syndrome, among others. In women with a regular menstrual cycle, the frequency of isolated anovulatory cycles is 1 to 14.5% (DeVilbiss et al., 2020), and an increased risk of anovulatory cycles is associated with obesity (Bloom et al., 2021). Anovulatory cycles are typical in girls during their first menstrual cycles (Spence, 1997).

Menarche

Menarche, the first menstrual bleeding, occurs between 8 and 15 years of age, with an average of 12.5 years (Lalys and Pineau, 2014), and it is a hallmark event in a woman's life. Menarche typically occurs 2 to 3 years after puberty onset and 6 months after the peak height velocity is achieved. The age at menarche is the result of genetic and environmental factors (Barros et al., 2019; Karapanou and Papadimitriou, 2010). Ethnical origin, body mass index (BMI), geography, and exercise were observed to affect the age at menarche (Karapanou and Papadimitriou, 2010). Afro-American and Hispanic-American girls achieve menarche at younger ages than Caucasian girls in the United States (Wu et al., 2002), also higher BMI was associated with earlier menarche (Di et al., 2024). On the other hand, menarche usually occurs later in athletes suggesting that intense exercise may delay puberty (Malina, 1983). A declining trend of menarcheal age has been observed since the last century as environmental factors such as socioeconomic status or nutrition may be related to the earlier onset of puberty. The menstrual cycle length is typically between 21 to 45 days during the early years after menarche. Longer cycles may be related to anovulation due to immaturity of the hypothalamic-pituitary-ovarian axis (ACOG Committee Opinion No. 651).

Menopause

Perimenopause and menopause bring a significant change in a woman's life. Menopause – the last menstrual bleeding, is determined retrospectively after 12 months without menstruation (if another possible cause is ruled out). Menopause marks the end of a woman's reproductive capacity. For many women, this change is liberating from the point of view of the end of menstrual bleeding difficulties and the fear of pregnancy. Nowadays, women spend 30 to 40% of their lives in the post-menopausal period. The gradual reduction of reproductive function before menopause is then referred to as perimenopause. Menopause occurs at an average age of 51.5 years (Minkin, 2019). Smoking may contribute to an earlier onset of menopause (Takahashi and Johnson, 2015). Approximately 20% of women do not suffer any symptoms during this period. On the contrary, 20% suffer from severe symptoms. Vasomotor symptoms such as hot flushes (usually shorter than 5 minutes) associated with sweating, which sometimes limits the woman's activities (Minkin, 2019), or night sweats, affect up to 80% of women, usually during 5 to 7 years. These symptoms of menopause negatively impact sleep and mood and, thus, a woman's overall quality of life (Johnson et al., 2019). Other common symptoms of menopause include incontinence, sexual dysfunction, e.g., vaginal dryness or decreased libido, and muscle and joint pain (Nelson, 2008).

Endocrine regulation of the menstrual cycle

The menstrual cycle is regulated by the complex interaction of gonadotropin-releasing hormone (GnRH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), estrogen, and progesterone.

The hypothalamus produces GnRH and stimulates the anterior lobe of the pituitary gland, releasing FSH and LH. During the follicular phase, hypothalamus pulsatile release of GnRH occurs every 1 to 1.5 h and every 2 to 4 h during the luteal phase (Barbieri, 2014). Abnormalities in GnRH pulse frequency are associated with menstrual cycle abnormalities and reproductive disorders (Marques et al., 2022). FSH produced by the pituitary gland controls follicle growth and estrogen production in the ovaries. FSH peaks at the same time when the LH surge leads to ovulation. During the luteal phase, FSH remains low, preventing the development of a new Graafian follicle (Orlowski and Sarao, 2023). The pituitary gland also produces LH and controls the function of the ovaries, such as ovulation and corpus luteum formation. The LH surge occurs 34–36 h before ovulation and peaks approximately 10–12 h before ovulation (Reed and Carr, 2018).

Estrogens are responsible for the formation of secondary female sexual characteristics, e.g., specific deposition of subcutaneous fat. Estrogens reduce the amount of cholesterol in the plasma and reduce the activity of osteoclasts in bones, preventing osteoporosis. Estrogen levels increase from approximately 5 pg/ml during menstruation to 200 to 500 pg/ml during ovulation. Estrogen levels rise and fall twice during the cycle: they rise during the mid-follicular phase and drop after ovulation. The second rise is during the mid-luteal phase, and the second decrease occurs at the end of the menstrual cycle. The primary estrogen is estradiol. Estrogen regulates musculoskeletal function, and its receptors are observed in muscle, bone, ligament, and tendon tissues. In muscles, estrogen increases the anabolic response to exercise. Additionally, animal models show that the decrease in estrogens is related to a reduction of muscle strength and muscle mass. In tendons and ligaments, estrogen decreases their stiffness, affecting the risk of injuries (Chidi-Ogbolu and Baar, 2019; Reed and Carr, 2018).

Progesterone is the most well-known progestogen; it stimulates the growth and blood supply of the endometrium necessary for the implantation of the fertilized egg and maintaining pregnancy. Before giving birth, progesterone stimulates the growth of the mammary gland. The level of progesterone is increased during the luteal phase of the cycle. Progesterone increases the basal temperature by affecting the peripheral blood flow. Therefore, a 0.2 to 0.5 °C temperature increase is observed after ovulation. Progesterone increases mucous secretion of the cervix of the uterus, resulting in a barrier for sperms used in progestin-dependent contraceptives. Furthermore, progesterone interacts with estrogen, affecting bone mineral density (Cable and Grider, 2023).

Menstrual cycle monitoring

Menstrual cycle length is calculated from the first day of menstruation to the last day before the start of menstrual bleeding in the following cycle. The menstrual cycle length in a healthy woman ranges between 21 to 35 days. The duration of bleeding varies between 2 and 7 days. The fertile window is approximately 3–5 days (sperm lifespan) before ovulation and 1–2 days (oocyte lifespan) after ovulation (Su et al., 2017).

The cycle length can be monitored using a calendar, table, or smartphone application, in which it is also possible to write down the symptoms that a woman feels in a given phase (e.g., strength of bleeding, pain, or mood). The prediction of ovulation and fertile days by smartphone applications is usually calculated based on the cycle length information (the length of the luteal phase is relatively constant: 10–16 days). It may not correspond to the actual ovulation date. When monitoring the menstrual cycle, it is recommended to monitor the first day of heavy bleeding (the first day of the cycle), the number of days between the first day of the cycle and the first day of the following cycle (cycle length), and the number of days of bleeding (Su et al., 2017; Briden 2015).

The most common ovulation detection methods include ovulation tests based on LH, basal temperature measurement, cervical mucus observation, symptothermal method, and salivary ferning (Su et al., 2017).

- *Ovulation tests*: ovulation test kits can be obtained in pharmacies, and they detect LH in urine. The amount of LH increases about halfway through the cycle and triggers ovulation. A positive LH test is approximately 20 ± 3 h before ovulation itself. Ovulation tests are suitable for detecting ovulation if a woman wants to conceive a child; they are not ideal for determining ovulation as a contraceptive method, as sperm can survive in the female reproductive system for 3–5 days from the period before ovulation is detected (Su et al., 2017).
- *Basal temperature measurement*: during the follicular phase, the basal body temperature is lower, around 36.5 °C. The basal temperature decreases before ovulation (approximately 1 day before ovulation). After ovulation, due to progesterone, the temperature increases by 0.2 to 0.5 °C. At the end of the luteal phase, the corpus luteum disappears, the progesterone level decreases,

and 1–2 days before the start of menstruation, the basal temperature drops again. An increase in basal temperature, therefore, means ovulation. Basal temperature can be measured vaginally, orally, or rectally, ideally right after waking up at the same time, on the same part of the body, with the same device every day. Recording of measured values is possible using tables, online tools, or smartphone applications (Su et al., 2017). Nowadays, wearable devices such as bracelets record wrist skin temperature at night and predict ovulation (Uchida and Izumizaki, 2022).

- *Cervical mucus*: Cervical mucus changes throughout the cycle. Shortly after menstruation, the mucus appears minimally; in the subsequent period, it is thicker and sticky (it provides a barrier against sperm penetration and microorganisms into the uterus). During ovulation, it has the consistency of egg white. Cervical mucus is stimulated by estrogen when, during ovulation, the extracellular water in the body increases, the production of mucin in the cervical mucus decreases, the glycoprotein barrier is loosened, and the cervical mucus becomes easily permeable to sperm (Su et al., 2017). During ovulation, the mucus can be stretched between two fingers up to 6 cm. Changes in cervical mucus are evident 4 to 7 days before ovulation (Peters and Mahdy, 2022). Changes in cervical mucus can be recorded similarly to the basal temperature by the table method or smartphone application (Su et al., 2017). Thickening of cervical mucus is one of the main effects of progestogen-only hormonal contraceptives such as subcutaneous implants (Briden, 2015).
- *Symptothermal method*: this method is a combination of basal temperature measurement and cervical mucus observation (Su et al., 2017). The reliability of this method for predicting future cycles increases when using data from 6 to 12 past cycles. Women can then expect their fertile days, i.e., 2–3 days before and 3 days after the increase in basal temperature (Peters and Mahdy, 2022).
- *Salivary ferning*: ferning or arborization of saliva can be seen under the microscope during the preovulatory period. The saliva ferning is caused by the crystallization of NaCl, which is affected by increasing estrogen levels and adrenocorticotropic hormone influence on aldosterone before ovulation. However, the salivary ferning test seems to be an unreliable method for contraception (Owen, 2013; Saibaba et al., 2017; Su et al., 2017).

No consistent methods for relevant menstrual cycle monitoring have been established when performing research related to the menstrual cycle in a sports environment. This limit has been highlighted in several systematic reviews and meta-analyses. Additionally, no uniform vocabulary when describing different menstrual cycle phases can be confusing and make comparing the results difficult (Janse de Jonge et al., 2019; Paludo et al., 2022; Schmalenberger et al., 2020). McGawley et al. (2023) and Findlay et al. (2020) highlighted the need for improving menstrual health literacy and communication in sports.

A repeated measures study design is the golden standard approach to menstrual cycle research. Specifying the required cycle phases and associated hormonal levels to test a hypothesis is important. A different order of the phases at the first assessment was suggested to avoid the possible order and training effect in repeated measured study design. It was also recommended to monitor the first day of menstruation and perform ovulation testing for correct menstrual phase assessment (Schmalenberger et al., 2020).

Postural stability

Postural stability during standing is the ability to control and maintain the upright body balance by integrating visual, vestibular, and somatosensory inputs. The quiet standing is unstable in humans as a slight deviation from the perfect upright stance leads to gravity-induced torque acting on the body. The consequent center of gravity position changes result in body sway (Lipowicz et al., 2019; Peterka and Loughlin, 2004). The postural stability was observed to be affected by age (Liang et al., 2022; Maylor and Wing, 1996), gender (Al-Makhalas et al., 2023; Sell et al., 2018), BMI (Angyán et al., 2007), body height (Bryant et al., 2005; Krzykala et al., 2023), or intellectual disabilities (Lipowicz et al., 2019). Previous studies report that women have greater postural control compared to men, observed by a shorter center of pressure (CoP) sway path (Sullivan et al., 2009; Bryant et al., 2005). However, specific phases of a woman's life, such as pregnancy or menopause, were observed to deteriorate postural stability (Hita-Contreras et al., 2018; Opala-Berdzik et al., 2015).

This subchapter aimed to provide the necessary background for the research focused on the effect of the menstrual cycle on postural stability by briefly describing the static and dynamic postural stability, methods used for postural stability assessment, and the impact of dual-tasks on postural stability.

Static and dynamic postural stability

Postural stability results from complex interactions maintaining the projection of the center of mass within the relatively small support area (Latash, 2008). Postural control can be described as static or dynamic. Static postural control maintains the same support base while minimizing body movement, e.g., during standing. Dynamic postural control involves performing a movement when keeping the base of support, e.g., during the star excursion balance test when the participant maintains a single leg stance while reaching out in a different direction with the other foot. A poor correlation between the static and dynamic balance tests suggested including both when assessing the balance alteration (Thakkar and Senthil Kumar, 2017; Rizzato et al., 2021). Additionally, it is possible to measure dynamic stability, the ability to control the center of mass when the base of support changes, e.g., during the gait or postural transitions (Sibley et al., 2017). The most common postural transition task is the transition from a double-leg stance to a single-leg stance which allows time to stabilization and CoP oscillation analyses (Dingenen et al., 2013; Koshino et al., 2020).

Postural stability analysis

Postural stability is usually measured for research purposes by force platforms. Force platforms enable the calculation of the movement of the CoP, resulting in a CoP path length, CoP average velocity, and calculation of its anterior-posterior and medio-lateral sway length. The CoP is the projection of the center of mass within the base of support. Anterior-posterior sway reflects ankle torque in flexors and extensors, and medio-lateral sway is controlled by abductor and adductor muscles. In clinical practice, the CoP sway measurement is used to identify people with mobility limitations and predict fall risk (Bryant et al., 2005; Latash, 2008).

Static postural stability is usually measured during a quiet stance when having eyes open. However, the measuring protocols differ in foot position using feet apart, feet together, or a tandem stance, and by the measured time, which usually ranges between 10 to 60 s (Kędziorek and Błażkiewicz, 2020; Latash, 2008). Limiting vision or proprioception can be used to assess the sensory contribution to postural stability. When the sensory input is limited, such as by closing the eyes or adding a foam surface on the force platform, the magnitude of CoP sway substantially increases (Latash, 2008).

Dynamic postural stability can be assessed by the star excursion balance test, when the participant must maintain a single-leg stance while reaching as far as possible in eight positions with the contralateral leg (Ericksen et al., 2012); Y-balance test, when the participant maintains a single-leg stance while reaching out in three directions (Emami et al., 2018; Muniandy et al., 2023); or by testing the limits of stability, which represent the maximal distance a participant can intentionally sway in a given direction while maintaining a two-legged stance (Ozer Kaya and Toprak Celenay, 2016).

Postural stability with dual-task

Cognitive or motor dual-tasks when standing or walking are important activities in daily life: when using a smartphone, having a conversation, or carrying a bag (Liu et al., 2017). During the dual-task, the attention is directed toward an external source of attention (cognitive or motor task), leading to an automatic motor system function reflected in more effective performance in postural stability or gait (Resch et al., 2011; Schaefer et al., 2015; Wulf et al., 2001). However, with the increased cognitive load of the dual-task, cognitive-motor interference has been observed. Similarly, with aging, dual-tasks lead to a significant decrement in postural stability (Ghai et al., 2017; Salihu et al., 2022). One study considering the effect of the menstrual cycle on postural stability with dual-tasks (Keklicek et al., 2021) is known to the author and presented in Chapter 2. In young, healthy adults, significant improvement, deterioration, and no change in postural stability were reported during dual-task performance (Salihu et al., 2022).

Arithmetic tasks, especially serial subtractions, are commonly used as a cognitive dual-task. These tasks are classified as working memory tasks as they require information to be kept in mind while manipulating the data mentally (Bayot et al., 2018). Motor tasks can be divided into two categories by their complexity. Tasks like shirt buttoning require more cognitive resources than more straightforward tasks such as carrying a cup with water or a tray (Horvat et al., 2013). There are nine potential patterns of cognitive-motor interference, including no dual-task interference, motor facilitation, or cognitive-related motor interference (Plummer et al., 2013).

Previous studies report the beneficial effect of dual-task training on postural stability in fall-prone population groups (Ghai et al., 2017). It was hypothesized that participants could develop their coordination skills by dual-task training (Silsupadol et al., 2009). The dual-task training enhances neural functioning, as observed by increased activation in the dorsolateral prefrontal cortex, associated with improved performance in the dual-task training group of young healthy individuals (Erickson et al., 2007). Furthermore, dual-task training enhances postural stability and cognitive performance, as reported in systematic reviews by Fritz et al. (2015) and Ghai et al. (2017).

Gait

Gait is the key locomotor pattern in humans, enabling many activities in daily living. The first steps are a crucial developmental milestone in toddlers between 8 and 18 months of age (WHO, 2006). The individual walking pattern is influenced by age (Bosch et al., 2009), gender (Mather and Murdoch, 1994), BMI (Rosso et al., 2019), and mood (Michalak et al., 2009), among many others. A previous systematic review by Pollard and Wagnild (2017) reports that women at young adult age tend to walk more for leisure compared to men. Gender differences were also observed during the gait analysis. Women choose slower self-selected comfortable speed, shorter stride length, and narrower step width. Significant gender differences were observed also in hip, knee, and ankle joint kinematics. In more detail, women walk with a greater pelvic obliquity, greater arm swing, greater flexion, adduction, and internal rotation in hip joints, and greater valgus angles in knee joints compared to men (Bruening et al., 2015; Cho et al., 2003; Rowe et al., 2021).

This subchapter described the different phases of the gait cycle, methods used for the gait analysis, and the effect of dual-tasks on gait to provide the necessary background for the research focused on the impact of the menstrual cycle on gait.

Gait cycle

The gait cycle starts with the initial contact of one foot with the ground and ends when the same foot touches the ground again. The gait cycle can be divided into the stance phase when the foot is in contact with the ground, and the swing phase, when the limb moves forward without contact with the ground. The stance phase occupies approximately 60% of the gait cycle, and the swing phase constitutes about 40%. Two double stance phases when both feet are in contact with the ground occupy about 20% of the gait cycle (Levine et al., 2012; Leal-Junior and Frizera-Neto, 2022). During fast walking speed, the swing phase is prolonged; on the other hand, when walking slowly, the stance phase of the gait cycle is prolonged (Levine et al., 2012).

The stance phase can be divided into (1) initial contact (0%), when the heel strikes the ground to initiate weight acceptance, at this moment, starts the first phase of double support; (2) during the loading response phase (0 to 10%) the weight acceptance continues, this phase is the double support phase. The loading response phase ends when the contralateral foot leaves the ground; (3) during mid-stance (10 to 30%), the body is supported by a single leg. This phase ends when the heel of the ipsilateral foot leaves the ground; (4) terminal stance (30 to 50%) is characterized by the standing foot rolling over the forefoot. At the end of this phase, the contralateral foot contacts the ground; this event occurs approximately 50% of the cycle; and (5) during the pre-swing, toe-off phase, or terminal contact (50 to 60%), the second phase of double support occurs. This phase ends when toes leave the ground (Levine et al., 2012; Leal-Junior and Frizera-Neto, 2022).

The swing phase can be divided into (1) initial swing or feet adjacent (60 to 73 %); this phase ends when the foot is aligned with the contralateral ankle and the two feet are side by side; (2) mid-swing (73 to 87%) is a continuation of the swing till the tibia is in the vertical position; and (3) late swing phase (87 to 100%) which ends with the initial contact of the foot with the ground of a following gait cycle (Levine et al., 2012; Leal-Junior and Frizera-Neto, 2022).

Gait analysis

The history of gait analysis dates back to Aristotle (384–322 BC), who proposed the first known gait analysis by tracing head movements during walking (Nirenberg et al., 2018). Nowadays, kinematic and dynamic gait analyses are the most common in research. However, other methods, such as visual observation or gait speed measurement, are used in clinical practice (Levine et al., 2012).

Kinematic gait analysis is based on recording the position and orientation of body segments. The measurement requires two or more cameras in a calibrated three-dimensional system. The kinematic analysis software creates a three-dimensional model of the human from which velocities, accelerations, and joint angles during the motion can be obtained. The hip, knee, and ankle joints are the most analyzed in kinematic gait analysis (e.g., Gimunová et al., 2020; Gimunová et al., 2021a; Leal-Junior and Frizera-Neto, 2022).

Dynamic gait analysis or pedobarography is based on measuring ground reaction force through force platforms (Leal-Junior and Frizera-Neto, 2022). Force platforms software also provides additional information about foot contact area, contact time, peak pressure at different parts of the foot during the gait cycle, duration of various phases, and the spatiotemporal gait parameters. The dynamic gait analysis enables the qualitative and quantitative examination of plantar pressure distribution (e.g., Zulkifli and Loh, 2020; Gimunová et al., 2022a; Gimunová et al., 2018).

Spatiotemporal gait parameters, which can be obtained from both types of gait analysis, are important for gait description and are used in clinical practice. Step and stride length, step width, cadence, gait speed, stride time, stance time, and swing time are the most analyzed gait parameters as they were observed to change in different disabilities and with age (e.g., Gimunová et al., 2021b; Gimunová et al., 2022b; Herssens et al., 2018; Voss et al., 2020; Levine et al., 2012; Leal-Junior and Frizera-Neto, 2022).

Gait with dual-task

During the gait, cognition and motor control interact (Bayot et al., 2018). Testing the cognitive-motor interference when walking with a dual-task provides essential knowledge about cognitive involvement in gait control. Dual-tasks, when a cognitive or motor task is performed simultaneously while walking, are an everyday daily living activity, e.g., conversation (Kao and Pierro, 2021). In clinical practice, cognitive-motor interference testing is used to detect a risk of falls or aging-related cognitive decline (Bayot et al., 2018; Montero-Odasso et al., 2012). However, the gait pattern changes due to the dual-task interference in healthy young adults. The extent to which the gait pattern deteriorates during the dual-task depends on age and the cognitive demand of the task (Kao and Pierro, 2021; Yogev-Selingmann et al., 2008). In young, healthy adults, dual-tasking mainly affects gait velocity (Yogev-Selingmann et al., 2008). Additionally, increased step width was observed during dual-task walking in young, healthy adults (Kao and Pierro, 2021).

Detecting adults at risk of falls by testing gait with dual-tasks corresponds to a significant public health issue related to aging. Therefore, most of the research pertaining to dual-tasking is performed on the aging population (Montero-Odasso et al., 2012). Few studies consider emotional state, motivation, or pain in gait with dual-tasks, and only one study considering the menstrual cycle phase (Ates and Unluer, 2020) is known to the author and presented in Chapter 3.

Chapter 2. Changes in postural stability influenced by menstrual cycle

Chapter summary

The fluctuation of estrogen and progesterone affects general joint and ligament laxity, resulting in differences in the incidence of injury at different menstrual cycle phases. Previous studies described higher general joint and ligament laxity and a higher incidence of injuries at ovulation. These findings highlight the importance of a detailed knowledge of postural stability fluctuations across the menstrual cycle. The second chapter was divided into three parts: (i) a systematic review summarizing the previous studies on the effect of the menstrual cycle on postural stability; (ii) an experimental study focused on the effect of the menstrual cycle on postural stability in a situation with and without a dual-task; and (iii) a pilot study analyzing the effect of menarche on postural stability.

Twenty-two studies were included in the systematic review focused on the influence of the menstrual cycle on postural stability. Six of the included studies observed no significant difference in postural stability across the menstrual cycle, and sixteen showed that the menstrual cycle affects both static and dynamic postural stability. Most of these studies observed deteriorated results during the early follicular phase in dynamic postural stability and at ovulation in static postural stability.

This finding was confirmed by the second study in this chapter, which presented original data. At ovulation, postural stability measured by CoP average velocity was observed to deteriorate compared to the early follicular phase, probably due to the increased joint laxity. During all analyzed phases of the menstrual cycle, significant deterioration of CoP path and CoP average velocity was observed when performing mathematical, shirt buttoning, and smartphone reading dual-tasks.

The results of the pilot study on the effect of age at menarche on postural stability did not identify a clear association between age at menarche and postural stability parameters, as only small to moderate correlations were observed. Future studies on large samples will show the potential causal effect between the age at menarche, body height, body mass, and postural stability in women.

Does the menstrual cycle affect postural stability? A systematic review

Background

Changes in neuromuscular and biomechanical characteristics across the menstrual cycle have recently attracted more attention as they are related to the increased risk of injury in female athletes during particular phases of the menstrual cycle (Abt et al., 2007). Estrogen and progesterone levels vary across the cycle (as described in Chapter 1) and affect the musculoskeletal system by improving bone and muscle mass, decreasing stiffness in tendons and ligaments, and affecting the central nervous system which can influence the postural stability, and subsequently increase the risk for injury (Chidi-Ogbolu and Baar, 2019; N-Wihlbäck et al., 2006; Taraborrelli, 2015).

Postural stability is necessary not only for sports performance but also for daily activities. In experimental settings, static and dynamic postural stability is widely evaluated to assess factors contributing to the risk of injuries (Emami et al., 2018; Kacem et al., 2021). Factors affecting postural stability include age (Maylor and Wing, 1996), body composition (Hita-Contreras et al., 2013), body weight (Hue et al., 2007), body height (Krzykala et al., 2023), gender (Al-Makhalas et al., 2023) and probably also the phase of the menstrual cycle due to changing estrogen and progesterone levels (Emami et al., 2018).

Female athletes' incidence of non-contact anterior cruciate ligament injuries is significantly higher compared to males (Montalvo et al., 2019), and recent research showed that the use of oral contraceptives may reduce the injury risk by up to 20% (Herzberg et al., 2017). The fluctuation of estrogen and progesterone affects ligament laxity and muscular coordination (Petrofsky and Lee, 2015); it was hypothesized that the incidence of injury could be affected by menstrual cycle phases (Hertel et al., 2006). The risk of anterior cruciate ligament injury was reported to be greater during the preovulatory phase of the cycle compared to post-ovulatory phase in Alpine skiers (Beynnon et al., 2006; Ruedl et al., 2009), in late follicular phase compared to early follicular or luteal phase in football players (Martin et al., 2021), in the follicular phase compared to luteal phase in college athletes (Arendt et al., 2002) and during ovulation compared to luteal phase in athletes (Wojtys et al., 2002). Similarly, ankle instability was observed to have a higher incidence in females than males (Tanen et al., 2014) and to be affected by the menstrual cycle, showing higher general ankle joint laxity during ovulation (Yamazaki et al., 2021). These findings highlight the importance of a detailed knowledge of postural stability fluctuations across the menstrual cycle.

A systematic review on this topic was performed to summarise all the available previous research about the influence of the menstrual cycle on postural stability and answer the question from the title of this subchapter if the menstrual cycle can affect postural stability.

Methods

Type of the study: systematic review

A systematic review of the influence of the menstrual cycle on postural stability was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes (PRISMA) guidelines (Page et al., 2021). Systematic reviews are considered the "gold standard" for searching, appraising, and synthesizing the available literature related to a specific research question (Boland et al., 2017). The search was performed using PubMed, Web of Science, and Scopus in August 2023. PECO criteria were used to define the eligibility criteria for studies included in the systematic review. The PECO criteria consisted of *participants (P)* of females at reproductive age, *exposure (E)* to different phases of the menstrual cycle, *comparator (C)* between different menstrual cycle phases (e.g., follicular phase compared to luteal phase), and *outcome (O)* of change or maintenance of postural stability parameters during one phase against another.

The following terms with Boolean operators were used for the search: ("menstrual" OR "menstrual cycle" OR "follicular phase" OR "luteal phase" OR "menstruation" OR "ovarian cycle" OR "ovulation") AND ("postural stability" OR "posture" OR "balance test*" OR "static stability" OR "center of pressure" OR "centre of pressure" OR "posturography" OR "CoP" OR "postur*" OR "quiet standing"). The literature search did not exclude any studies published before specific date due to a limited number of scientific studies focused on postural stability changes across the menstrual cycle. A similar approach was used previously (Ahrari et al., 2022; Gimunová et al., 2024). All studies identified in the search were imported into Rayyan systematic review software (Ouzzani et al., 2016), facilitating selection. Rayyan software's key features enable the import of articles from databases, highlighting keywords to help the selection process and track decisions about the article during the screening process (e.g., included, excluded). Exclusion criteria included animal studies, non-English language, review articles, conference papers, books, and book chapters, and no full text available. Additionally, data from women taking oral contraception or with any musculoskeletal or neurological disease affecting postural stability were not considered. The title and abstract of the remaining studies were screened. The full texts of the included studies were screened to confirm the relevance of these studies to this systematic review. Artificial intelligence was not used in these steps; the author performed the whole screening process. Figure 1 summarizes the study selection process in the PRISMA flow diagram as suggested in PRISMA guidelines (Page et al., 2021).

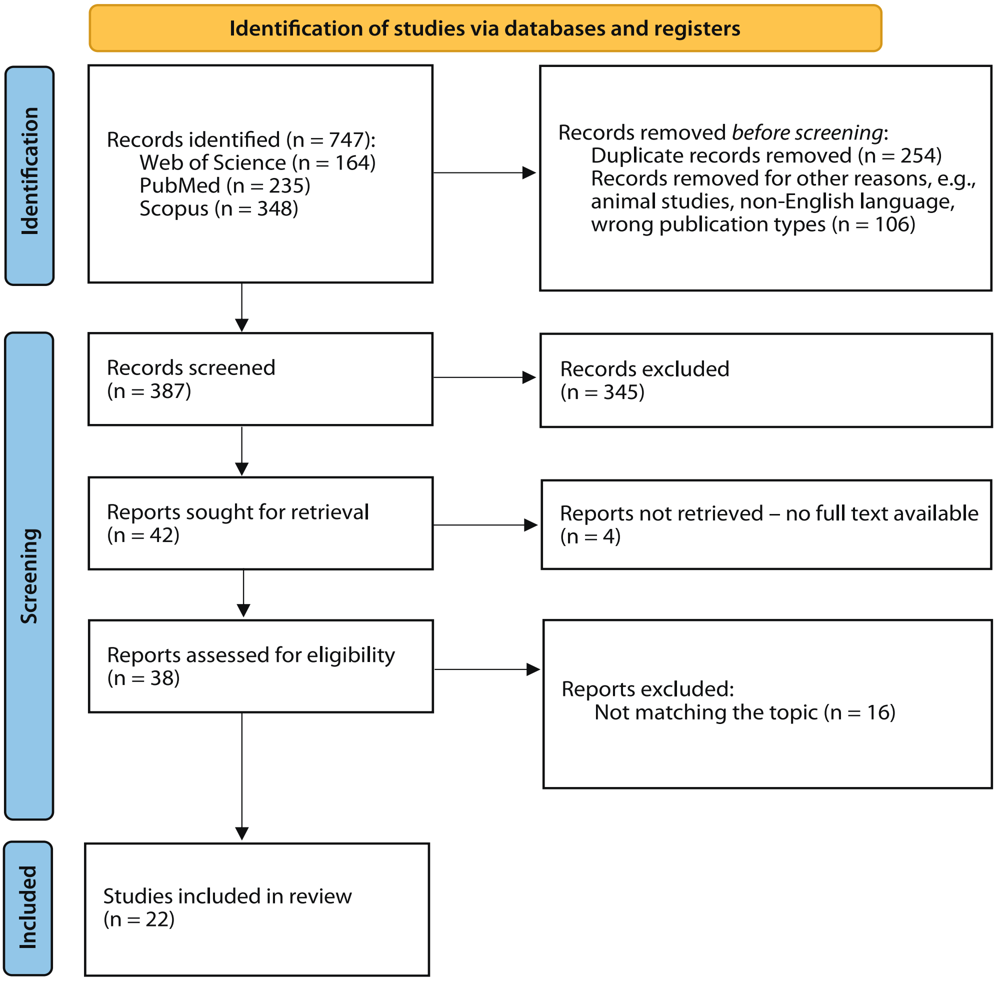

Figure 1. PRISMA flow diagram of the study selection process (template from Page et al., 2021)

For data extraction, a pre-defined form in Microsoft Excel consisting of (i) study characteristics (author(s), publication year and country, sample size, and characteristics); (ii) menstrual cycle measurement; and (iii) analyzed postural stability parameters and its measurement; and (iv) results were used.

Selected relevant items from Downs and Black Quality Assessment Checklist (Downs and Black, 1998) were used to perform the methodological quality assessment of included studies focusing on the quality of reporting, external and internal validity, and statistical power. The original Downs and Black Quality Assessment Checklist consists of 27 questions (Downs and Black, 1998). For this systematic review, the following items were considered relevant. A similar approach was used in previous review studies (e.g., Gimunová et al., 2022c; Paludo et al., 2022).

1. *Is the hypothesis/aim/objective clearly described?*
2. *Are the main outcomes to be measured clearly described in the Introduction or Methods section?*
3. *Are the characteristics of the participants included in the study clearly described?*
4. *Are the main findings of the study clearly described?*
5. *Does the study provide estimates of random variability provided for main outcomes?*
6. *Have the probability values been reported for the main outcomes?*
7. *Were the subjects asked to participate in the study representative of the entire population from which they were recruited?*
8. *Were those subjects who were prepared to participate representative of the entire population from which they were recruited?*
9. *If any of the results of the study were based on "data dredging", was this made clear?*
10. *Were the statistical tests used to assess the main outcomes appropriate?*
11. *Were the outcome measures used accurate (valid and reliable)?*
12. *Were losses of patients to follow-up taken into account?*
13. *Did the study have sufficient power to detect a clinically important effect where the probability value for a difference due to chance is less than 5%?*

A binary score for each question was used: 0 = no/unable to determine, 1 = yes. The final score (in %) was classified as follows: < 45.4% "poor" methodological quality; 45.5–61.0% "fair" methodological quality; and > 61.0% "good" methodological quality (Meignié et al., 2021). The quality assessment was not used to exclude any study.

Results

By the databases search, 747 studies were identified (PubMed: 235 studies, Web of Science: 164 studies, Scopus: 348 studies). After duplicate removal (254 studies), animal studies, wrong publication types (e.g., review, book chapter, letter to editor, conference abstract), and studies in other language than English were excluded (106 studies). In 387 studies, titles and abstracts were screened, and 345 studies were excluded as they did not describe postural stability parameters about the menstrual cycle. In the last stage, the full texts of the remaining 38 studies were read, and after excluding 16 studies that did not match the topic, 22 studies were included in this systematic review.

The final score of the Downs and Black Quality Assessment Checklist evaluating the methodological quality of included studies (Table 1) ranged from 66.7% (Darlington et al., 2001; Fridén et al., 2005; Lee et al., 2017; Sung and Kim, 2018) to 91.7% (Elvan et al., 2023; Lee and Petrofsky, 2018), indicating a good methodological quality.

Table 1. Final score of methodological quality of included studies

Classification	Final score	Study
Good methodological quality	91.7%	Elvan et al., 2023; Lee and Petrofsky, 2018
	84.6%	Kacem et al., 2017
	83.3%	Abt et al., 2007; Ericksen et al., 2012; Hertel et al., 2006; Lee and Yim, 2016; Ozer Kaya and Toprak Celenay, 2016; Senol et al., 2021
	76.9%	Keklicek et al., 2021
	75.0%	Ates and Unluer, 2020; Emami et al., 2018; Guler et al., 2020; Mokošáková et al., 2018; Muniandy et al., 2023; Petrofsky and Lee, 2015; Reschechtko et al., 2023; Yim et al., 2018
	66.7%	Darlington et al., 2001; Fridén et al., 2005; Lee et al., 2017; Sung and Kim, 2018

Table 2. Downs and Black Quality Assessment Checklist of included studies

	Reporting						External validity		Internal validity				Power
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
Darlington et al. (2001)	0	1	1	1	1	0	1	UD	1	1	1	0	0
Fridén et al. (2005)	0	1	1	1	1	0	1	UD	1	1	1	0	0
Hertel et al. (2006)	1	1	1	1	1	1	1	UD	1	1	1	0	0
Abt et al. (2007)	1	1	1	1	1	1	1	UD	1	1	1	0	0
Ericksen et al. (2012)	1	1	1	1	1	1	1	UD	1	1	1	0	0
Petrofsky and Lee (2015)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Ozer Kaya and Toprak Celenay (2016)	1	1	1	1	1	1	1	UD	1	1	1	0	0
Lee and Yim (2016)	1	1	1	1	1	0	1	UD	1	1	1	1	0
Lee et al. (2017)	0	1	1	1	1	0	1	UD	1	1	1	0	0
Emami et al. (2018)	1	1	1	1	1	0	1	UD	1	1	1	0	0
Lee and Petrofsky (2018)	1	1	1	1	1	1	1	UD	1	1	1	0	1
Mokošáková et al. (2018)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Sung and Kim (2018)	0	1	1	1	1	0	1	UD	1	1	1	0	0

	Reporting						External validity		Internal validity				Power
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
Yim et al. (2018)	1	1	1	1	1	0	1	UD	1	1	1	0	0
Ates and Unluer (2020)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Guler et al. (2020)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Kacem et al. (2021)	0	1	1	1	1	1	1	1	1	1	1	0	1
Keklicek et al. (2021)	0	1	1	1	1	1	1	1	1	1	1	0	0
Senol et al. (2021)	1	1	1	1	1	1	1	UD	1	1	1	0	0
Reschechtko et al. (2023)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Elvan et al. (2023)	1	1	1	1	1	1	1	UD	1	1	1	0	1
Muniandy et al. (2023)	0	1	1	1	1	0	1	UD	1	1	1	0	1

UD: unable to determine

The most common methodological deficit was not describing the study hypothesis, not reporting the probability values, not reporting the losses of participants during the follow-up, and no sample size calculation (Table 2). The representativeness of the entire population was not possible to determine based on the method description.

The included studies' publication years ranged from 2001 (Darlington et al., 2001) to 2023 (Elvan et al., 2023; Muniandy et al., 2023; Reschechtko et al., 2023). From included studies, six studies were from Turkey (Ates and Unluer, 2020; Elvan et al., 2023; Guler et al., 2020; Keklicek et al., 2021; Ozer Kaya and Toprak Celenay, 2016; Senol et al., 2021), five studies were from the USA (Abt et al., 2007; Ericksen et al., 2012; Hertel et al., 2006; Petrofsky and Lee, 2015; Reschechtko et al., 2023), five studies were from Korea (Lee et al., 2017; Lee and Yim, 2016; Lee and Petrofsky, 2018; Sung and Kim, 2018; Yim et al., 2018), one study was from Malaysia (Muniandy et al., 2023), New Zealand (Darlington et al., 2001), Iran (Emami et al., 2018), Slovakia (Mokošáková et al., 2018), Sweden (Fridén et al., 2005) and Tunisia (Kacem et al., 2017).

The sample sizes of included studies ranged between 9 (Fridén et al., 2005) to 63 participants (Elvan et al., 2023). In most studies, menstrual cycle phases were assessed by the day of the cycle. Additionally, to confirm ovulation, eight of the included studies used self-administrated ovulation tests (Abt et al., 2007; Elvan et al., 2023; Ericksen et al., 2012; Fridén et al., 2005; Hertel et al., 2006; Kacem et al., 2021; Lee and Yim, 2016; Yim et al., 2018), one study used saliva ferning (Ates and Unluer, 2020), or oral basal body temperature measurement (Sung and Kim, 2018). A study by Darlington et al. (2001) analyzed data from two menstrual cycles, a study by Fridén et al. (2005) analyzed data from two to three menstrual cycles, and the rest of the included studies analyzed data from one menstrual cycle. In Table 3, the characteristics of the included studies are shown.

Table 3. Sample characteristics of included studies and the methods of menstrual cycle monitoring

Authors	Country	Sample size	Age	Menstrual cycle monitoring	Phases comparison
Darlington et al. (2001)	New Zealand	12	21.9 ± 4.0	day of the cycle	day 5, 12, 21, 25
Fridén et al. (2005)	Sweden	9	26 ± 2	day of the cycle + ovulation test	day 3–5, ovulation, 7 days after ovulation
Hertel et al. (2006)	USA	14	19.3 ± 1.3	day of the cycle + ovulation test	day 4–7, ovulation, 7–10 days after ovulation
Abt et al. (2007)	USA	10	21.4 ± 1.4	day of the cycle + ovulation test	day 3, 24–36 h after ovulation, 7 days after ovulation
Ericksen et al. (2012)	USA	20	23.8 ± 6.5	day of the cycle + ovulation test	5 days before ovulation, 5 days after ovulation
Petrofsky and Lee (2015)	USA	15	25.7 ± 2.1	day of the cycle	menstruation and ovulation
Ozer Kaya and Toprak Celenay (2016)	Turkey	13	21.00 ± 1.25	day of the cycle	day 1, 7–9, 20–23
Lee and Yim (2016)	Korea	14	20.34 ± 1.39	day of the cycle + ovulation test	day 1–3, ovulation
Lee et al. (2017)	Korea	18	19.11 ± 0.9	day of the cycle	day 1–3, ovulation (day 12–13)
Emami et al. (2018)	Iran	30	18 to 25	day of the cycle + ovulation test	day 3–5, ovulation (day 12–14)
Lee, Petrofsky (2018)	Korea	15	25.9 ± 1.8	day of the cycle	day 1–3, ovulation (day 12–14)

Authors	Country	Sample size	Age	Menstrual cycle monitoring	Phases comparison
Mokošáková et al. (2018)	Slovakia	11	24.64 ± 1.52	day of the cycle	day 2, 7, 14, 21, 28
Sung and Kim (2018)	Korea	32	19.83 ± 0.92	day of the cycle + oral basal body temperature monitoring	day 5, ovulation, day 25
Yim et al. (2018)	Korea	20	20.67 ± 1.6	day of the cycle + ovulation test	day 1–3, ovulation
Ates and Unluer (2020)	Turkey	13	35.15 ± 7.19	day of the cycle + saliva ferning	day 1–3, ovulation, 7 days after ovulation
Guler et al. (2020)	Turkey	19	20.47 ± 1.07	day of the cycle	day 2–3, 14, 21
Kacem et al. (2021)	Tunisia	12	21.0 ± 1.6	day of the cycle + ovulation test	day 13, 21, 27
Keklicek et al. (2021)	Turkey	22	18 to 30	day of the cycle	day 1, feeling good day
Senol et al. (2021)	Turkey	43	19 to 23	day of the cycle	day 1–3, 12–17, 18–23, 24–28
Reschechtko et al. (2023)	USA	19	21.89 ± 2.08	day of the cycle	days 2, 4, 11, 21
Elvan et al. (2023)	Turkey	63	19 to 26	day of the cycle + ovulation test	preovulatory, post-ovulatory phase
Muniandy et al. (2023)	Malaysia	45	18 to 26	day of the cycle	day 1–3, 12–13

Dynamic postural stability was measured by a star excursion balance test (Ericksen et al., 2012), its modification Y-balance test (Emami et al., 2018; Kacem et al., 2021; Muniandy et al., 2023), and by measuring limits of stability on a force platform (Ozer Kaya and Toprak Celenay, 2016; Sung et Kim, 2018; Ates and Unluer, 2020; Guler et al., 2020). During the star excursion balance test, the participant must maintain a single-leg stance while reaching as far as possible in eight positions with the contralateral leg (Ericksen et al., 2012). During the Y-balance test, the participant maintains a single-leg stance while reaching out in three directions (Emami et al., 2018; Muniandy et al., 2023). Limits of stability represent the maximal distance a participant can intentionally sway in a given direction while maintaining a two-legged stance (Ozer Kaya and Toprak Celenay, 2016; Sung et Kim, 2018; Ates and Unluer, 2020; Guler et al., 2020).

Different balance and force platforms measured static postural stability (Table 4). Biodex balance system was used in four studies (Ozer Kaya and Toprak Celenay, 2016; Ates and Unluer, 2020; Guler et al., 2020; Senol et al., 2021), Zebris platform was used in three studies (Keklicek et al., 2021; Lee and Yim, 2016; Yim et al., 2018) and AMTI platform was used in two studies (Fridén et al., 2005; Hertel et al., 2006). The static postural stability measurement differed by the stance conditions: feet position (feet apart, together, tandem, single leg stance), visual feedback (eyes open, eyes closed), the surface of the force plate (firm or foam), and by the measured time which ranged from 6 (Petrofsky and Lee, 2015; Lee and Petrofsky, 2018) to 120 seconds (Fridén et al., 2005). Two studies used a clinical test of sensory interaction on balance (CTSIB) protocol assessing the sensory contribution to postural control (Darlington et al., 2001; Elvan et al., 2023). A timed single-leg stance test as a balance assessment was used in one study (Emami et al., 2018). A quiet stance with dual-tasks was used in a study by Keklicek et al. (2021). The motor dual-task consisted of standing when holding 7 cubes, and the cognitive dual-task consisted of standing when subtracting the number 7 from the number greater than 200 given by a researcher (Keklicek et al., 2021).

Table 4. Postural stability analysis characteristics of included studies

Authors	Static postural stability measurement	Dynamic postural stability measurement
Darlington et al. (2001)	balance platform, CTSIB protocol using 12 tests (feet apart, feet together, firm and foam surface, EO, EC, 20 s)	
Fridén et al. (2005)	force platform (AMTI), feet together, EO, EC (120 s), and single leg EO (30 s)	
Hertel et al. (2006)	force platform (AMTI Accusway), single leg stance EO (10 s)	
Abt et al. (2007)	force plate (Kistler), single leg stance EO (10 s)	
Ericksen et al. (2012)		star excursion balance test
Petrofsky and Lee (2015)	force platform, 8 tasks (feet apart, feet tandem, firm and foam surface, EO, EC, 6 s)	
Ozer Kaya and Toprak Celenay (2016)	Biodex balance system, OSI	LoS
Lee and Yim (2016)	force platform (Zebris), 8 tasks (EO, EC, firm and foam surface, feet apart, feet tandem, 10 s)	

Authors	Static postural stability measurement	Dynamic postural stability measurement
Lee et al. (2017)	force plate (Good balance system), feet apart (30 s)	
Emami et al. (2018)	single-leg stance test	Y-balance test
Lee and Petrofsky (2018)	force platform, 8 tasks (feet apart, feet tandem, firm and foam surface, EO, EC, 6 s)	
Mokošáková et al. (2018)	force platform, 4 tasks (firm and foam surface, EO, EC, 50 s)	
Sung and Kim (2018)		Biodex balance system, LoS
Yim et al. (2018)	force platform (Zebris), feet tandem, foam surface (10 s)	
Ates and Unluer (2020)	Biodex balance system, OSI (EO, EC, 20 s)	Biodex balance system, LoS (10 s)
Guler et al. (2020)	Biodex balance system, OSI (EO, EC, 20 s)	Biodex balance system, LoS
Kacem et al. (2021)	stabilometric platform, single leg stance (EO, EC, 25.6 s)	
Keklicek et al. (2021)	force platform (Zebris), feet apart, (60 s) and with dual-tasks	
Senol et al. (2021)	Biodex balance system, OSI (EO, 20 s)	
Reschechtko et al. (2023)	force plate (BtrackS Balance Test), feet apart, EC (20 s)	
Elvan et al. (2023)	force platform (Balance master tester), CTSIB protocol (two feet, EO, EC, firm surface, 10 s), single leg stance	force platform (Balance master tester), LoS
Muniandy et al. (2023)		Y-balance test

EO: eyes open; EC: eyes closed; OSI: overall stability index; LoS: limits of stability, CTSIB: clinical test of sensory interaction on balance protocol

In Table 5, the main results of the included studies are summarized. Results of the Y-balance test suggest better dynamic stability near ovulation compared to menstruation (Emami et al., 2018; Muniandy et al., 2023), deteriorated results of the Y-balance test were observed in the late luteal phase (Kacem et al., 2021). The star excursion balance test showed no significant difference between the analyzed menstrual cycle phases (Ericksen et al., 2012). The limits of stability test results are contradictory. Better results of limits of stability were observed in post-ovulatory (Elvan et al., 2023), ovulatory (Sung and Kim, 2018), or luteal phase (Ates and

Table 5. Postural stability parameters and primary outcomes of included studies

Authors	Y-balance test	A-P CoP	M-L CoP	ellipse area	CoP velocity	CoP sway length	OSI	LoS	Star excursion balance test	Single-leg stance test
Darlington et al. (2001)		≈	↑ on days 5 and 25							
Fridén et al. (2005)		≈	≈	≈						
Hertel et al. (2006)										≈
Abt et al. (2007)										≈
Ericksen et al. (2012)									≈	
Petrofsky and Lee (2015)						↑ ovulation				
Ozer Kaya and Toprak Celenay (2016)							≈	↓ day 1		
Lee and Yim (2016)					↑ ovulation					
Lee et al. (2017)		↑ ovulation	↑ ovulation		↑ ovulation					
Emami et al. (2018)	↑ ovulation									↑ ovulation
Lee and Petrofsky (2018)				↑ ovulation	↑ ovulation					
Mokošáková et al. (2018)		↑ in ovulation	≈							

Authors	Y-balance test	A-P CoP	M-L CoP	ellipse area	CoP velocity	CoP sway length	OSI	LoS	Star excursion balance test	Single-leg stance test
Sung and Kim (2018)								↑ ovulation		
Yim et al. (2018)		↑ ovulation	↑ ovulation	≈	↑ ovulation	≈				
Ates and Unluer (2020)							≈	↑ luteal phase		
Guler et al. (2020)		≈	≈				≈	↓ ovulation		
Kacem et al. (2021)	↓ late luteal phase	≈	≈	≈						
Keklicek et al. (2021)		≈	≈			≈				
Senol et al. (2021)							↓ day 1–3			
Reschechtko et al. (2023)						≈				
Elvan et al. (2023)		≈	≈	≈	≈			↑post-ovulatory phase		
Muniandy et al. (2023)	↓ day 1–3									

CoP: center of pressure; A-P CoP: anterior-posterior CoP excursions; M-L CoP: medio-lateral CoP excursions; OSI: overall stability index; LoS: limits of stability; ↓ statistically significant decrease; ≈ no statistically significant change; ↑ a statistically significant increase

Unluer, 2020), and deteriorated results were observed during menstruation (Ozer Kaya and Toprak Celenay, 2016) and ovulatory phases (Guler et al., 2020).

The results of a single-leg stance were observed not to differ across the menstrual cycle (Abt et al., 2007; Hertel et al., 2006) or to be better at ovulation (Emami et al., 2018). Similarly, the overall stability index was observed to not differ across the menstrual cycle (Ates and Unluer, 2020; Guler et al., 2020; Kaya et Celenay, 2016) or to deteriorate during menstruation (Senol et al., 2021). A poorer balance was observed when CoP sway length was measured at ovulation (Petrofsky and Lee, 2015). In other studies, the CoP sway length did not differ across the cycle (Keklicek et al., 2021; Reschechtko et al., 2023; Yim et al., 2018). Greater postural sway velocity was observed at ovulation in four studies (Lee and Petrofsky, 2018; Lee et al., 2017; Lee and Yim, 2016; Yim et al., 2018) and no change across the cycle in one study (Elvan et al., 2023). Greater postural sway velocity at ovulation was observed during the two most challenging balance tasks; however, no change was observed for more manageable tasks across the cycle in a study by Lee and Yim (2016). The ellipse area was not affected by the menstrual cycle in three studies (Elvan et al., 2023; Fridén et al., 2005; Kacem et al., 2021), and increased ellipse area was observed at ovulation by Lee and Petrofsky (2018). Anterior-posterior CoP excursions were observed to be greater at ovulation in three studies (Lee et al., 2017; Mokošáková et al., 2018; Yim et al., 2018) and not to be affected by the cycle in six studies (Darlington et al., 2001; Elvan et al., 2023; Fridén et al., 2005; Kacem et al., 2021; Keklicek et al., 2021; Guler et al., 2020). Medio-lateral CoP excursions were more significant at ovulation in two studies (Lee et al., 2017; Yim et al., 2018). On the other hand, a study by Darlington et al. (2001) observed greater medio-lateral CoP excursions on days 5 and 25. Six different studies observed no significant difference in medio-lateral CoP across the menstrual cycle (Elvan et al., 2023; Fridén et al., 2005; Guler et al., 2020; Kacem et al., 2021; Keklicek et al., 2021; Mokošáková et al., 2018).

Discussion

A systematic review was performed to summarize the available literature focused on the effect of the menstrual cycle on postural stability. Twenty-two relevant studies were identified during the systematic review process. Their results show that the menstrual cycle might affect postural stability. Dynamic postural stability tested by the Y-balance test shows deteriorated results during the early follicular phase when the menstrual bleeding occurs compared to ovulation (Emami et al., 2018; Muniandy et al., 2023), and during the late luteal phase when premenstrual syndrome symptoms may occur (Kacem et al., 2021). Static postural stability seems to deteriorate during ovulation when greater ligament laxity was described due to the peak of estrogen levels (Chidi-Ogbolu and Baar, 2019; N-Wihlbäck et al., 2006; Taraborrelli, 2015), as greater CoP sway excursions were observed in this phase compared to other phases of the cycle. However, the contradictory results of the included studies make the generalization difficult.

In a study by Petrofsky and Lee (2015), it was stressed that the day of measurement and ovulation test confirmation is crucial as estradiol peaks at ovulation and then falls. Nevertheless, the results are still ambiguous when considering only 10 studies that confirmed the ovulation phase by ovulation tests. Half of these studies found no effect of the menstrual cycle on postural stability (Abt et al., 2007; Ericksen et al., 2012; Fridén et al., 2005; Hertel et al., 2006; Kacem et al., 2021). Two studies found deteriorated results of static postural stability at ovulation (Lee and Yim, 2016; Yim et al., 2018), two studies reported better results of dynamic postural stability at ovulation (Emami et al., 2018; Sung and Kim), and one study observed deteriorated results of dynamic postural stability during menstruation (Ates and Unluer, 2020). Future studies are needed to clarify the effect of the menstrual cycle on postural stability.

Premenstrual syndrome, primary dysmenorrhea, and oral contraceptives are other factors affecting the postural stability changes across the cycle (Fridén et al., 2005; Keklicek et al., 2021; Mokošáková et al., 2018). Estrogen levels vary across the natural menstrual cycle with a peak during ovulation. Estrogens decrease stiffness in tendons and ligaments, which is considered one of the key factors in deteriorated postural stability during ovulation (Chidi-Ogbolu and Baar, 2019; N-Wihlbäck et al., 2006; Taraborrelli, 2015). On the other hand, oral contraceptives stabilize estrogen levels, possibly decreasing postural stability differences across the cycle.

Oral contraceptives were observed to decrease anterior-posterior CoP excursions during a quiet stance with eyes open compared to naturally cycling women during the late luteal phase. This finding indicates a positive effect of oral contraceptives on postural stability when naturally cycling women may experience symptoms of premenstrual syndrome (Mokošáková et al., 2018). On the other hand, no difference between oral contraception users and naturally cycling women was observed in postural sway across the menstrual cycle in a study by Reschechtko et al. (2023).

Premenstrual syndrome is a common cyclic disorder in women of reproductive age, and it consists of both emotional and physical symptoms such as mood lability, breast tenderness, bloating, headache, and fatigue, which can affect daily activities. More severe affective symptoms are classified as premenstrual dysphoric disorder (Dickerson et al., 2003; Yonkers et al., 2008). Some of the premenstrual syndrome symptoms were reported in 100% of participants in Palestine (Abu Alwafa et al., 2021). In Turkey, the reported prevalence of premenstrual syndrome was 66% (Erbil and Yucesoy, 2023). In Brazil, the observed prevalence of premenstrual syndrome was 46.9%, and 11.1% of participants suffered from premenstrual dysphoric disorder (Rezende et al., 2022). In women with premenstrual syndrome, a deteriorated postural stability during a single leg stance during the mid-luteal phase of the cycle compared to women without premenstrual syndrome was observed in a study by Fridén et al. (2005), suggesting that premenstrual syndrome can affect the postural stability. Furthermore, physical symptoms of premenstrual syndrome were observed to increase the risk of fracture in adolescent athletes (Takeda et al., 2016).

Primary dysmenorrhea, defined as painful menstruation in the absence of any other pathology, affects between 45 and 95% of menstruating women. Primary dysmenorrhea has an immediate negative effect on the quality of life, mood, sleep quality, and daily activities during menstruation (Iacovides et al., 2015). Primary dysmenorrhea is caused by the overproduction of prostaglandins by the endometrium, which leads to uterine hypercontractility, resulting in uterine muscle ischemia, hypoxia, and pain (Guimaraes and Povoa, 2020). Up to 88% of women with primary dysmenorrhea report a negative effect on academic performance, and up to 38% report limited sports participation during menstruation (Hailemeskel et al., 2016). The negative impact of primary dysmenorrhea during menstruation on leg strength and aerobic capacity was observed previously (Chantler et al., 2009). Keklicek et al. (2021) observed deteriorated postural stability during menstruation in women with primary dysmenorrhea when loaded with cognitive or motor dual-tasks compared to women without dysmenorrhea. Their findings show that primary dysmenorrhea is not only a specific pain disorder but affects the general condition of the person, making dual-tasking difficult. Their study compared day 1 of the menstrual cycle and other days without menstruation when women reported feeling well (Keklicek et al., 2021). Therefore, future studies on the effect of dual-tasks on postural stability across the menstrual cycle are needed to clarify the influence of estrogen variation on the relationship between cognitive processing and motor behavior.

Limitations of this review

The focus on different postural stability parameters, diverse methodological approaches, and different measurement devices used in included studies are significant limitations for generalizing the results. The various criteria of menstrual cycle phases definition and the difference in analyzed menstrual cycle phases constitute another limitation of this review.

Conclusions

Twenty-two studies were included in this systematic review. Results of sixteen of the included studies show that the menstrual cycle affects both static and dynamic postural stability. Six studies observed no significant difference in postural stability across the menstrual cycle. Most of these studies observed deteriorated results during the early follicular phase in dynamic postural stability and at ovulation in static postural stability. However, the ambiguous results of the included studies show the need for future research.

The effect of the menstrual cycle on postural stability in situations with and without dual-task

This study aimed to analyze the effect of different menstrual cycle phases on postural stability. This research also aimed to investigate the impact of dual-tasks on postural stability across the menstrual cycle to clarify the influence of estrogen variation on cognitive processing relationship to motor behavior.

Methods

Type of the study: experimental study

A total of 49 women were evaluated as potential participants in this study. Due to the repeated-measures design of this study and related time demands, 28 women completed measurements three times during their menstrual cycle (at the early follicular phase, ovulation, and mid-luteal phase), and their results are presented. The inclusion criteria comprised the age between 18 and 35 years and having a regular menstrual cycle (eumenorrhea). The exclusion criteria consisted of using oral contraceptives in the last 6 months, pregnancy in the previous 3 years, having any orthopedic or neurological disease, or taking regular medication.

Participants' anthropometric and menstrual cycle characteristics are shown in Table 6. All participants (n=28, 100%) report adverse menstrual symptoms during menstruation, such as abdominal pain, low back pain, headache, or fatigue. In most participants (n=27; 96.4%), the duration of adverse symptoms is the first 2 days of menstruation, and one participant (n=1; 3.6%) reported the duration of adverse symptoms during the whole menstruation. Furthermore, 10 participants (35.7%) reported lower engagement in physical activity during menstruation, 9 participants (32.1%) reported missing work or school due to adverse menstrual symptoms, and 17 participants (60.7%) used painkillers at least once in 6 months to lower the adverse menstrual symptoms.

Table 6. Participants' anthropometric and menstrual cycle characteristics (n=28)

	Median	x25–x75
Age (years)	23.00	21.75–28.25
Body height (cm)	169.50	165.00–172.25
Body mass (kg)	61.50	60.00–66.25
BMI	22.05	21.16–23.75
Menstrual cycle length (days)	28.00	26.75–29.00
Menstruation length (days)	5.00	4.00–6.00
Age of menarche (years)	13.00	12.00–14.00

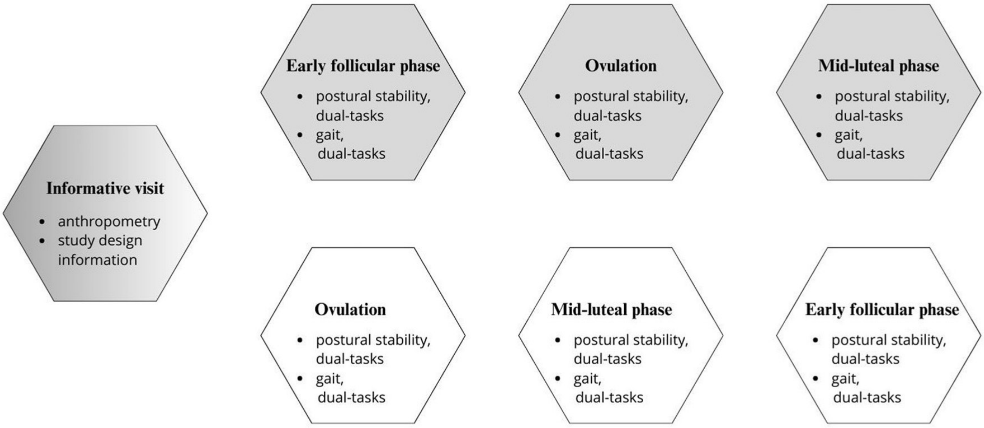

Figure 2. Study design flow diagram. 28 women completed the study: 18 women started the measurements at the early follicular phase, and 10 women began the measurements at ovulation

Study design

Participants were measured three times during the menstrual cycle: at early follicular phase (day 2 of menstruation), at ovulation (up to 48h after confirming ovulation by the ovulation test), and at mid-luteal phase (7 days after ovulation). The study design is shown in Figure 2. Participants were informed about the study's aim and design during a first informative visit to the Faculty of Sports Studies, Masaryk University, Brno, Czech Republic. Participants were given ovulation test kits detecting LH in urine for at-home use (Livsane test, Core technology) and instructed to contact the researcher when ovulation was confirmed or menstruation occurred. Ovulation test kits were used regularly from day 6 to 15 of the menstrual cycle, depending on the length of the menstrual cycle, until the ovulation was confirmed. Participants also filled out a short questionnaire about their menstrual cycle characteristics, body mass, and height, which were measured using InBody 720 and a stadiometer (SECA). Additionally, written informed consent was obtained from the participants during the first visit. The study was approved by the Research Ethics Committee of Masaryk University (EKV-2021-109).

The measurements were identical during the early follicular, ovulation, and mid-luteal phases. To avoid the possible order and training effect in repeated measured study design as recommended by Schmalenberger et al. (2020), 18 women started the measurements at the early follicular phase, and 10 women began the measurements at ovulation. During the measurement, participants were asked to stand as still as possible on a Zebris platform (FDM, GmbH, Munich, Germany) for 30 s, narrow stance, upper limbs alongside the body, seven times: when having eyes open, eyes closed, eyes open, eyes closed, eyes open with the mathematical dual-task, eyes open with shirt buttoning dual-task, eyes open with smartphone reading dual-task (Figure 3). The better attempt (defined as a shorter CoP path) from the two eyes open and eyes closed measurements were used in further analysis.

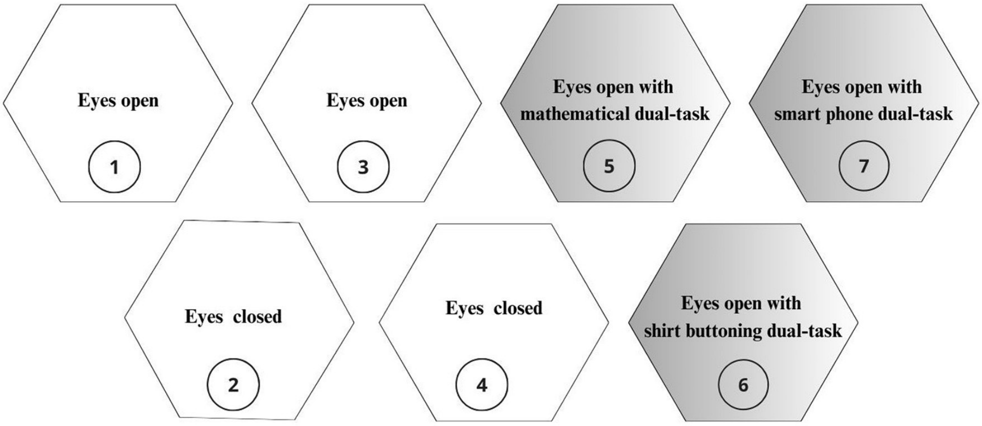

Figure 3. Postural stability measurement design

During the mathematical dual-task, participants were asked to stand as still as possible and simultaneously count backward from the number greater than 200 the researcher told her. Participants made calculations by subtracting 7 from each number. A different starting number was used for each measurement. During the shirt buttoning dual-task, participants were asked to stand as still as possible and simultaneously perform shirt buttoning. During a dual-task smartphone reading, participants were asked to stand as still as possible and simultaneously read an article from the Faculty of Sport Studies, Masaryk University webpage on their smartphone.

The following variables were obtained from the Zebris software:

- Anterior-posterior CoP path (mm): the sum of anterior-posterior CoP sways
- Medio-lateral CoP path (mm): the sum of medio-lateral CoP sways
- CoP path (mm): the sum of all CoP sways
- CoP average velocity (mm/s): the average velocity of CoP sways calculated as the CoP path divided by the measured time
- Force left foot (%): average load distribution of the left foot
- Force right foot (%): average load distribution of the right foot

After the postural stability measurements, the gait measurements followed (for more information, see Chapter 3).

Statistical analysis

Most of the variables did not satisfy the assumption of normal distribution, as assessed by the Shapiro-Wilk test. Descriptive statistics are presented as median, lower quartile (x25), and upper quartile (x75). Friedman Analysis of Variance (ANOVA) was employed to assess variations in postural stability across different phases of the menstrual cycle under conditions of eyes open, eyes closed, dual mathematical task, shirt buttoning task, and smartphone reading task. A Bonferroni correction was applied to mitigate the risk of Type I error, adjusting the alpha level to 0.013. Additionally, Friedman ANOVA with Bonferroni correction (adjusted alpha set at 0.013) was used to examine cognitive-motor interference, specifically differences in postural stability under conditions of eyes open, eyes closed, and during dual-tasks across the various phases of the menstrual cycle. To assess the effect size, Cohen's w was used (< 0.30 small effect; 0.30–0.50 medium effect; > 0.50 large effect). The statistical analyses were conducted using IBM SPSS Statistics (Armonk, NY, USA).

Results

Postural stability eyes open

When comparing postural stability during different phases of the menstrual cycle (Table 7), statistically significant deterioration in CoP path and CoP average velocity was observed at ovulation compared to the early follicular phase ($p=0.013$; Cohen's $w=0.155$).

Postural stability eyes closed

No statistically significant difference in analyzed postural stability parameters when having eyes closed (Table 8) was observed between the early follicular phase ovulation and mid-luteal phase.

Postural stability with a mathematical task

No statistically significant difference after Bonferroni corrections in analyzed postural stability parameters (Table 9) was observed between the early follicular ovulation and mid-luteal phase when performing mathematical tasks.

Postural stability with shirt buttoning task

No statistically significant difference after Bonferroni corrections in analyzed postural stability parameters (Table 10) when performing the shirt buttoning task was observed between the early follicular phase ovulation and mid-luteal phase.

Postural stability with smartphone task

When comparing postural stability with smartphone reading tasks during different phases of the menstrual cycle (Table 11), statistically significant deterioration in CoP path and CoP average velocity was observed at the mid-luteal phase compared to ovulation ($p=0.002$; Cohen's $w=0.219$).

Cognitive-motor interference during different phases of menstrual cycle

Cognitive-motor interference was observed when comparing the postural stability with eyes open and postural stability with dual-tasks with a small to large effect calculated by Cohen's w (Table 12). The significantly better results of CoP path and CoP average velocity were observed when having eyes open compared to eyes closed, postural stability with mathematical, shirt buttoning, and smartphone reading dual-tasks ($p < 0.001$). During the early follicular phase, the force on the right foot

Table 7. Descriptive characteristics of postural stability parameters when having eyes open and statistical analysis results

	Early follicular phase			Ovulation			Mid-luteal phase			*p-value*
	Median	x25	x75	Median	x25	x75	Median	x25	x75	
Anterior-posterior CoP path (mm)	13.90	3.30	29.54	12.54	−8.85	23.28	16.79	2.80	30.94	0.164
Medio-lateral CoP path (mm)	−4.38	−9.65	−1.55	−4.22	−8.09	1.36	−5.95	−10.45	−1.44	0.313
CoP path (mm)	290.49	241.05	346.09	343.50	313.93	476.60	297.61	235.36	355.32	0.013^{A}
CoP average velocity (mm/s)	9.68	8.04	11.54	11.45	10.46	15.89	9.92	7.85	11.84	0.013^{A}
Force left foot (%)	42.63	34.58	49.13	45.04	37.31	54.11	42.33	35.11	48.02	0.033
Force right foot (%)	57.37	50.87	65.42	54.96	45.89	62.69	57.67	51.98	64.89	0.033

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 8. Descriptive characteristics of postural stability parameters when having eyes closed and statistical analysis results

	Early follicular phase			Ovulation			Mid-luteal phase			p-value
	Median	x25	x75	Median	x25	x75	Median	x25	x75	
Anterior-posterior CoP path (mm)	14.42	4.05	22.93	14.43	4.77	23.17	12.38	0.27	21.74	0.629
Medio-lateral CoP path (mm)	−3.08	−7.53	1.66	−3.97	−8.38	−1.18	−3.40	−7.65	− 0.01	0.267
CoP path (mm)	500.88	405.53	729.78	466.13	403.99	553.54	501.60	426.11	579.90	0.629
CoP average velocity (mm/s)	16.70	13.52	24.33	15.54	13.47	18.45	16.72	14.20	19.33	0.629
Force left foot (%)	46.03	36.60	50.43	45.17	38.77	49.25	46.58	40.68	51.73	0.867
Force right foot (%)	53.97	49.57	63.40	54.83	50.75	61.23	53.43	48.27	59.32	0.867

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen’s w

Table 9. Descriptive characteristics of postural stability parameters when performing mathematical dual-tasks and results of statistical analysis

	Early follicular phase			Ovulation			Mid-luteal phase			p-value
	Median	x25	x75	Median	x25	x75	Median	x25	x75	
Anterior-posterior CoP path (mm)	9.80	−0.89	21.12	12.54	−8.85	23.28	8.64	−2.25	20.35	0.565
Medio-lateral CoP path (mm)	−6.17	−9.47	−2.87	−4.22	−8.09	1.36	−6.15	−9.42	−3.66	0.409
CoP path (mm)	430.30	314.99	628.32	343.50	313.93	476.60	464.63	332.08	612.38	0.015
CoP average velocity (mm/s)	14.34	10.50	20.94	11.45	10.46	15.89	15.49	11.07	20.41	0.015
Force left foot (%)	42.42	35.55	54.52	45.04	37.31	54.11	46.33	37.28	55.46	0.629
Force right foot (%)	57.58	45.48	64.45	54.96	45.89	62.69	53.67	44.54	62.72	0.629

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 10. Descriptive characteristics of postural stability parameters when performing shirt buttoning dual-task and statistical analysis results

	Early follicular phase			Ovulation			Mid-luteal phase			p-value
	Median	x25	x75	Median	x25	x75	Median	x25	x75	
Anterior-posterior CoP path (mm)	12.03	1.81	20.58	17.81	9.31	24.98	11.29	0.33	21.04	0.031
Medio-lateral CoP path (mm)	−6.17	−10.80	−1.71	−4.31	−7.63	−1.91	−4.43	−8.89	−1.24	0.105
CoP path (mm)	511.66	378.00	623.58	425.91	347.68	495.08	454.12	368.14	574.70	0.036
CoP average velocity (mm/s)	17.06	12.60	20.79	14.20	11.59	16.50	15.14	12.27	19.16	0.036
Force left foot (%)	46.72	38.97	53.71	44.79	38.99	47.60	44.28	37.91	50.99	0.021
Force right foot (%)	53.28	46.29	61.03	55.21	52.40	61.01	55.72	49.01	62.09	0.021

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen’s w

Table 11. Descriptive characteristics of postural stability parameters when performing smartphone reading dual-task and statistical analysis results

	Early follicular phase			Ovulation			Mid-luteal phase			p-value
	Median	x25	x75	Median	x25	x75	Median	x25	x75	
Anterior-posterior CoP path (mm)	18.05	6.86	28.90	19.30	9.02	32.25	18.32	8.20	33.27	0.368
Medio-lateral CoP path (mm)	−5.26	−9.92	−2.89	−3.63	−8.04	−2.12	−3.53	−5.91	−2.53	0.507
CoP path (mm)	382.50	347.47	538.75	363.92	334.05	398.79	456.79	374.64	519.23	0.002^{C}
CoP average velocity (mm/s)	12.75	11.58	17.96	12.13	11.14	13.29	15.23	12.49	17.31	0.002^{C}
Force left foot (%)	40.97	32.78	49.34	40.47	31.88	45.32	40.22	32.99	45.80	0.409
Force right foot (%)	59.03	50.66	67.22	59.53	54.68	68.12	59.78	54.20	67.01	0.409

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen’s w

Table 12. Results of statistical analysis of cognitive-motor interference during the menstrual cycle's early follicular phase, ovulation, and mid-luteal phase

	Early follicular phase		Ovulation		Mid-luteal phase	
	p-value	Cohen's w	p-value	Cohen's w	p-value	Cohen's w
Anterior-posterior CoP path (mm)	$<.001^{*}$	0.236	0.387	0.037	0.009	0.120
Medio-lateral CoP path (mm)	0.290	0.044	0.055	0.083	0.387	0.037
CoP path (mm)	$<.001^{ABCD}$	$0.406^{\times}$	$<.001^{ABCD}$	$0.374^{\times}$	$<.001^{ABCD}$	$0.518^{\times}$
CoP average velocity (mm/s)	$<.001^{ABCD}$	$0.406^{\times}$	$<.001^{ABCD}$	$0.374^{\times}$	$<.001^{ABCD}$	$0.518^{\times}$
Force left foot (%)	$<.001^{A}$	0.261	0.011^{+}	0.116	$<.001^{*}$	0.179
Force right foot (%)	$<.001^{A}$	0.261	0.011^{+}	0.116	$<.001^{*}$	0.179

A statistically significant difference between mathematical tasks and eyes open;
B statistically significant difference between shirt buttoning task and eyes open;
C statistically significant difference between smartphone task and eyes open;
D statistically significant difference between eyes closed and eyes open;
* statistically significant difference between smartphone task and other dual-task;
+ statistically significant difference between smartphone task and shirt buttoning dual-task;
× medium and large effect of Cohen's w

was greater during single task condition compared to the mathematical dual-task ($p < 0.001$). On the other foot, the force was significantly lower when having eyes open compared to the mathematical dual-task ($p < 0.001$). During the early follicular phase, the anterior-posterior CoP path was substantially longer with the smartphone reading task compared to the eyes closed, mathematical task, and shirt buttoning task ($p < 0.001$). Additionally, at ovulation and mid-luteal phase, the force of the right foot was significantly higher with smartphone reading dual-task compared to the shirt buttoning task and other dual-tasks ($p = 0.011$ and $p < 0.001$, respectively).

Discussion

Postural stability parameters were analyzed at three phases of the menstrual cycle: the early follicular phase, ovulation, and mid-luteal phase. During each data measurement session, data from postural stability, such as when having eyes open, eyes closed, and eyes open with three different dual-tasks were obtained. Results show that the postural stability with eyes open is affected during ovulation when the CoP path and CoP average velocity are significantly higher. Postural stability with smartphone reading dual-task significantly deteriorated during the mid-luteal phase of the cycle, observed by higher CoP path and CoP average velocity. No difference in eyes closed and mathematical and shirt buttoning dual-task postural stability performance between analyzed menstrual cycle phases was observed. The cognitive-motor interference was observed in the CoP path and CoP average velocity at all analyzed phases of the cycle.

The systematic review results in this chapter show that postural stability can be affected by the menstrual cycle. Similarly to the results of this study, static postural stability was reported to deteriorate at ovulation previously. At ovulation, greater CoP sway length was reported by Petrofsky and Lee (2015), and greater postural sway velocity was reported by Lee and Petrofsky (2018), Lee et al. (2017), Lee and Yim (2016), and Yim et al. (2018). At ovulation, when the estradiol levels are highest, a higher general ankle joint laxity, higher elasticity of plantar fascia, which supports the foot arch, and higher anterior cruciate ligament laxity were observed (Lee et al., 2013; Petrofsky and Lee, 2015; Yamazaki et al., 2021). A previous study by Shultz et al. (2012) confirmed that sex hormone concentration changes across the menstrual cycle are sufficient to influence collagen metabolism and associated joint function (Shultz et al., 2012). The generalized joint laxity and generalized joint hypermobility were previously associated with impaired postural stability parameters in women (Aydin et al., 2017; Steinberg et al., 2021). It can be assumed that increased joint laxity at ovulation affects the performance of postural stability. However, some of the previous studies reported no change in CoP sway length and CoP sway velocity across the menstrual cycle (Elvan et al., 2023; Keklicek et al., 2021; Reschechtko et al., 2023; Yim et al., 2018).

When the sensory input is limited, e.g., by closing the eyes, the postural stability was observed to be affected (Andreeva et al., 2021; Carneiro et al., 2012; Choy et al., 2003; Palm et al., 2009). Similarly, the findings of this study show a significant deterioration in postural stability when comparing eyes closed and eyes open conditions. There was no change across the menstrual cycle in postural stability when limiting the visual input. A previous study by Andreeva et al. (2021) shows that practicing sports can lead to a more negligible deterioration in postural stability when closing the eyes. On the other hand, with age and obesity, the deterioration in postural stability when having eyes closed is more evident (Carneiro et al., 2012; Choy et al., 2003).

Standing while using a smartphone is a frequent dual-task in daily living. During the mid-luteal phase, significant deterioration of postural stability with smartphone reading task was observed in this study. Previously, higher CoP path and CoP velocity were observed while texting and talking on a smartphone compared to quiet standing in healthy young adults (Onofrei et al., 2020; Nurwulan et al., 2015). Studies by Onofrei et al. (2020) and Nurwulan et al. (2015) identified texting on a smartphone as more demanding than talking on a smartphone. During the late luteal phase, cognitive functions were observed to deteriorate compared to ovulation (Guven Yorgun and Ozakbas, 2019), which might be the reason why significant deterioration of postural stability with smartphone reading task was observed in the mid-luteal phase in this study. The significant differences in left and right foot force distribution when performing smartphone reading dual-tasks compared to other dual-tasks might reflect holding the smartphone.

In previous studies, the deterioration of postural stability parameters during cognitive or motor dual-tasks has been associated with an increased risk of falls and injuries (Agmon et al., 2014; Glenn et al., 2015). During all analyzed phases of the menstrual cycle, significant deterioration of CoP path and CoP average velocity was observed when performing mathematical, shirt buttoning, and smartphone reading dual-tasks. Similarly, previous studies reported a substantial decrease in postural stability when performing different dual-tasks (e.g., Onofrei et al., 2020; Mujdeci et al., 2016). However, some previous studies report significant improvement in postural stability or no statistically significant change when performing dual-tasks in young adults (e.g., Bernard-Demanze et al., 2009; Dault et al., 2001). A previous study by Keklicek et al. (2021) focused on postural stability during the menstrual cycle when loaded with cognitive or motor dual-tasks. Their study compared day 1 of the menstrual cycle and other days without menstruation when women reported feeling well. Their results show no significant differences in postural stability in situations with and without a dual-task between menstruation and other days without menstruation in healthy women. However, in women with primary dysmenorrhea, the postural stability was observed to be significantly deteriorated in situations with dual-tasks showing that individuals with primary dysmenorrhea experience difficulties with multi-tasking across the cycle (Keklicek et al., 2021). Similarly, a significant deterioration in postural stability parameters with dual-tasks was observed in this study. Despite no diagnosis of primary dysmenorrhea, 100% of participants in this study reported adverse menstrual symptoms during menstruation. Future studies will bring a more detailed insight into the possible relationship between adverse menstrual symptoms and dual-task performance at different phases of the cycle.

The menstrual cycle characteristics of this study's participants were similar to those reported by previous studies. All participants in this study reported adverse menstrual symptoms during menstruation, such as abdominal pain, low back pain, headache, or fatigue. In previous studies, the prevalence of menstruation-related symptoms ranged between 85% (Schoep et al., 2019) and 90% of women (Doohan et al., 2023). More than 32% of our participants reported missing work or school due to adverse menstrual symptoms. In West African countries, work absenteeism due to menstruation ranged between 11% and 19%, and school absenteeism ranged between 15% and 23% (Hennegan et al., 2021). The reported work and school absenteeism in Spain was 20% and 63%, respectively. Spanish women described teleworking, or timetable flexibility (76%), and menstrual leave (50%) as preferred menstrual management in workplaces (Medina-Perucha et al., 2023). Lower engagement in physical activities was described in this study by 32% of participants. In a study by Medina-Perucha et al. (2023), up to 80% of women reported not practicing physical activities during menstruation. Up to 40% of Netherlands women use painkillers to alleviate symptoms and fulfill their daily activities during menstruation (Schoep et al., 2019). In our study, up to 61% of participants use painkillers at least once in 6 months to lower the adverse menstrual symptoms. As Schoep et al. (2019) described in European society, there is a shortage of open communication about the menstrual cycle. The high prevalence of school and work absenteeism highlights the need for supportive menstrual management policies in work and educational environments (Medina-Perucha et al., 2023).

Limitations of this study

There are several limitations of this study. As the static postural stability measured by CoP sway on a force platform is not a direct measure of balance, some aspects of balance associated with changes in hormone levels during the menstrual cycle might not be captured. Ovulation kits have been used in previous studies to detect ovulation. Still, serum tracking and profiling would be a more precise option for determining the ovulation timing.

Conclusions

In conclusion, this study provides valuable insight into postural stability changes across the menstrual cycle. Confirming previous findings, a deterioration in postural stability was observed at ovulation, which is likely linked to increased joint laxity. During the mid-luteal phase, significant deterioration of postural stability with smartphone reading task was observed in this study. Moreover, during all analyzed phases of the menstrual cycle, considerable deterioration of CoP path and CoP average velocity was observed when performing mathematical, shirt buttoning, and smartphone reading dual-tasks. These findings show the influence of hormonal fluctuations across the menstrual cycle on postural stability and the related risk of injuries. Future research might explore these associations, focusing on interventions enhancing postural control tailored to the specific menstrual cycle phases.

Does the age at menarche affect postural stability?

Background

Timing of menarche and associated altered hormonal environment may have significant health consequences during adulthood in women. Earlier age at menarche has been associated with obesity (Pierce and Leon, 2005), higher BMI (Zurawiecka and Wronka, 2021; Gill et al., 2018), greater bone mineral density (Magnus et al., 2020), higher blood pressure (Werneck et al., 2018), higher risk for depression (Hirtz et al., 2022), higher neuroticism score (Magnus et al., 2020), and higher risk for type 2 diabetes (Elks et al., 2013) in adulthood. Current studies using Mendelian randomization focus on the causal effect of age at menarche and confounding factors such as pubertal adiposity or socio-economic factors. The results show the causal effect of the age at menarche and adult BMI. Early age at menarche was associated with hormonal and psychological changes resulting in increased BMI (Gill et al., 2018). In a previous study by Zurawiecka and Wronka (2021), the age at menarche before the age of 12 years was associated with a higher risk of overweight and obesity; on the other hand, the age at menarche after the age of 14 years was associated with a higher risk of underweight and lower risk of overweight and obesity (Zurawiecka and Wronka, 2021).

The association between the age at menarche and physical performance in adulthood is not well-researched. A previous study by Le Noan-Lainé et al. (2023) showed a positive correlation between the age at menarche and gait speed in adulthood. No statistically significant association between the age at menarche and gait speed was observed in a study by Ravi et al. (2020). However, in their research, the age at menarche was associated with explosive strength of lower limbs measured by jump height during adulthood. A higher jump was associated with age at menarche after the age of 14 years. Furthermore, the age at menarche after 14 years was associated with more leisure-time step count in adulthood. For knee extension strength, no statistically significant association was observed with age at menarche (Ravi et al., 2020). Postural stability was observed to be affected by body composition (Hita-Contreras et al., 2013) and body weight (Hue et al., 2007), and possibly it can also be affected by age at menarche as it influences body weight and BMI (Gill et al., 2018; Pierce and Leon, 2005; Zurawiecka and Wronka, 2021).

Feasibility research, which concentrates on evaluating data collection methods, study protocol procedures, and potential outcomes, minimizes research inefficiencies.

Within this framework, pilot studies represent a subset of feasibility studies designed to investigate a specific research question on a smaller scale (Chan, 2019; Kristunas et al., 2019). This pilot study aimed to test the methods of data collection and potential outcomes of the effect of age at menarche on postural stability parameters.

Methods

Type of the study: pilot study

Participants' characteristics were described in detail in Chapter 2. In brief, 28 young female adults were included in this study. Participants reported their age and age at menarche, their body height, and body mass were measured using InBody 720 and a stadiometer (SECA). Subsequently, BMI was calculated. Participants' characteristics are shown in Table 13.

Table 13. Participants' characteristics

	Median	x25–x75
Age (years)	23.00	21.75–28.25
Body height (cm)	169.50	165.00–172.25
Body mass (kg)	61.50	60.00–66.25
BMI	22.05	21.16–23.75
Age of menarche (years)	13.00	12.00–14.00

The Zebris platform (FDM GmbH, Munich, Germany) measured postural stability parameters barefooted. Participants were asked to stand as still as possible for 30 seconds, with a narrow stance, when their eyes were open, and then the measurement was repeated when their eyes were closed. Two attempts were measured for each condition (eyes open, eyes closed). The better attempt, considering the CoP path (mm), was used in further analysis. Participants were measured during the mid-luteal phase of the menstrual cycle. A detailed description of the measurement procedure is in Chapter 2. The following variables were obtained from the Zebris platform: anterior-posterior CoP path (mm), medio-lateral CoP path (mm), CoP path (mm), and CoP average velocity (mm/s). The Research Ethics Committee of Masaryk University approved the study (EKV-2021-109).

Statistical analysis

Descriptive statistics, represented by the median and interquartile range (IQR, x25–x75), were employed due to the non-normal distribution of the variables, as determined by the Shapiro-Wilk test. Spearman's rho was used to investigate correlations among variables such as age of menarche, body mass, body height, BMI, and postural stability parameters. Correlations were referred to according to Hopkins et al. (2009) as trivial (0–0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), nearly perfect (0.9) and perfect (1.0). Fisher's z-transformed Spearman rank correlation values were used to evaluate effect size. The statistical analyses were conducted using IBM SPSS Statistics (Armonk, NY, USA), with a statistical significance set at alpha 0.05.

Results

No statistically significant correlation between the age at menarche and body height (Spearman's rho = 0.344, moderate correlation; p = 0.079; Fisher's z = 0.359), body mass (Spearman's rho = 0.095; p = 0.638; Fisher's z = 0.095), and BMI (Spearman's rho = −0.009; p = 0.963; Fisher's z = −0.009) was observed. The descriptive statistics of postural stability parameters and results of Spearman's rho for eyes open are shown in Table 14. Only a small correlation was observed between the age at menarche, body mass, BMI, and anterior-posterior CoP path. Additionally, a small correlation was observed between the body's height and medio-lateral CoP path, CoP path, and CoP average velocity. However, none of the small correlations did reach the statistical significance.

The descriptive statistics of postural stability parameters and results of Spearman's rho for eyes closed are shown in Table 15. A small correlation was observed between age at menarche and anterior-posterior CoP path, CoP path, and CoP average velocity. A moderate correlation was observed between the body height and anterior-posterior CoP path and the medio-lateral CoP path, and a small correlation was observed between the body height and CoP path and the CoP average velocity. None of these small and moderate correlations reached statistical significance.

Discussion

This pilot study aimed to test the methods of data collection and potential outcomes of the effect of age at menarche on postural stability parameters. Earlier age at menarche has been associated with an increased risk of sarcopenia (Fan et al., 2023). Sarcopenia, characterized by reduced muscle mass and quality, increases postural instability (Okayama et al., 2022). However, no study focused on the relationship between age at menarche and postural stability is known to the author.

Previous research focused on the age at menarche showed an increased risk of injury in post-menarche girls and women in sports compared to their pre-menarche peers (Decloe et al., 2014; Kim and Lim, 2014; O'Kane et al., 2016). In ice-hockey players, girls with menarche at age 11 or 12 were reported to be at increased risk of injury compared to pre-menarche players (Decloe et al., 2014). In post-menarche elite artistic gymnasts, greater knee loads showed an increased anterior cruciate ligament injury risk when performing a single-legged drop landing compared to pre-menarche group (Kim and Lim, 2014). It was hypothesized that hormone changes during the menstrual cycle, or the inadequate neuromuscular adaptation to control the longer

Table 14. Descriptive statistics and correlation results between postural stability parameters when having eyes open with age at menarche and anthropometrical parameters

	Median	x25	x75	Age at menarche Spearman's rho	Body height Spearman's rho	Body mass Spearman's rho	BMI Spearman's rho
Anterior-posterior CoP path (mm)	16.79	2.80	30.94	-0.157^{A}	−0.016	0.253^{A}	0.225^{A}
Medio-lateral CoP path (mm)	−5.95	−10.45	−1.44	0.055	-0.145^{A}	0.005	0.048
CoP path (mm)	297.61	235.36	355.32	0.040	0.291^{A}	0.029	−0.083
CoP average velocity (mm/s)	9.92	7.85	11.84	0.040	0.291^{A}	0.029	−0.083

* $p < 0.05$

A – small (0.1–0.3), B – moderate correlation (0.3–0.5), C – large (0.5–0.7), D – very large (0.7–0.9), E – nearly perfect (0.9), and F – perfect (1.0)

Table 15. Descriptive statistics and correlation results between postural stability parameters when having eyes closed with the age at menarche and anthropometrical parameters

	Median	x25	x75	Age at menarche Spearman's rho	Body height Spearman's rho	Body mass Spearman's rho	BMI Spearman's rho
Anterior-posterior CoP path (mm)	12.38	0.27	21.74	-0.147^{A}	-0.317^{B}	−0.023	0.057
Medio-lateral CoP path (mm)	−3.40	−7.65	−0.01	−0.052	-0.342^{B}	−0.024	0.044
CoP path (mm)	501.60	426.11	579.90	0.140^{A}	0.254^{A}	0.026	−0.048
CoP average velocity (mm/s)	16.72	14.20	19.33	0.140^{A}	0.254^{A}	0.026	−0.048

* $p < 0.05$

A – small (0.1–0.3), B – moderate correlation (0.3–0.5), C – large (0.5–0.7), D – very large (0.7–0.9), E – nearly perfect (0.9), and F – perfect (1.0) body segments and greater body mass during maturation are the possible underlying factors (Decloe et al., 2014; Kim and Lim, 2014).

A moderate correlation was observed between the age at menarche and body height in this study, as reported previously (Froehle et al., 2017; Zurawiecka and Wronka, 2022). The age at menarche affects the growth by being linked to the onset of epiphyseal closure (Froehle et al., 2017). Women with later menarche were observed to reach a higher adult body height compared to women with earlier menarche. More specifically, the EPIC study found that each year of delay in menarche leads to approximately 0.31 cm taller body height in European women (Onland-Moret et al., 2005).

Similarly to the results of this study, postural stability was previously observed to be affected by body height and body weight (Hue et al., 2007; Krzykala et al., 2023). Increased body weight and body height correlates with decreased postural stability. Body height and body weight were reported to be affected by the age of menarche (Froehle et al., 2017; Zurawiecka and Wronka, 2022; Gill et al., 2018; Wronka, 2010). Still, no direct evidence links age at menarche to postural stability as the results of this study show only small correlations between the age at menarche and postural stability parameters. Further research is needed to explore this potential relationship.

Limitations of this study

The results of this pilot study should be interpreted in the context of the following limitations – a low number of participants, and using basic statistics allowed assessing the pilot results. However, there is a need for caution when generalizing the results. Mendelian randomization explored a potential causal relationship between exposure and outcome and was applied in previous studies on the effects of age on menarche (e.g., Denos et al., 2023; Fan et al., 2023). Future studies on large samples using Mendelian randomization will show the potential causal effect between the age at menarche, body height, and body mass and their impact on postural stability.

Conclusions

To conclude, this pilot study did not identify any clear association between the age at menarche and postural stability parameters. However, the observed small to moderate correlation suggests a potential relationship that requires further research.

Chapter conclusions

RQ1: How do different menstrual cycle phases affect postural stability parameters?
It can be assumed that the increased joint laxity at ovulation caused by the peak of estrogen levels (Chidi-Ogbolu and Baar, 2019; N-Wihlbäck et al., 2006; Taraborrelli, 2015) affects the performance of postural stability.

A systematic review of the influence of the menstrual cycle on postural stability was performed according to PRISMA guidelines. By the databases search, 747 studies were identified. After the screening process, 22 studies were included in the systematic review. Their results show that static postural stability seems to deteriorate during ovulation when greater ligament laxity is described. Dynamic postural stability shows deteriorated results during the early follicular phase when menstrual bleeding occurs (Emami et al., 2018; Muniandy et al., 2023), and during the late luteal phase when premenstrual syndrome symptoms may occur (Kacem et al., 2021). Still, six of the included studies found no effect of the menstrual cycle on postural stability.

An experimental study on the effect of different menstrual cycle phases on postural stability was included in the second part of this chapter. In the experimental study, 28 women completed postural stability measurements three times during their menstrual cycle (at the early follicular phase, ovulation, and mid-luteal phase). Results showed that postural stability is affected during ovulation when the CoP path and CoP average velocity were significantly higher.

To conclude, static postural stability parameters were observed to be affected by the menstrual cycle showing deteriorated results during ovulation. Dynamic postural stability seems to be deteriorated during early follicular and late luteal phases. These findings highlight the importance of considering the menstrual cycle phase in targeted interventions enhancing postural stability for women.

RQ2: How do different menstrual cycle phases affect postural stability parameters in situation with dual-task?
A previous study by Keklicek et al. (2021) focused on postural stability during the menstrual cycle when loaded with cognitive or motor dual-tasks. Their study compared day 1 of the menstrual cycle and other days without menstruation when women reported feeling well. The motor dual-task consisted of standing when holding 7 cubes, and the cognitive dual-task consisted of standing when subtracting the number 7 from the number greater than 200 given by a researcher. Their results show no significant differences in postural stability in situations with and without a dual-task between menstruation and other days without menstruation in healthy women ($n = 22$). However, in women with primary dysmenorrhea ($n = 12$) the postural stability was observed to be significantly deteriorated in situations with dual-tasks showing that individuals with primary dysmenorrhea experience difficulties with multi-tasking across the cycle (Keklicek et al., 2021).

An experimental study on the effect of dual-task on postural stability across the menstrual cycle was included in the second part of this chapter. In the experimental study, 28 women completed postural stability measurements with mathematical, shirt buttoning, and smartphone reading dual-tasks three times during their menstrual cycle (at the early follicular phase, ovulation, and mid-luteal phase). Statistically significant deterioration in CoP path and CoP average velocity was observed with all three dual-tasks compared to quiet standing in the situation without dual-task across the menstrual cycle similar to women with primary dysmenorrhea in the study by Keklicek et al. (2021). Despite no diagnosis of primary dysmenorrhea, 100% of our participants reported adverse menstrual symptoms during menstruation.

To conclude, postural stability with dual-tasks seems to deteriorate across the menstrual cycle. Future studies will bring a more detailed insight into the possible relationship between adverse menstrual symptoms and dual-task performance at different phases of the cycle.

RQ3: How does the age at menarche influence postural stability parameters in adult women?

The association between the age at menarche and physical performance in adulthood is not well-researched. In previous studies, age at menarche was associated with gait speed, and jump height (Le Noan-Lainé et al., 2023; Ravi et al., 2020).

In a pilot study described in this chapter, postural stability parameters in eyes open and closed conditions were measured in 28 women who reported their age at menarche. Only small correlations were observed between the age at menarche and anterior-posterior CoP path when having eyes open, and between the age at menarche and anterior-posterior CoP path, CoP path, and CoP average velocity when having eyes closed.

To conclude, no clear association between the age at menarche and postural stability parameters was observed. However, the observed small correlations suggest a potential relationship that requires further research on a larger sample.

Chapter 3. Changes in gait influenced by menstrual cycle

Chapter summary

Little is known about the effect of the different menstrual cycle phases on women's body movement. The third chapter was divided into three parts: (i) a systematic review summarizing the previous studies on the effect of the menstrual cycle on gait; (ii) an experimental study focused on the effect of the menstrual cycle on gait in a situation with and without a dual-task; and (iii) a pilot study analyzing the effect of menarche on spatiotemporal and dynamic gait parameters.

Six studies were included in the systematic review on the impact of the menstrual cycle on gait, and their results show that the menstrual cycle affects several aspects of gait. Included studies observed that the number of steps performed per day increases near ovulation and that the attractiveness of female gait for male observers changes across the cycle. There was no change in foot arch height during walking or in the timed up-and-go test and timed up-and-go test with dual-task. No study used dynamic gait analysis using force plates to analyze the effect of different menstrual cycle phases on dynamic gait parameters.

The dynamic and spatiotemporal gait parameters were analyzed in the second part of this chapter, which presents the original data. Its results show that the gait is affected during the early follicular phase when cadence and stride length are significantly lower/shorter, probably due to menstrual-related discomfort and pain. The cognitive-motor interference was observed with smartphone reading task showing the importance of studying the distracted gait with a smartphone.

In the last part of this chapter, the pilot study focused on the effect of the age at menarche on the spatiotemporal and dynamic gait parameters was presented. Similarly to previous studies, gait speed, stride length, and step width were observed to correlate with the age at menarche. Future studies focused on the effect of age at menarche on movement will bring a more detailed insight into the cumulative exposure to estrogen on motor behavior and physical performance.

Does the menstrual cycle affect gait? A systematic review

Background

Several previous studies focused on behavioral, visual, olfactory, and vocal changes in women near ovulation; however, little is known about the effect of the fertility phase of the menstrual cycle on women's body movement (Fink et al., 2012). From an evolutionary point of view, near ovulation, when the fertility risk and the possibility of pregnancy are high, the pressure to choose a good partner increases. Previous studies described several unconscious processes changing women's physical appearance and attractiveness for men, e.g., more skin revealing and sexier clothing usage on fertile days, changes in body odors and voice (Gueguen, 2012; Durante et al., 2008; Gildersleeve et al., 2012). It was hypothesized that changes in attractiveness near ovulation could be caused incidentally by-product of estrogen level variation during the menstrual cycle (Gildersleeve et al., 2012). On the other hand, evolutionary psychologists Gangestad and Thornhill (2008) argue that the term oestrus appropriately applies to the fertile phase of the menstrual cycle in humans. Oestrus, as defined in Encyclopaedia Britannica (2023), is '*the period in the sexual cycle of female mammals, except the higher primates, during which they are in heat – i.e., ready to accept a male and to mate. One or more oestrus periods may occur during a species' breeding season. Before ovulation, the endometrium (uterine lining) thickens in preparation for holding the fertilized ova. As the proliferation of uterine tissue reaches its peak, receptivity is highest—this is the estrous period. Some animals (e.g., dogs) are monoestrous, having only one heat during a breeding season. Others (e.g., ground squirrels) are polyoestrous: if not impregnated, they will come into heat repeatedly during the breeding season. Males can recognize a female in heat by smell; certain substances (pheromones) are secreted only at this portion of her cycle. The female's genital area may be swollen during oestrus, and she may show by a variety of behavioral signals that she is ready to mate.*' During the oestrus, female mammals increase their physical activity, and from the activity data obtained, e.g., by pedometers or other electronic activity tags, it is possible to effectively detect the oestrus in animals (e.g., in cows as described by Lovendahl and Chagunda, 2010). Therefore, it can be hypothesized that natural human female physical activity also increases near ovulation (Morris and Udry, 1970).

The gait pattern provides a lot of information about the walker. Even an untrained observer can identify the gender of the subject based on their gait (Mather and Murdoch, 1994); from the gait kinematics, it is possible to identify the person (Troje et al., 2005), mood (Michalak et al., 2009) and emotions of the walker (Birch et al., 2016). Recently, machine-learning algorithms have been able to identify mental health (clinically significant symptoms of depression and anxiety) based on the natural gait pattern of a person (Miao et al., 2021). Therefore, it is possible to hypothesize that the gait pattern in women can be affected by different phases of the menstrual cycle and that men would rate women's gait more attractive during the fertile phase of the cycle as female body movements may serve as a potential cue to ovulation (Fink et al., 2012).

The menstrual cycle is characterized by significant changes in estrogen secretion, increasing 10- to 100-fold over the cycle. The musculoskeletal system is affected by estrogen. Estrogen improves bone and muscle mass and strength and increases collagen content in connective tissues. In tendons and ligaments, it decreases stiffness, affecting physical performance, including gait, and increasing the risk of ligament injury (Chidi-Ogbolu and Baar, 2019). Increased laxity of the plantar fascia near ovulation can result in a decreased height of the longitudinal foot arch, affecting the gait pattern (Tagawa et al., 2023).

A systematic review on this topic was performed to summarise all the available previous research about the influence of the menstrual cycle on gait and answer the question from the beginning of this subchapter if the menstrual cycle can affect the gait.

Methods

Type of the study: systematic review

A systematic review of the gait parameters changes influenced by the menstrual cycle was performed according to the PRISMA guidelines (Page et al., 2021). The search was performed using PubMed, Web of Science, and Scopus in August 2023. The PECO criteria consisted of *participants (P)* of females at reproductive age, *exposure (E)* to different phases of the menstrual cycle, *comparator (C)* between different menstrual cycle phases (e.g., follicular phase compared to luteal phase), and *outcome (O)* of change or maintenance of gait parameters during one phase against another.

The following terms with Boolean operators were used for the search: ("menstrual" OR "menstrual cycle" OR "follicular phase" OR "luteal phase" OR "menstruation" OR "ovarian cycle" OR "ovulation") AND ("gait" OR "walking" OR "stride" OR "walk*" OR "locomotion" OR "locomotor"). The literature search did not exclude any studies published before specific date due to a limited number of scientific studies focused on gait during different menstrual cycle phases, as described in Chapter 2. All studies identified in the search were imported into Rayyan systematic review software (Ouzzani et al., 2016) to continue the selection process. Exclusion criteria consisted of animal studies, non-English language, review articles, conference papers, books, and book chapters, and no full text available. Additionally, data from women taking oral contraception or with any musculoskeletal or neurological disease affecting the locomotion were not considered. The title and abstract of the remaining studies were screened. The full texts of the included studies were screened to confirm the relevance of these studies to this systematic review. Artificial intelligence was not used in these steps; the author performed the whole screening process. Figure 4 summarizes the study selection process in the PRISMA flow diagram.

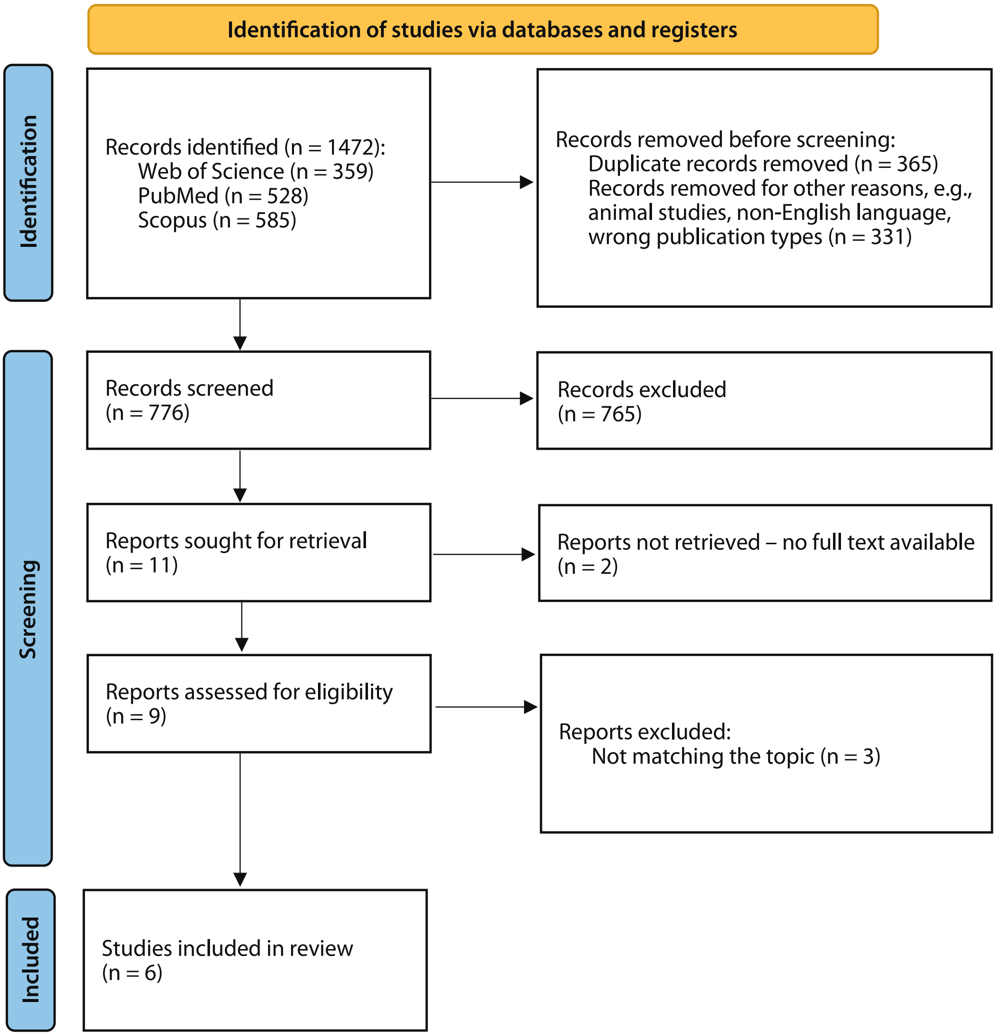

Figure 4. PRISMA flow diagram of the study selection process (template from Page et al., 2021)

For data extraction, a pre-defined form in Microsoft Excel consisting of (i) study characteristics (author(s), publication year and country, sample size, and characteristics); (ii) menstrual cycle measurement; (iii) analyzed gait parameters and its measurement; and (iv) results were used.

Selected relevant items from the Downs and Black Quality Assessment Checklist (Downs and Black, 1998) were used to assess the included studies' methodological quality. The Downs and Black Quality Assessment Checklist consists of 27 questions assessing the quality of reporting, external and internal validity, and statistical power. For this systematic review, 13 items (Downs and Black, 1998) were considered relevant. The list of relevant items is shown in Chapter 2.

A binary score for each question: 0=no/unable to determine, 1=yes was used when assessing the quality of included studies. The final score (in %) was classified as follows: < 45.4% "poor" methodological quality; 45.5–61.0% "fair" methodological quality"; and > 61.0% "good" methodological quality (Meignié et al., 2021). The quality assessment was not used to exclude any study.

Results

By the databases search, 1472 studies were identified (PubMed: 528 studies, Web of Science: 359 studies, Scopus: 585 studies). After duplicate removal (365 studies), animal studies, wrong publication types (e.g., review, book chapter, letter to editor, conference abstract), and studies in languages other than English were excluded (331 studies). In 776 studies, titles and abstracts were screened, and 765 studies were excluded as they did not describe gait parameters related to the menstrual cycle. In the last stage, the full text of the remaining 9 studies was read, and after excluding 3 studies that did not match the topic, 6 studies were included in this systematic review.

The final score of Downs and Black Quality Assessment Checklist evaluating the methodological quality of included studies (Table 16) ranged from 63.6% (Morris and Udry, 1970) to 90.8% (Gueguen, 2012; Tagawa et al., 2023), indicating a good methodological quality.

Table 16. Final score of methodological quality of included studies

Classification	Final score	Study
Good methodological quality	90.9%	Gueguen, 2012; Tagawa et al., 2023
	81.8%	Fink et al., 2012; Provost et al., 2008
	75.0%	Ates and Unluer, 2020
	63.6%	Morris and Udry, 1970

The most common methodological deficit consisted of not reporting the probability values, and no sample size calculation. The representativeness of the entire population and the losses of participants during the follow-up were not possible to determine based on the method description (Table 17).

Table 17. Downs and Black Quality Assessment Checklist of included studies

	Reporting						External validity		Internal validity				Power
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
Morris and Udry (1970)	1	1	0	1	0	0	UD	UD	1	1	1	1	0
Provost et al. (2008)	1	1	1	1	1	0	1	UD	1	1	1	UD	0
Fink et al. (2012)	1	1	1	1	1	0	1	UD	1	1	1	UD	0
Gueguen (2012)	1	1	1	1	1	1	1	UD	1	1	1	UD	0
Ates and Unluer (2020)	0	1	1	1	1	1	1	UD	1	1	1	0	0
Tagawa et al. (2023)	1	1	1	1	1	1	UD	UD	1	1	1	UD	1

UD unable to determine

The year of publication of the included studies ranged from 1970 (Morris and Udry, 1970) to 2023 (Tagawa et al., 2023). From included studies, one study was from the USA (12.5%, Morris and Udry, 1970), France (12.5%, Gueguen, 2012), Canada (12.5%, Provost et al., 2008), Germany (12.5%, Fink et al., 2012), Japan (12.5%, Tagawa et al., 2023) and Turkey (12.5%, Ates and Unluer, 2020).

Three of the included studies focused on the attractiveness of gait during different phases of menstrual cycle (Fink et al., 2012; Gueguen, 2012; Provost et al., 2008), one of the included studies focused on the number of steps per day fluctuations during the menstrual cycle (Morris and Udry, 1970), one study focused on dynamic longitudinal arch changes during the cycle (Tagawa et al., 2023), and one study focused on motor and cognitive dual-tasks during Timed Up-and-Go test (TUG) at different phases of the cycle (Ates and Unluer, 2020). The TUG test is a simple test measuring the time during which the subject gets up from a chair, walks three meters, turns around, walks back, and sits back on the chair (Ortega-Bastidas, 2023).

The sample sizes of the included studies ranged between 13 (Ates and Unluer, 2020) to 103 participants (Gueguen, 2012). In most studies, menstrual cycle phases were assessed by the day of the cycle. In a study by Provost et al. (2008), salivary ferning confirmed peak fertility. A study by Gueguen (2012) used a salivary LH test to confirm ovulation. A study by Ates and Unluer (2020) used a Lady-Q microscope saliva examination to confirm ovulation. In a study by Tagawa et al. (2023) urine LH test was used to confirm ovulation. Most of the studies followed their participants during one menstrual cycle. A study by Morris and Udry (1970) included more than three menstrual cycles. One cross-sectional study divided their participants by the fertile and non-fertile days of the cycle (Gueguen, 2012). In Table 18, the characteristics of the included studies are shown.

The gait (Table 19) was assessed by kinematic analysis in four of the included studies (Fink et al., 2012; Gueguen, 2012; Provost et al., 2008; Tagawa et al., 2023), by pedometers (Morris and Udry, 1970), or by TUG, TUG test with motor task consisting of carrying three glasses of water, and TUG test with a cognitive task which consists of counting backward from 100 by 3s or listing the names starting with the letter “A” (Ates and Unluer, 2020). In three studies, male observers evaluated the attractiveness of female participants’ gait on a short video during different menstrual cycle phases using a Likert scale. The male observers were not aware of the hormonal status of the female walkers (Fink et al., 2012; Gueguen, 2012; Provost et al., 2008).

Table 18. Sample characteristics of included studies and the methods of menstrual cycle monitoring

Authors	Country	Sample size	Age	Menstrual cycle monitoring	Phases comparison
Morris and Udry (1970)	USA	34	30	day of the cycle	every day during 1 to 3+ cycles
Provost et al. (2008)	Canada	19	22.10 ± 4.10	day of the cycle + ovulation test	late follicular phase (14–16 days before period) vs. luteal phase (5–7 days before period)
Fink et al. (2012)	Germany	48	24.75 ± 3.90	day of the cycle	late follicular phase (5 days before estimated ovulation) vs. luteal phase (days 19–24)
Gueguen (2012)	France	103	18–22	day of the cycle + ovulation test	cross-sectional study, high vs. low fertility risk groups
Ates and Unluer (2020)	Turkey	13	35.15 ± 7.19	day of the cycle + ovulation test	day 1–3 vs. ovulation vs. luteal phase (7 days after ovulation)
Tagawa et al. (2023)	Japan	16	college students	day of the cycle + ovulation test	follicular phase vs. ovulation

Table 19. Gait analysis characteristics of included studies

Authors	Gait analysis	Attractiveness evaluation
Morris and Udry (1970)	pedometer	
Provost et al. (2008)	kinematic analysis	35 men (18.80 ± 1.90), 6-point Likert scale
Fink et al. (2012)	kinematic analysis	100 men (22.99 ± 3.03), 7-point Likert scale
Gueguen (2012)	kinematic analysis	2 men, 5-point Likert scale
Ates and Unluer (2020)	TUG, TUG with motor and cognitive dual-tasks	
Tagawa et al. (2023)	kinematic analysis	

Table 20. Gait parameters and primary outcomes of included studies

Authors	Attractiveness	Gait speed	Navicular height	Pedometer units
Morris and Udry (1970)				↑ ovulation, ↑ beginning, and end of the cycle
Provost et al. (2008)	↑ luteal phase			
Fink et al. (2012)	↑ late follicular			
Gueguen (2012)	↑ high fertility risk	↓ high fertility risk ahead of the man		
Ates and Unluer (2020)		≈		
Tagawa et al. (2023)			≈	

↓ statistically significant decrease; ≈ no statistically significant change; ↑ statistically significant increase

In table 20, analyzed gait parameters, and the primary outcomes of the included studies are shown. Pedometer measurement analysis during 1 to 3+ consecutive menstrual cycles showed that female activity is increased around ovulation (Morris and Udry, 1970). No difference in longitudinal foot arch height during the gait was observed during different menstrual cycle phases (Tagawa et al., 2023). Similarly, no difference between analyzed menstrual cycle phases was observed by Ates and Unluer (2020) in the TUG test and TUG test with dual-tasks. In a study by Gueguen

(2012) studying nonverbal behavior, female participants were asked to walk ahead of a male confederate. The results show that the gait speed was slower in women at high fertility risk near ovulation when walking ahead of men compared to their low fertility risk peers (Gueguen, 2012). The attractiveness of female gait for male observers was reported to be higher near ovulation in two studies (Fink et al., 2012; Gueguen, 2012) and in the luteal phase in one study (Provost et al., 2008).

Discussion

A systematic review was performed to summarize the available literature focused on the effect of the menstrual cycle on gait. Six relevant articles were identified during the systematic review process. Their results show that the menstrual cycle can affect primarily the attractiveness of the gait.

Pedometer records showed that female physical activity increases near ovulation, similar to other female mammals, which perform higher general activity levels around oestrus (Morris and Udry, 1970). On the other hand, in female primates, no change in physical activity levels across the menstrual cycle was observed, suggesting no need to control the menstrual cycle phase when monitoring physical activity in female primates (Hunnell et al., 2007). A study by Doohan et al. (2023) on the general population of 881 adult women found that adverse menstrual symptoms during the period, such as abdominal cramps, lethargy, abdominal bloating, lower back pain, or heavy bleeding, which were reported as regular during menses in 90.5% of participants, were influential factors for avoidance or reduced performance in physical activity. Only 8.6% of participants reported that their menstrual symptoms do not affect physical activity engagement, showing that the likelihood of engagement in physical activity is lower when menstrual symptoms are present (Doohan et al., 2023).

A poor correlation between static and dynamic assessment of the foot arch was observed previously, and their separate interpretation was suggested (Scholz et al., 2017). In a study by Tagawa et al. (2023), no difference in longitudinal foot arch height during the gait was observed when comparing different phases of the menstrual cycle phases. However, in a static standing position, a significant decrease in navicular height during ovulation was described and possibly associated with the increased laxity of the plantar fascia during this phase of the menstrual cycle (Tagawa et al., 2023). Similarly, foot length was reported to significantly increase during ovulation compared to menstruation due to increased elasticity of plantar fascia (Petrofsky and Lee, 2015).

When comparing gait at different menstrual cycle phases, Gueguen (2012) observed a slower gait speed near ovulation when walking ahead of a physically attractive man. The attractiveness of female gait for male observers was reported to be higher near ovulation in two studies (Fink et al., 2012; Gueguen, 2012) and in the luteal phase in one study (Provost et al., 2008). It was hypothesized that subtle behavior cues are influenced by the menstrual cycle. When walking, women cannot use the classic non-verbal behaviors, e.g., a gaze or smile, but at their high fertility risk phase of the cycle, they use their gait to be noticed as more attractive (Gueguen, 2012). It is a question of whether the results of physical performance and gait during different phases of the menstrual cycle can be affected by the presence of a male researcher.

A study by Fink et al. (2012) described a more substantial effect of male observers' rating gait as more attractive near ovulation compared to the luteal phase than in dance moves. In a study by Provost et al. (2008), a more attractive gait for male observers was reported during the luteal phase compared to the late follicular phase near ovulation, and a discriminant function analysis of the gait kinematics used in their study was able to classify the gait at late follicular or luteal phases correctly. Authors of that study hypothesized that it could be a protective mechanism from sexual assault during the high fertility risk phase as gait pattern can be seen from a considerable distance (Provost et al., 2008) while women still can be attractive to people they choose to be with as men judge women's faces to be more attractive near ovulation (Roberts et al., 2004). In a more recent study by Catena et al. (2019), male observers rated early follicular female faces when estradiol levels are lower as less attractive than at the fertile phase near ovulation and luteal phase. However, they rated faces at ovulation and luteal phase equally attractive, which suggests limited male observers' capacity to detect ovulation cues (Catena et al., 2019).

No difference between analyzed menstrual cycle phases was observed by Ates and Unluer (2020) in the TUG test and TUG test with dual-tasks. However, a group of multiple sclerosis patients observed deteriorated results of the TUG test with dual-tasks during the early follicular phase (Ates and Unluer, 2020). Dual-tasks are common in daily life, e.g., when we have to verbally respond to our partner without stopping walking. In experimental settings, dual-tasks are used to investigate the effect of cognitive processing on motor behavior. The participant is usually asked to perform two tasks simultaneously. If the physical activity performance is inferior in quality or longer in time compared to single task measurement, the same resources in the cognitive and sensory-motor systems are needed for these tasks (Tramontano et al., 2017). Hormonal fluctuation across the menstrual cycle was observed to alter neurological and motor functions. During the late luteal phase, cognitive functions were observed to deteriorate compared to ovulation (Guven Yorgun and Ozakbas, 2019). Future studies are needed to assess changes in gait quality through gait analysis, not just by using the TUG test when performing dual-tasks across the menstrual cycle.

Limitations of this review

A low number of included studies, their focus on different gait parameters, and diverse methodological approaches are significant limitations for the generalization of the results. The various criteria of menstrual cycle phases definition and the difference in analyzed menstrual cycle phases constitute another limitation of this review.

Conclusions

To sum up, six studies were included in this review, and their results show that the menstrual cycle affects several aspects of gait. Included studies observed that the number of steps performed per day increases near ovulation and that the attractiveness of female gait for male observers changes across the cycle. No change in foot arch height during walking or in the TUG test and TUG test with the dual-task was observed. No study used force plates to analyze the effect of different menstrual cycle phases on dynamic gait parameters. Therefore, future research is needed to provide dynamic gait analysis from a kinanthropological point of view across the menstrual cycle.

The effect of the menstrual cycle on gait in situations with and without dual-task

The primary aim of this study was to analyze the effect of different phases of the menstrual cycle on gait patterns. Second, this research aimed to investigate the impact of dual-tasks on gait across the menstrual cycle to clarify the influence of estrogen variation on cognitive processing relationship to motor behavior.

Methods

Type of the study: experimental study

One menstrual cycle was followed in 28 participants: median age 23.00, x25 = 21.75, x75 = 28.25; median body mass was 61.50 kg (x25 = 60.00, x75 = 66.25); median body height was 169.50 cm (x25 = 165.00, x75 = 172.25); and median BMI was 22.05 (x25 = 21.16, x75 = 23.75) described in more detail in Chapter 2. All participants were measured three times during the study: on day 2 of the menstrual cycle (early follicular phase), within 48 h after ovulation confirmed by ovulation test kit (ovulation), and 7 days after ovulation (mid-luteal phase). The Research Ethics Committee of Masaryk University approved the study (EKV-2021-109).

Gait parameters were measured barefooted by Zebris platform (FDM GmbH, Munich, Germany; 149 × 54.2 cm) placed at the center of a custom-designed 10 m walkway surrounding the platform to provide a level walking surface. Participants were asked to walk at their natural speed. During each measuring session, participants were asked to (i) walk barefooted 6 times across the platform without any dual-task and (ii) walk barefooted 6 times across the platform with a mathematical task. Participants were asked to walk and simultaneously count backward from the number greater than 200, the researcher told her. Participants calculated by subtracting 7 from each number; (iii) walked barefooted 6 times across the platform with a motor task. Participants were asked to walk and simultaneously perform shirt buttoning; (iv) walk barefooted 6 times across the platform with a smartphone reading task (Figure 5).

Participants were asked to walk and simultaneously read an article from the Faculty of Sport Studies, Masaryk University webpage on their smartphone. Smartphone usage during walking is a common dual-task in daily life (Rubio Baranano et al., 2022).

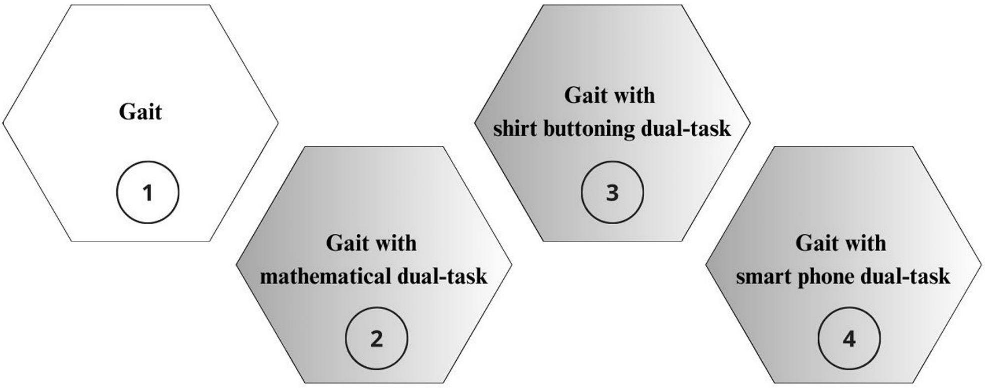

Figure 5. Gait measurement design

The following variables were obtained from the Zebris software:

- foot rotation (°), the angle between the longitudinal axis of the foot and the walking direction,
- stride length (cm), the distance between two heel contacts of the same foot,
- step width (cm), the distance between the right and left foot,
- stance phase (%), the phase of the gait cycle during which the foot is in contact with the ground,
- single limb support (%), the phase of the gait cycle during which only one foot has contact with the ground,
- swing phase (%), the phase of the gait cycle during which the foot has no contact with the ground,
- double stance phase (%), the sum of the phases during which both feet have contact with the ground,
- stride time (s), the time between heel contacts between the same foot,
- cadence (steps/min), step frequency,
- gait velocity (km/h), average gait speed during the measured interval,
- and maximal pressure at the forefoot, midfoot, and heel (N/cm^2), the average maximum values reached in the forefoot, midfoot, and heel.

Statistical analysis

Most of the variables did not meet the assumption of normal distribution tested by the Shapiro-Wilk test. The descriptive data are shown as median: lower quartile (x25) – upper quartile (x75). Friedman ANOVA was used to compare differences between analyzed phases of the menstrual cycle in gait without a dual-task, gait with a mathematical task, gait with a shirt buttoning task, and gait with a smartphone reading task. A Bonferroni correction was applied to an alpha level 0.05 to avoid Type I error rate (adjusted alpha was set at 0.004). Friedman ANOVA with Bonferroni correction (adjusted alpha was set on 0.004) was used to analyze the cognitive-motor interference (differences between gait without dual-task and dual-task) at analyzed menstrual cycle phases. Cohen's w was used to assess the effect size (< 0.30 small effect; 0.30–0.50 medium effect; > 0.50 large effect). The statistical analysis was performed using IBM SPSS Statistics (Armonk, NY, USA).

Results

Gait without dual-task

During the gait without the dual-task (Table 21), statistically significant differences between analyzed menstrual cycle phases were observed with a small effect by Cohen's w in stride length, which significantly increased at the mid-luteal phase compared to the early follicular phase ($p=0.002$) and ovulation ($p=0.022$), and cadence, which was significantly decreased at early follicular phase compared to ovulation ($p=0.017$) and mid-luteal phase ($p=0.009$).

Gait with a mathematical task

No statistically significant difference after Bonferroni correction in analyzed gait parameters was observed between the early follicular phase, ovulation, and mid-luteal phase when performing gait with the mathematical dual-task (Table 22).

Gait with shirt buttoning task

No statistically significant difference after Bonferroni correction in analyzed gait parameters was observed between the early follicular phase, ovulation, and mid-luteal phase when performing gait with shirt buttoning dual-task (Table 23).

Gait with smartphone task

No statistically significant difference in analyzed gait parameters was observed between the early follicular phase, ovulation, and mid-luteal phase when performing gait with a smartphone dual-task (Table 24).

Table 21. Descriptive characteristics of gait parameters without dual-task and results of statistical analysis

	Early follicular phase			Ovulation			Mid-luteal phase			
	Median	x25	x75	Median	x25	x75	Median	x25	x75	p-value
Foot rotation (°)	4.72	3.09	7.20	4.36	2.77	6.86	6.00	4.19	8.49	0.125
Stride length (cm)	123.64	119.41	128.73	125.76	119.83	133.81	129.57	121.53	132.96	0.001^{BC}
Step width (cm)	9.41	7.79	11.29	9.71	8.02	10.69	9.93	7.67	10.95	0.707
Stance phase (%)	64.29	62.60	65.15	63.20	62.75	64.38	63.12	61.54	64.00	0.053
Single limb support (%)	37.74	35.79	39.22	37.37	35.88	38.46	36.88	36.00	38.46	0.698
Swing phase (%)	35.71	34.85	37.40	36.80	35.62	37.26	37.33	36.54	39.29	0.053
Double stance phase (%)	26.36	24.58	28.95	25.96	24.13	27.59	25.00	22.86	26.85	0.048
Stride time (s)	1.13	1.06	1.20	1.10	1.07	1.16	1.08	1.05	1.14	0.006
Cadence (steps/min)	105.29	100.00	112.56	109.34	102.57	111.19	110.44	104.54	114.66	0.004^{AB}
Velocity (km/h)	4.09	3.77	4.30	3.93	3.60	4.35	3.88	3.74	4.15	0.876
Max. pressure forefoot (N/cm^2)	38.71	31.75	42.33	35.90	32.92	40.00	38.28	34.17	43.14	0.056
Max. pressure midfoot (N/cm^2)	12.63	8.88	17.40	13.04	10.38	15.83	11.26	9.75	16.25	0.446
Max. pressure heel (N/cm^2)	27.50	23.25	30.29	28.49	25.08	30.33	28.54	26.20	31.10	0.621

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 22. Descriptive characteristics of gait parameters mathematical task and results of statistical analysis

	Early follicular phase			Ovulation			Mid-luteal phase			
	Median	x25	x75	Median	x25	x75	Median	x25	x75	p-value
Foot rotation (°)	5.45	3.04	8.51	5.04	3.53	8.10	5.86	3.66	8.37	0.895
Stride length (cm)	125.34	114.05	135.50	126.18	114.05	132.11	127.03	116.87	132.96	0.078
Step width (cm)	9.75	8.25	11.71	9.58	8.81	11.41	9.80	8.49	11.87	0.772
Stance phase (%)	62.95	61.30	63.80	63.30	61.39	63.71	62.28	61.02	64.21	0.495
Single limb support (%)	36.77	35.66	38.14	37.04	35.93	38.18	37.72	35.79	38.98	0.157
Swing phase (%)	37.05	36.20	38.70	36.70	36.29	38.61	37.61	36.54	38.98	0.495
Double stance phase (%)	25.47	24.22	27.36	25.93	24.17	28.22	25.00	22.03	27.36	0.060
Stride time (s)	1.16	1.08	1.25	1.12	1.08	1.20	1.10	1.08	1.18	0.093
Cadence (steps/min)	103.51	95.10	111.81	108.44	99.45	111.24	109.09	101.70	111.81	0.155
Velocity (km/h)	3.90	3.73	4.18	3.92	3.51	4.16	4.10	3.65	4.29	0.633
Max. pressure forefoot (N/cm^2)	35.31	32.67	40.17	34.79	31.58	37.00	37.58	32.58	41.10	0.093
Max. pressure midfoot (N/cm^2)	13.29	10.06	16.67	14.25	11.56	17.79	13.08	10.75	15.25	0.045
Max. pressure heel (N/cm^2)	27.50	22.83	29.50	28.61	23.58	30.00	28.14	24.25	31.00	0.236

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 23. Descriptive characteristics of gait parameters shir buttoning task and results of statistical analysis

	Early follicular phase			Ovulation			Mid-luteal phase			
	Median	x25	x75	Median	x25	x75	Median	x25	x75	p-value
Foot rotation (°)	4.77	2.56	8.08	4.70	2.88	8.20	5.80	3.15	7.93	0.459
Stride length (cm)	122.80	114.33	134.65	120.68	114.96	127.88	124.49	117.43	132.96	0.226
Step width (cm)	10.56	8.72	11.39	10.56	8.59	12.10	9.92	8.64	12.08	0.495
Stance phase (%)	63.16	62.26	64.95	63.32	61.80	64.29	62.73	61.11	63.88	0.153
Single limb support (%)	37.50	35.71	39.18	37.63	35.77	38.75	37.27	36.12	38.89	0.478
Swing phase (%)	36.84	35.06	37.74	36.68	35.71	38.20	36.28	35.09	38.36	0.153
Double stance phase (%)	26.09	24.28	28.04	25.66	23.73	27.66	26.13	24.07	27.44	0.717
Stride time (s)	1.12	1.08	1.17	1.12	1.06	1.16	1.11	1.06	1.17	0.111
Cadence (steps/min)	107.79	101.77	111.81	106.52	103.45	113.21	108.12	102.60	113.21	0.156
Velocity (km/h)	4.18	3.81	4.37	3.82	3.45	4.19	4.05	3.56	4.35	0.936
Max. pressure forefoot (N/cm^2)	37.86	30.75	40.83	35.00	31.90	40.25	35.88	33.33	40.56	0.104
Max. pressure midfoot (N/cm^2)	12.67	9.58	16.33	12.83	9.92	16.83	13.00	9.50	15.42	0.999
Max. pressure heel (N/cm^2)	28.17	24.42	30.17	28.08	24.36	29.90	28.69	24.67	30.58	0.505

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 24. Descriptive characteristics of gait parameters smartphone task and results of statistical analysis

	Early follicular phase			Ovulation			Mid-luteal phase			
	Median	x25	x75	Median	x25	x75	Median	x25	x75	p-value
Foot rotation (°)	5.06	2.95	7.92	5.28	1.62	7.78	5.67	0.85	8.56	0.446
Stride length (cm)	122.80	114.33	127.03	125.34	117.72	133.81	117.72	115.18	133.38	0.682
Step width (cm)	9.80	8.81	12.36	10.96	8.06	12.64	10.82	8.15	12.24	0.999
Stance phase (%)	63.37	61.39	64.90	62.96	61.61	64.22	62.69	61.11	64.23	0.241
Single limb support (%)	37.29	34.92	38.60	37.60	35.43	38.33	37.31	35.77	38.89	0.812
Swing phase (%)	36.64	35.10	38.61	37.04	35.78	38.39	36.84	35.44	38.24	0.241
Double stance phase (%)	26.92	23.45	28.93	25.35	23.68	26.85	25.67	23.33	27.97	0.217
Stride time (s)	1.14	1.10	1.18	1.12	1.06	1.17	1.12	1.09	1.16	0.242
Cadence (steps/min)	105.26	101.71	109.16	107.65	102.77	111.84	107.57	103.93	109.76	0.144
Velocity (km/h)	4.29	3.92	4.62	4.03	3.56	4.28	4.11	3.92	4.43	0.091
Max. pressure forefoot (N/cm^2)	36.80	34.08	40.00	37.00	32.67	42.75	37.96	35.17	40.50	0.698
Max. pressure midfoot (N/cm^2)	12.42	9.42	14.58	12.58	10.42	16.29	12.11	10.83	13.83	0.659
Max. pressure heel (N/cm^2)	27.42	25.25	30.75	28.75	24.58	30.86	28.42	25.50	29.67	0.446

A significant difference between the early follicular phase and ovulation;
B significant difference between early follicular phase and mid-luteal phase;
C significant difference between ovulation and mid-luteal phase;
* medium and large effect of Cohen's w

Table 25. Results of statistical analysis of cognitive-motor interference during the menstrual cycle's early follicular phase, ovulation, and mid-luteal phase

	Early follicular phase		Ovulation		Mid-luteal phase	
	p-value	Cohen's w	p-value	Cohen's w	p-value	Cohen's w
Foot rotation (°)	0.444	0.034	0.634	0.021	0.320	0.045
Stride length (cm)	<.001^{C}	0.259	0.611	0.022	<.001^{C}	0.215
Step width (cm)	0.124	0.071	0.695	0.018	0.452	0.034
Stance phase (%)	0.987	0.002	0.002^{C}	0.181	0.875	0.009
Single limb support (%)	0.039	0.107	0.630	0.021	0.904	0.007
Swing phase (%)	0.987	0.002	0.002^{C}	0.181	0.875	0.009
Double stance phase (%)	0.120	0.075	0.769	0.014	0.786	0.014
Stride time (s)	0.007	0.154	0.014	0.131	0.082	0.086
Cadence (steps/min)	0.007	0.156	0.029	0.112	0.145	0.069
Velocity (km/h)	<.001^{C}	0.252	0.200	0.057	0.025	0.120
Max. pressure forefoot (N/cm^2)	0.008	0.146	0.654	0.020	0.032	0.113
Max. pressure midfoot (N/cm^2)	0.728	0.016	0.925	0.006	0.260	0.051
Max. pressure heel (N/cm^2)	0.947	0.005	0.970	0.003	0.631	0.022

A statistically significant difference between mathematical task and gait without dual-task;
B statistically significant difference between shirt buttoning task and gait without dual-task;
C statistically significant difference between smartphone task and gait without a dual-task;
* medium and large effect of Cohen's w

Cognitive-motor interference during different phases of menstrual cycle

Cognitive-motor interference was observed when comparing the gait without the dual-task and the gait with dual-task at different menstrual cycle phases with a small effect calculated by Cohen's w (Table 25). During the early follicular phase, the stride length significantly decreased with the smartphone task compared to gait without the dual-task ($p=0.009$). Similarly, gait velocity significantly decreased with smartphone task compared to gait without dual-task ($p=0.019$). At ovulation, the stance phase (%) was considerably shorter with the smartphone task compared to the gait without a dual-task ($p=0.027$), and the swing phase (%) was significantly longer with the smartphone task compared to the gait without a dual-task ($p=0.027$). At the mid-luteal phase, stride length was considerably shorter with a smartphone task than gait without a dual-task ($p=0.0001$).

Discussion

Dynamic gait parameters were analyzed at three phases of the menstrual cycle: the early follicular phase, ovulation, and mid-luteal phase. Data from gait without dual-tasks and gait with three different dual-tasks were obtained during each data measurement session. Results show that the gait without a dual-task is affected during the early follicular phase when cadence and stride length are significantly lower/shorter. No difference between analyzed menstrual cycle phases was observed in mathematical, shirt buttoning, or smartphone reading dual-task gait performance. Cognitive-motor interference was observed only with smartphone reading tasks during all cycle phases.

The systematic review results in this chapter show that the menstrual cycle can affect the natural gait pattern, especially its attractiveness for male observers. During the gait without a dual-task, cadence significantly decreased at the early follicular phase compared to ovulation and mid-luteal phase. Stride length was considerably shorter at the early follicular phase compared to the mid-luteal phase. Cadence and step length were lower/shorter in people with chronic low back pain compared to healthy controls previously (e.g., Vickers et al., 2017). Those gait alterations might be related to minimizing the excessive lumbosacral movement in persons with chronic low back pain (Vickers et al., 2017; Pakzad et al., 2016; Smith et al., 2022). Abdominal cramps, lethargy, abdominal bloating, lower back pain, or heavy bleeding are regular symptoms during menstruation in more than 90% of women (Doohan et al., 2023). Therefore, the lower cadence and shorter stride length observed in this study can result from an attempt to limit trunk motion as the menstrual pain response.

In young adults, the cost of dual-tasks when walking at a natural speed ranges between 0.99% (in a study by Lajoie et al., 1996) to 26.00% (in a study by Li et al., 2001 and Bock, 2008) as described in a systematic review by Beurskens and Bock (2012). A study by Lajoie et al. (1996) used a verbal response ("top") to an auditory stimulus as a dual-task to average the pace of walking, finding a non-significant difference. In a study by Li et al. (2001), a complex visuospatial decision task was used, showing significantly reduced gait velocity when walking with dual-tasks. A study by Bock (2008) used checking boxes of different colors on paper with a pen while walking, finding a significant decrease in gait velocity when performing the dual-task. The results of the current study show that the mathematical task and shirt buttoning task were not demanding enough to introduce gait changes in young women.

Smartphone reading requires a slower gait speed. During slower gait speed, the head motion is more regular and coupled with phone motion, resulting in a more stable retinal image allowing reading the screen (Rubio Baranano et al., 2021; Saraiva et al., 2023). The duration of stance and swing phases are influenced by gait speed (Iosa et al., 2019). In this study, a statistically significant decrease in walking speed with a smartphone dual-task compared to gait without a dual-task was observed only during the early follicular phase when menstrual-related pain occurs. A previous study suggests that pain leads to higher dual-task costs of gait and might affect the risk of falls in dual-task situations in daily living (Hamacher et al., 2016). Stride length decreased with smartphone reading dual-task during early follicular and mid-luteal phases. Shorter step/stride length improves stability. The center of mass is closer to the leading foot when the step length is shorter, reducing the risk of slip-related falls (Espy et al., 2010). Still, pedestrian-phone-related accidents have been increasing in the last few years. Up to 50% of persons (pedestrians and bike riders) involved in road injury reported using a phone within one minute before the injury happened (Ren et al., 2021). The estimated prevalence of distracted walking by pedestrians with smartphones is 25–40% (Rahim et al., 2023), highlighting the importance of distracted gait analysis.

Future studies comparing the gait parameters of women with and without primary dysmenorrhea would bring a more detailed insight into the gait alterations related to different symptoms related to menstruation.

Limitations of this study

This study has several limitations. Firstly, serum hormone levels were not measured. The ovulation was assessed using ovulation kits. Secondly, the repeated design of this study could affect the results of dual-task performance due to familiarization with the tasks.

Conclusions

In conclusion, this study shows that the gait without a dual-task is affected during the early follicular phase when cadence and stride length are significantly lower/shorter, probably due to menstrual-related discomfort and pain. Future studies focused on the gait alterations related to different symptoms related to menstruation would bring essential insight into this field. No difference between analyzed menstrual cycle phases was observed in mathematical, shirt buttoning, or smartphone reading dual-task gait performance. Notably, cognitive-motor interference was observed with smartphone reading tasks at all cycle phases, showing the importance of analyzing the distracted gait with a smartphone.

Does the age at menarche affect spatiotemporal and dynamic gait parameters?

Background

Traditionally, the effect of menarche on physical performance was researched in adolescent girls by comparing pre-menarche and post-menarche groups of similar age. Results of these studies suggest higher performance in the post-menarche group related to somatic growth (e.g., Athayde et al., 2021).

The association between the age at menarche and physical performance during adulthood is a recently introduced topic. Previous studies focusing on different age groups indicate a possible effect of the age at menarche on gait parameters. In perimenopausal women, later age at menarche was observed to be positively associated with walking speed (Le Noan-Lainé et al., 2023). In adolescent girls, earlier age at menarche was correlated with a broader base of support and valgus knee alignment during the gait (Froehle et al., 2017). Earlier age at menarche was associated with sarcopenia in a study by Fan et al. (2023). Sarcopenia may affect muscle strength and gait speed. The causal relationship analyzed by Mendelian randomization was observed between the age at menarche and gait speed (Fan et al., 2023). These results suggest deteriorated muscle function associated with earlier age at menarche (Fan et al., 2023; Le Noan-Lainé et al., 2023). On the other hand, no statistically significant effect of the age at menarche on gait speed was observed in perimenopausal women in a study by Ravi et al. (2020).

Feasibility studies aim to clarify any uncertainty about future research. Pilot studies are a subset of feasibility studies that aim to explore a research question and include future study research on a smaller scale. Performing feasibility research focused on testing the data collection, study protocol procedures, and outcomes use can reduce the research waste. The results of pilot studies should indicate whether to proceed with the main trial (Chan, 2019; Kristunas et al., 2019). This study aimed to test the methods of data collection of spatiotemporal and dynamic gait parameters (e.g., plantar pressures) in association with the age at menarche as only gait speed and kinematic gait parameters were researched in previous studies (Froehle et al., 2017; Le Noan-Lainé et al., 2023; Ravi et al., 2020).

Methods

Type of the study: pilot study

This study used data from 28 participants (median age 23.00, x25 = 21.75, x75 = 28.25), described in detail in Chapter 2. The study was approved by the Research Ethics Committee of Masaryk University, Brno, Czech Republic (EKV-2021-109). Participants reported their menarche age, body weight, and height were measured using InBody 720 and a stadiometer (SECA). Gait parameters were measured barefooted by the Zebris platform (FDM GmbH, Munich, Germany) at natural walking speed during the mid-luteal phase of the menstrual cycle. The measurement procedure is described in detail in Chapter 3.

The following variables were obtained from the Zebris software: foot rotation (°), stride length (cm), step width (cm), stance phase (%), single limb support (%), swing phase (%), double stance phase (%), stride time (s), cadence (steps/min), gait velocity (km/h) and maximal pressure at forefoot, midfoot and heel (N/cm^2).

Statistical analysis

The descriptive statistics are shown as median and lower quartile (x25) – upper quartile (x75) as most of the variables did not meet the assumption of normal distribution tested by the Shapiro-Wilk test. Spearman's rho was used to analyze the correlation between the age of menarche, body mass, body height, BMI, and gait parameters. Correlations were referred to according to Hopkins et al. (2009) as trivial (0–0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), nearly perfect (0.9) and perfect (1.0). Fisher's z-transformed Spearman rank correlation values were used to evaluate effect size. The statistical analysis was performed using IBM SPSS Statistics (Armonk, NY, USA). The level of statistical significance was set at alpha 0.05.

Results

The median age at menarche was 13.00 years (x25 = 12.00, x75 = 14.00), median body mass was 61.50 kg (x25 = 60.00, x75 = 66.25), median body height was 169.50 cm (x25 = 165.00, x75 = 172.25), and median BMI was 22.05 (x25 = 21.16, x75 = 23.75). Table 26 provides descriptive statistics of gait parameters and the results of Sperman's rho to show the correlation with age at menarche. No statistically significant correlation between age at menarche and body height (Spearman's rho = 0.344, moderate correlation; p = 0.079; Fisher's z = 0.359), body mass (Spearman's rho = 0.095; p = 0.638; Fisher's z = 0.095), and BMI (Spearman's rho = −0.009; p = 0.963; Fisher's z = −0.009) was observed. Age at menarche was significantly correlated with stride length (Spearman's rho = 0.470; p = 0.015; Fisher's z = 0.510), step width (Spearman's rho = 0.401; p = 0.038; Fisher's z = 0.425), and gait velocity (Spearman's rho = 0.420; p = 0.033; Fisher's z = 0.448). Small to large correlations were observed.

Table 26. Descriptive statistics of gait parameters and correlation with age at menarche, body height, body mass, and BMI

	Median	x25	x75	Age at menarche Spearman's rho	Body hight Spearman's rho	Body mass Spearman's rho	BMI Spearman's rho
Foot rotation (°)	6.00	4.19	8.49	0.111^{A}	0.080	0.172^{A}	0.117^{A}
Stride length (cm)	129.57	121.53	132.96	0.470^{*B}	0.561^{*C}	0.222^{A}	-0.139^{A}
Step width (cm)	9.93	7.67	10.95	0.401^{*B}	0.020	0.287^{A}	0.349^{B}
Stance phase (%)	63.12	61.54	64.00	−0.072	-0.135^{A}	−0.010	0.107^{A}
Single limb support (%)	36.88	36.00	38.46	0.378^{B}	0.198^{A}	-0.405^{*B}	-0.420^{*B}
Swing phase (%)	37.33	36.54	39.29	0.072	0.135^{A}	0.010	-0.107^{A}
Double stance phase (%)	25.00	22.86	26.85	-0.311^{B}	-0.328^{B}	0.276^{A}	0.426^{*B}
Stride time (sec)	1.08	1.05	1.14	0.002	0.230^{A}	-0.144^{A}	-0.181^{A}
Cadence (steps/min)	110.44	104.54	114.66	0.057	-0.213^{A}	0.143^{A}	0.176^{A}
Velocity (km/h)	3.88	3.74	4.15	0.420^{*B}	0.329^{B}	0.261^{A}	−0.014
Max. pressure forefoot (N/cm^2)	38.28	34.17	43.14	−0.005	0.138^{A}	0.098	0.031
Max. pressure midfoot (N/cm^2)	11.26	9.75	16.25	0.163^{A}	0.230^{A}	0.448^{*B}	0.318^{B}
Max. pressure heel (N/cm^2)	28.54	26.20	31.10	0.068	0.130^{A}	0.116^{A}	-0.100^{A}

* $p < 0.05$
A small (0.1–0.3), B moderate correlation (0.3–0.5), C large (0.5–0.7), D very large (0.7–0.9), E nearly perfect (0.9), and F perfect (1.0)

Additionally, Spearman's rho showed a statistically significant correlation between body height and stride length (Spearman's rho=0.561, large correlation; p=0.003; Fisher's z=0.635). Statistically significant correlation between body mass and single limb support (Spearman's rho=−0.405, moderate correlation; p=0.040; Fisher's z=−0.430) and maximum pressure at midfoot (Spearman's rho=0.448, moderate correlation; p=0.019; Fisher's z=0.482) were observed. A statistically significant correlation was observed for BMI with single limb support (Spearman's rho=−0.420, moderate correlation; p=0.033; Fisher's z=−0.448) and double stance phase (Spearman's rho=0.426, moderate correlation; p=0.030; Fisher's z=0.455).

Discussion

This study focused on the spatiotemporal and dynamic gait parameters associated with the menarche age. Similarly to previous studies, gait speed was significantly correlated with the age at menarche (Froehle et al., 2017; Le Noan-Lainé et al., 2023; Fan et al., 2023). Furthermore, stride length and step width were observed to correlate with the age at menarche.

Similarly to the results of this pilot study, a previous study by Le Noan-Lainé et al. (2023) describes a positive association between the age at menarche and fast walking speed in adult peri- and post-menopausal women, suggesting a persisting effect of the age at menarche on gait in adulthood. Also, in a study by Fan et al. (2023), women with later menarche were observed to have faster walking speeds.

Age at menarche is determined by multiple factors such as heredity, hormone metabolism, socioeconomic background, physical activity, and lifestyle (Fan et al., 2023). Menarche occurs two to three years after puberty onset and six months after the peak height velocity is achieved (Barros et al., 2019; Karapanou and Papadimitriou, 2010). In adult women, the age at menarche reflects the cumulative exposure to estrogen, which was reported to inhibit muscle growth previously (Fan et al., 2023). In post-menopausal women, higher estradiol levels were associated with slow walking speed, weak grip strength, weight loss, fatigue, and low physical activity (Carcaillon et al., 2012). Furthermore, higher age at menarche was associated with lower BMI, bone mass density, and fat mass during adulthood (Ravi et al., 2023; Yang et al., 2023). The elevated gonadal hormones and adverse psychological outcomes were described as the possible mediators in the association between the age at menarche and adult BMI (Gill et al., 2018).

Similarly to the results of this study, anthropometric characteristics were previously associated with gait parameters. Step length was observed to be affected by age, body height, and body fat mass (e.g., Park et al., 2022). Flat foot, manifested by increased pressure on the midfoot, was associated with higher body mass and BMI (Rosende-Bautista et al., 2021; Shen et al., 2023; Zhao et al., 2020). Single limb support and double stance phases were previously correlated with body mass and BMI (Meng et al., 2017). The shorter single limb support phase and prolonged double stance phase are characteristic of the gait of obese adults as it can be more challenging for them to control the movement of the center of mass during the single limb support phase due to excessive body mass on lower joints (Dufek et al., 2012; Meng et al., 2017).

Menarche affects growth as it is linked to the onset of epiphyseal closure. Accordingly, a study by Froehle et al. (2017) reported shorter stature and shorter segment lengths in participants with earlier menarche. Additionally, in their study, an increased base of support and valgus knee alignment, which may lead to a higher risk for sports-related knee injuries, were observed to correlate with earlier age at menarche (Froehle et al., 2017). Future studies can include more age groups of women to provide more comprehensive information about the effect of age at menarche on gait.

Limitations of this study

There is a need for caution when generalizing the results. Main limitations of this pilot study consist of a low number of participants, and using basic statistics. Future studies on large samples using Mendelian randomization will show the potential causal effect between the age at menarche and gait parameters.

Conclusions

In conclusion, this pilot study confirmed the correlation between the age at menarche and gait parameters, as reported in previous studies. Results of this study suggest that future studies focused on the effect of age at menarche on gait can concentrate primarily on gait speed and spatiotemporal gait characteristics.

Chapter conclusions

RQ4: How do different menstrual cycle phases affect spatiotemporal and dynamic gait parameters?

Little is known about the effect of the different phases of the menstrual cycle on gait. A systematic review of the influence of the menstrual cycle on gait was performed according to PRISMA guidelines. By the databases search, 1472 studies were identified. After the screening process, 6 studies were included in the systematic review. Their results show that the number of steps performed per day increases near ovulation (Morris and Udry, 1970) and that the attractiveness of female gait for male observers increases during ovulation and luteal phase (Fink et al., 2012; Gueguen, 2012; Provost et al., 2008). No change in foot arch height during walking (Tagawa et al., 2023) or in the TUG test (Ates and Unluer, 2020) was observed.

An experimental study on the effect of different menstrual cycle phases on spatiotemporal and dynamic gait parameters was included in the second part of this chapter. In the experimental study, 28 women completed gait measurements three times during their menstrual cycle (at the early follicular phase, ovulation, and mid-luteal phase). Results showed that the gait is affected during the early follicular phase when cadence and stride length were significantly lower/shorter, probably as a result from an attempt to limit trunk motion due to the menstrual discomfort and pain. Furthermore, stride length was significantly shorter during the ovulation.

To conclude, spatiotemporal gait parameters were observed to be affected by the early follicular phase and ovulation. No change in plantar pressure or foot arch during the gait was observed. These findings highlight the need for future studies focused on the gait alterations related to different menstrual symptoms.

RQ5: How do different menstrual cycle phases affect spatiotemporal and dynamic gait parameters in situation with dual-task?
A previous study by Ates and Unluer (2020) reported no difference between different menstrual cycle phases in the TUG test with motor dual-task consisting of carrying three glasses of water, and TUG test with a cognitive dual-task which consists of counting backward from 100 by 3s or listing the names starting with the letter "A" in healthy women (n = 13). However, a group of multiple sclerosis patients (n = 14) observed deteriorated results of the TUG test with dual-tasks during the early follicular phase (Ates and Unluer, 2020).

An experimental study on the effect of dual-task on spatiotemporal and dynamic gait parameters across the menstrual cycle was included in the second part of this chapter. In the experimental study, 28 women completed gait measurements with mathematical, shirt buttoning, and smartphone reading dual-tasks three times during their menstrual cycle (at the early follicular phase, ovulation, and mid-luteal phase). Statistically significant deterioration with smartphone reading dual-task was observed in all analyzed phases of the cycle compared to gait in situation without dual-task.

To conclude, no effect of menstrual cycle phases on gait with dual-task was observed. Still, the results show the importance of analyzing the distracted gait with a smartphone.

RQ6: How does the age at menarche influence spatiotemporal and dynamic gait parameters in adult women?
In adult women, later age at menarche was observed to be positively associated with walking speed (Fan et al., 2023; Le Noan-Lainé et al., 2023). On the other hand, no statistically significant effect of the age at menarche on gait speed was observed in perimenopausal women in a previous study by Ravi et al. (2020).

In a pilot study described in this chapter, spatiotemporal and dynamic gait parameters were measured in 28 women who reported their age at menarche. The results show that the age at menarche was significantly correlated with stride length, step width, and gait velocity.

To conclude, spatiotemporal gait parameters were observed to be affected by the age at menarche. Correlations between the age at menarche and dynamic gait parameters did not reach statistical significance. These findings suggest that future studies focused on the effect of age at menarche on gait can concentrate primarily on spatiotemporal gait characteristics.

Summary

Little is known about the effect of the menstrual cycle on women's body movement. The fluctuation of estrogen and progesterone affects general joint and ligament laxity, resulting in differences in the incidence of injury at different menstrual cycle phases. These findings highlight the importance of a detailed knowledge of postural stability fluctuations across the menstrual cycle. This book summarized the current knowledge about the effect of the menstrual cycle on postural stability and gait following the current rigorous standards of academic work. It presented possible directions for future research in this field. Postural stability is a crucial factor for balance, risk for falls, and consequent risk of injuries, and gait is the basic locomotor pattern in humans. These two fundamental elements of human movement were detailly analyzed in this book to enhance the knowledge about the effect of different menstrual cycle phases on motor behavior.

Systematic reviews are considered the "gold standard" for searching, appraising, and synthesizing the available literature related to a specific research question. Therefore, this method was used when presenting the current literature on the effect of the menstrual cycle on postural stability and gait. Twenty-two studies were included in the systematic review focused on the influence of the menstrual cycle on postural stability. Six of the included studies observed no significant difference in postural stability across the menstrual cycle, and sixteen showed that the menstrual cycle affects both static and dynamic postural stability. Most of these studies observed deteriorated results during the early follicular phase in dynamic postural stability and at ovulation in static postural stability. Six studies were included in the systematic review on the effect of the menstrual cycle on gait, and their results show that the menstrual cycle affects several aspects of gait. Included studies observed that the number of steps performed per day increases near ovulation and that the attractiveness of female gait for male observers changes across the cycle. No change in foot arch height during walking or in the TUG test and TUG test with the dual-task was observed. None of the included studies used dynamic gait analysis using force plates to analyze the effect of different menstrual cycle phases on dynamic gait parameters.

The findings from performed systematics reviews were confirmed and elaborated by the original data on the effect of the menstrual cycle on postural stability and gait presented in this book. At ovulation, postural stability was observed to deteriorate, probably due to increased joint laxity. During all analyzed phases of the menstrual cycle, significant deterioration of CoP path and CoP average velocity was observed when performing mathematical, shirt buttoning, and smartphone reading dual-tasks.

The gait was also affected by the menstrual cycle. During the early follicular phase, cadence and stride length were significantly lower/shorter, probably due to menstrual-related discomfort and pain. The cognitive-motor interference was observed with smartphone reading tasks at all phases of the cycle, showing the importance of analyzing the distracted gait with a smartphone as it is related to the risk of falls in daily situations.

The last part of this book presented a pilot study on the effect of age at menarche on postural stability and gait. Its findings did not identify a clear association between the age at menarche and postural stability parameters, as only small to moderate correlations were observed. Future studies on large samples will show the potential causal effect between the age at menarche, body height, body mass, and postural stability. A moderate correlation was observed between the gait speed, stride length, step width, and the age of menarche, as reported previously. Future studies focused on the effect of age at menarche on movement will bring a more detailed insight into the cumulative exposure to estrogen on women's movement.

Increasing the knowledge about the underlying mechanisms linking female physiology to movement biomechanics and performance holds implications for research and practical applications in the health sciences and sports. In the future, women could benefit from injury prevention programs tailored to specific menstrual cycle phases, optimizing performance by implementing targeted strategies corresponding to specific menstrual cycle phases and improving communication about the menstrual cycle with the sport-related personnel.

References

Abt, J. P., Sell, T. C., Laudner, K. G., McCrory, J. L., Loucks, T. L., Berga, S. L., & Lephart, S. M. (2007). Neuromuscular and biomechanical characteristics do not vary across the menstrual cycle. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA*, *15*(7), 901–907. https://doi.org/10.1007/s00167-007-0302-3

Abu Alwafa, R., Badrasawi, M., & Haj Hamad, R. (2021). Prevalence of premenstrual syndrome and its association with psychosocial and lifestyle variables: a cross-sectional study from Palestine. *BMC women's health*, *21*(1), 233. https://doi.org/10.1186/s12905-021-01374-6

ACOG Committee Opinion No. 651: Menstruation in Girls and Adolescents: Using the Menstrual Cycle as a Vital Sign. (2015). *Obstetrics and gynecology*, *126*(6), e143–e146. https://doi.org/10.1097/AOG.0000000000001215

Agmon, M., Belza, B., Nguyen, H. Q., Logsdon, R. G., & Kelly, V. E. (2014). A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults. *Clinical interventions in aging*, *9*, 477–492. https://doi.org/10.2147/CIA.S54978

Ahrari, K., Omolaoye, T. S., Goswami, N., Alsuwaidi, H., & du Plessis, S. S. (2022). Effects of space flight on sperm function and integrity: A systematic review. *Frontiers in physiology*, *13*, 904375. https://doi.org/10.3389/fphys.2022.904375

Al-Makhalas, A., Abualait, T., Ahsan, M., Abdulaziz, S., & Al Muslem, W. (2023). A gender based comparison and correlation of spatiotemporal gait parameters and postural stability. *Acta biomedica : Atenei Parmensis*, *94*(2), e2023057. https://doi.org/10.23750/abm.v94i2.13602

Andreeva, A., Melnikov, A., Skvortsov, D., Akhmerova, K., Vavaev, A., Golov, A., Draugelite, V., Nikolaev, R., Chechelnickaia, S., Zhuk, D., Bayerbakh, A., Nikulin, V., & Zemková, E. (2021). Postural stability in athletes: The role of sport direction. *Gait & posture*, *89*, 120–125. https://doi.org/10.1016/j.gaitpost.2021.07.005

Angyán, L., Téczely, T., & Angyán, Z. (2007). Factors affecting postural stability of healthy young adults. *Acta physiologica Hungarica, 94*(4), 289–299. https://doi.org/10.1556/APhysiol.94.2007.4.1

Arendt, E. A., Bershadsky, B., & Agel, J. (2002). Periodicity of noncontact anterior cruciate ligament injuries during the menstrual cycle. *The journal of gender-specific medicine : JGSM : the official journal of the Partnership for Women's Health at Columbia*, *5*(2), 19–26.

AteŞ, Y., & ÜnlÜer, N. Ö. (2020). An investigation of knee position sense, balance, and dual-task performance in different phases of menstrual cycle in females with multiple sclerosis: a pilot study. *Multiple sclerosis and related disorders*, *44*, 102235. https://doi.org/10.1016/j.msard.2020.102235

Athayde, M. S. D. S., Kons, R. L., Fukuda, D. H., & Detanico, D. (2021). Body Size Measurements and Physical Performance of Youth Female Judo Athletes with Differing Menarcheal Status. *International journal of environmental research and public health, 18*(23), 12829. https://doi.org/10.3390/ijerph182312829

Aydın, E., Metin Tellioğlu, A., Kurt Ömürlü, İ., Polat, G., & Turan, Y. (2017). Postural balance control in women with generalized joint laxity. *Turkish journal of physical medicine and rehabilitation*, *63*(3), 259–265. https://doi.org/10.5606/tftrd.2017.160

Barbieri R. L. (2014). The endocrinology of the menstrual cycle. *Methods in molecular biology (Clifton, N.J.)*, *1154*, 145–169. https://doi.org/10.1007/978-1-4939-0659-8_7

Barros, B. S., Kuschnir, M. C. M. C., Bloch, K. V., & Silva, T. L. N. D. (2019). ERICA: age at menarche and its association with nutritional status. *Jornal de pediatria*, *95*(1), 106–111. https://doi.org/10.1016/j.jped.2017.12.004

Bayot, M., Dujardin, K., Tard, C., Defebvre, L., Bonnet, C. T., Allart, E., & Delval, A. (2018). The interaction between cognition and motor control: A theoretical framework for dual-task interference effects on posture, gait initiation, gait and turning. *Neurophysiologie clinique = Clinical neurophysiology, 48*(6), 361–375. https://doi.org/10.1016/j.neucli.2018.10.003

Bernard-Demanze, L., Dumitrescu, M., Jimeno, P., Borel, L., & Lacour, M. (2009). Age-related changes in posture control are differentially affected by postural and cognitive task complexity. *Current aging science*, *2*(2), 139–149.

Beurskens, R., & Bock, O. (2012). Age-related deficits of dual-task walking: a review. *Neural plasticity*, 131608. https://doi.org/10.1155/2012/131608

Beynnon, B. D., Johnson, R. J., Braun, S., Sargent, M., Bernstein, I. M., Skelly, J. M., & Vacek, P. M. (2006). The relationship between menstrual cycle phase and anterior cruciate ligament injury: a case-control study of recreational alpine skiers. *The American journal of sports medicine*, *34*(5), 757–764. https://doi.org/10.1177/0363546505282624

Birch, I., Birch, T., & Bray, D. (2016). The identification of emotions from gait. *Science & justice : journal of the Forensic Science Society*, *56*(5), 351–356. https://doi.org/10.1016/j.scijus.2016.05.006

Bloom, M. S., Perkins, N. J., Sjaarda, L. A., Mumford, S. L., Ye, A., Kim, K., Kuhr, D. L., Nobles, C. J., Connell, M. T., & Schisterman, E. F. (2021). Adiposity is associated with anovulation independent of serum free testosterone: A prospective cohort study. *Paediatric and perinatal epidemiology*, *35*(2), 174–183. https://doi.org/10.1111/ppe.12726

Bock O. (2008). Dual-task costs while walking increase in old age for some, but not for other tasks: an experimental study of healthy young and elderly persons. *Journal of neuroengineering and rehabilitation, 5*, 27. https://doi.org/10.1186/1743-0003-5-27

Boland, A., Cherry, G., & Dickson, R. (2017). *Doing a systematic review : a student's guide.* 2nd edition. SAGE.

Bosch, K., Nagel, A., Weigend, L., & Rosenbaum, D. (2009). From "first" to "last" steps in life-pressure patterns of three generations. *Clinical biomechanics (Bristol, Avon)*, *24*(8), 676–681. https://doi.org/10.1016/j.clinbiomech.2009.06.001

Briden L. (2015). *Period repair manual : natural treatment for better hormones and better periods*. Greenpeak Publishing.

Bruening, D. A., Frimenko, R. E., Goodyear, C. D., Bowden, D. R., & Fullenkamp, A. M. (2015). Sex differences in whole body gait kinematics at preferred speeds. *Gait & posture*, *41*(2), 540–545. https://doi.org/10.1016/j.gaitpost.2014.12.011

Bruinvels, G., Burden, R. J., McGregor, A. J., Ackerman, K. E., Dooley, M., Richards, T., & Pedlar, C. (2017). Sport, exercise and the menstrual cycle: where is the research?. *British journal of sports medicine*, *51*(6), 487–488. https://doi.org/10.1136/bjsports-2016-096279

Bruinvels, G., Burden, R., Brown, N., Richards, T., & Pedlar, C. (2016). The Prevalence and Impact of Heavy Menstrual Bleeding (Menorrhagia) in Elite and Non-Elite Athletes. *PloS one*, *11*(2), e0149881. https://doi.org/10.1371/journal.pone.0149881

Bryant, E. C., Trew, M. E., Bruce, A. M., Kuisma, R. M., & Smith, A. W. (2005). Gender differences in balance performance at the time of retirement. *Clinical biomechanics (Bristol, Avon), 20*(3), 330–335. https://doi.org/10.1016/j.clinbiomech.2004.11.006

Cable, J. K., & Grider, M. H. (2023). Physiology, Progesterone. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK558960/

Carcaillon, L., García-García, F. J., Tresguerres, J. A., Gutiérrez Avila, G., Kireev, R., & Rodríguez-Mañas, L. (2012). Higher levels of endogenous estradiol are associated with frailty in postmenopausal women from the toledo study for healthy aging. *The Journal of clinical endocrinology and metabolism*, *97*(8), 2898–2906. https://doi.org/10.1210/jc.2012-1271

Carmichael, M. A., Thomson, R. L., Moran, L. J., & Wycherley, T. P. (2021). The Impact of Menstrual Cycle Phase on Athletes' Performance: A Narrative Review. *International journal of environmental research and public health*, *18*(4), 1667. https://doi.org/10.3390/ijerph18041667

Carneiro, J. A., Santos-Pontelli, T. E., Vilaça, K. H., Pfrimer, K., Colafêmina, J. F., Carneiro, A. A., & Ferriolli, E. (2012). Obese elderly women exhibit low postural stability: a novel three-dimensional evaluation system. *Clinics (Sao Paulo, Brazil)*, *67*(5), 475–481. https://doi.org/10.6061/clinics/2012(05)12

Catena, T. M., Simmons, Z. L., & Roney, J. R. (2019). Do women's faces become more attractive near ovulation?. *Hormones and behavior*, *115*, 104560. https://doi.org/10.1016/j.yhbeh.2019.07.008

Chan C. L. (2019). A website for pilot and feasibility studies: giving your research the best chance of success. *Pilot and feasibility studies, 5*, 122. https://doi.org/10.1186/s40814-019-0522-6

Chantler, I., Mitchell, D., & Fuller, A. (2009). Diclofenac potassium attenuates dysmenorrhea and restores exercise performance in women with primary dysmenorrhea. *The journal of pain*, *10*(2), 191–200. https://doi.org/10.1016/j.jpain.2008.08.006

Chidi-Ogbolu, N., & Baar, K. (2019). Effect of Estrogen on Musculoskeletal Performance and Injury Risk. *Frontiers in physiology*, *9*, 1834. https://doi.org/10.3389/fphys.2018.01834

Cho, S. H., Park, J. M., & Kwon, O. Y. (2004). Gender differences in three dimensional gait analysis data from 98 healthy Korean adults. *Clinical biomechanics (Bristol, Avon)*, *19*(2), 145–152. https://doi.org/10.1016/j.clinbiomech.2003.10.003

Choy, N. L., Brauer, S., & Nitz, J. (2003). Changes in postural stability in women aged 20 to 80 years. *The journals of gerontology. Series A, Biological sciences and medical sciences*, *58*(6), 525–530. https://doi.org/10.1093/gerona/58.6.m525

Costanzo, L. S. *Physiology*. 5th ed. Philadelphia: Saunders/Elsevier, 2014. ISBN 978-1-4557-0847-5.

Cowley, E. S., Moore, S. R., Olenick, A. A., & McNulty, K. L. (2024). "Invisible Sportswomen 2.0"—Digging Deeper Into Gender Bias in Sport and Exercise Science Research: Author Gender, Editorial Board Gender, and Research Quality. *Women in Sport and Physical Activity Journal*, *32*(1), 1–8. https://doi.org/10.1123/wspaj.2023-0039

Cowley, E. S., Olenick, A. A., McNulty, K. L., & Ross, E. Z. (2021). "Invisible Sportswomen": The Sex Data Gap in Sport and Exercise Science Research. *Women in Sport and Physical Activity Journal*, *29*(2), 146–151.

Darlington, C. L., Ross, A., King, J., & Smith, P. F. (2001). Menstrual cycle effects on postural stability but not optokinetic function. *Neuroscience letters*, *307*(3), 147–150. https://doi.org/10.1016/s0304-3940(01)01933-4

Dault, M. C., Frank, J. S., & Allard, F. (2001). Influence of a visuo-spatial, verbal and central executive working memory task on postural control. *Gait & posture*, *14*(2), 110–116. https://doi.org/10.1016/s0966-6362(01)00113-8

Decloe, M. D., Meeuwisse, W. H., Hagel, B. E., & Emery, C. A. (2014). Injury rates, types, mechanisms and risk factors in female youth ice hockey. *British journal of sports medicine*, *48*(1), 51–56. https://doi.org/10.1136/bjsports-2012-091653

Denos, M., Sun, Y. Q., Jiang, L., Brumpton, B. M., & Mai, X. M. (2023). Age at Menarche, age at Natural Menopause, and Risk of Lung and Colorectal Cancers: A Mendelian Randomization Study. *Journal of the Endocrine Society, 7*(8), bvad077. https://doi.org/10.1210/jendso/bvad077

DeVilbiss, E. A., Stanford, J. B., Mumford, S. L., Sjaarda, L. A., Kim, K., Zolton, J. R., Perkins, N. J., & Schisterman, E. F. (2021). Sporadic anovulation is not an important determinant of becoming pregnant and time to pregnancy among eumenorrheic women: A simulation study. *Paediatric and perinatal epidemiology*, *35*(1), 143–152. https://doi.org/10.1111/ppe.12692

Di, S., Ning, M., Yunfei, L., Jiajia, D., Panliang, Z., Shan, C., Ziyue, C., Jun, M., & Yi, S. (2024). Association between BMI and age at menarche or spermarche among both sexes: Findings from six successive national surveys in China. *Journal of global health*, *14*, 04099. https://doi.org/10.7189/jogh.14.04099

Dickerson, L. M., Mazyck, P. J., & Hunter, M. H. (2003). Premenstrual syndrome. *American family physician*, *67*(8), 1743–1752.

Dingenen, B., Staes, F. F., & Janssens, L. (2013). A new method to analyze postural stability during a transition task from double-leg stance to single-leg stance. *Journal of biomechanics*, *46*(13), 2213–2219. https://doi.org/10.1016/j.jbiomech.2013.06.026

Doohan, M. A., King, N., White, M. J., & Stewart, I. B. (2023). Trends in menstrual cycle symptoms, physical activity avoidance, and hormonal contraceptive use in a general population of adult women. *Sexual & reproductive healthcare : official journal of the Swedish Association of Midwives*, *36*, 100853. https://doi.org/10.1016/j.srhc.2023.100853

Downs, S. H., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of epidemiology and community health*, *52*(6), 377–384. https://doi.org/10.1136/jech.52.6.377

Dufek, J. S., Currie, R. L., Gouws, P. L., Candela, L., Gutierrez, A. P., Mercer, J. A., & Putney, L. G. (2012). Effects of overweight and obesity on walking characteristics in adolescents. *Human movement science*, *31*(4), 897–906. https://doi.org/10.1016/j.humov.2011.10.003

Durante, K. M., Li, N. P., & Haselton, M. G. (2008). Changes in women's choice of dress across the ovulatory cycle: naturalistic and laboratory task-based evidence. *Personality & social psychology bulletin*, *34*(11), 1451–1460. https://doi.org/10.1177/0146167208323103

Elks, C. E., Ong, K. K., Scott, R. A., van der Schouw, Y. T., Brand, J. S., Wark, P. A., Amiano, P., Balkau, B., Barricarte, A., Boeing, H., Fonseca-Nunes, A., Franks, P. W., Grioni, S., Halkjaer, J., Kaaks, R., Key, T. J., Khaw, K. T., Mattiello, A., Nilsson, P. M., Overvad, K., … InterAct Consortium (2013). Age at menarche and type 2 diabetes risk: the EPIC-InterAct study. *Diabetes care, 36*(11), 3526–3534. https://doi.org/10.2337/dc13-0446

Elliott-Sale, K. J., Minahan, C. L., de Jonge, X. A. K. J., Ackerman, K. E., Sipilä, S., Constantini, N. W., Lebrun, C. M., & Hackney, A. C. (2021). Methodological Considerations for Studies in Sport and Exercise Science with Women as Participants: A Working Guide for Standards of Practice for Research on Women. *Sports medicine (Auckland, N.Z.)*, *51*(5), 843–861. https://doi.org/10.1007/s40279-021-01435-8

Elvan, A., Kirişçi, S., Başer Seçer, M., Çeliker Tosun, Ö., & Tosun, G. (2024). Does Phase of the Menstrual Cycle Affect Balance and Postural Control?. *Journal of motor behavior*, *56*(1), 69–77. https://doi.org/10.1080/00222895.2023.2241403

Emami, F., Kordi Yoosefinejad, A., & Motealleh, A. (2019). Comparison of static and dynamic balance during early follicular and ovulation phases in healthy women, using simple, clinical tests: a cross sectional study. *Gynecological endocrinology : the official journal of the International Society of Gynecological Endocrinology*, *35*(3), 257–260. https://doi.org/10.1080/09513590.2018.1519788

Encyclopedia Britannica: https://www.britannica.com/science/estrus (15.8.2023)

Erbil, N., & Yücesoy, H. (2023). Premenstrual syndrome prevalence in Turkey: a systematic review and meta-analysis. *Psychology, health & medicine*, *28*(5), 1347–1357. https://doi.org/10.1080/13548506.2021.2013509

Ericksen, H., & Gribble, P. A. (2012). Sex differences, hormone fluctuations, ankle stability, and dynamic postural control. *Journal of athletic training*, *47*(2), 143–148. https://doi.org/10.4085/1062-6050-47.2.143

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., Kim, J. S., Alvarado, M., & Kramer, A. F. (2007). Training-induced functional activation changes in dual-task processing: an FMRI study. *Cerebral cortex (New York, N.Y. : 1991)*, *17*(1), 192–204. https://doi.org/10.1093/cercor/bhj137

Espy, D. D., Yang, F., Bhatt, T., & Pai, Y. C. (2010). Independent influence of gait speed and step length on stability and fall risk. *Gait & posture, 32*(3), 378–382. https://doi.org/10.1016/j.gaitpost.2010.06.013

Fan, W., Gu, P., Pu, B., Yue, D., Xin, Q., Zheng, X., Zeng, Z., & Fan, S. (2023). Bidirectional two-sample mendelian randomization analysis identifies causal associations between age at menarche and sarcopenia-related traits. *Genes & genomics, 45*(8), 1085–1095. https://doi.org/10.1007/s13258-023-01415-4

Findlay, R. J., Macrae, E. H. R., Whyte, I. Y., Easton, C., & Forrest Née Whyte, L. J. (2020). How the menstrual cycle and menstruation affect sporting performance: experiences and perceptions of elite female rugby players. *British journal of sports medicine*, *54*(18), 1108–1113. https://doi.org/10.1136/bjsports-2019-101486

Fink, B., Hugill, N., & Lange, B. P. (2012). Women‘s body movements are a potential cue to ovulation. *Personality and Individual Differences, 53*(6), 759–763. https://doi.org/10.1016/j.paid.2012.06.005

Fridén, C., Ramsey, D. K., Backstrom, T., Benoit, D. L., Saartok, T., & Lindén Hirschberg, A. (2005). Altered postural control during the luteal phase in women with premenstrual symptoms. *Neuroendocrinology*, *81*(3), 150–157. https://doi.org/10.1159/000086592

Fritz, N. E., Cheek, F. M., & Nichols-Larsen, D. S. (2015). Motor-Cognitive Dual-Task Training in Persons With Neurologic Disorders: A Systematic Review. *Journal of neurologic physical therapy : JNPT*, *39*(3), 142–153. https://doi.org/10.1097/NPT.0000000000000090

Froehle, A. W., Grannis, K. A., Sherwood, R. J., & Duren, D. L. (2017). Relationships Between Age at Menarche, Walking Gait Base of Support, and Stance Phase Frontal Plane Knee Biomechanics in Adolescent Girls. *PM & R : the journal of injury, function, and rehabilitation*, *9*(5), 444–454. https://doi.org/10.1016/j.pmrj.2016.07.532

Gangestad, S. W., & Thornhill, R. (2008). Human oestrus. *Proceedings. Biological sciences*, *275*(1638), 991–1000. https://doi.org/10.1098/rspb.2007.1425

Ghai, S., Ghai, I., & Effenberg, A. O. (2017). Effects of dual-tasks and dual-task training on postural stability: a systematic review and meta-analysis. *Clinical interventions in aging, 12*, 557–577. https://doi.org/10.2147/CIA.S125201

Gildersleeve, K. A., Haselton, M. G., Larson, C. M., & Pillsworth, E. G. (2012). Body odor attractiveness as a cue of impending ovulation in women: evidence from a study using hormone-confirmed ovulation. *Hormones and behavior*, *61*(2), 157–166. https://doi.org/10.1016/j.yhbeh.2011.11.005

Gill, D., Brewer, C. F., Del Greco M, F., Sivakumaran, P., Bowden, J., Sheehan, N. A., & Minelli, C. (2018). Age at menarche and adult body mass index: a Mendelian randomization study. *International journal of obesity (2005), 42*(9), 1574–1581. https://doi.org/10.1038/s41366-018-0048-7

Gimunová, M., Bozděch, M., Skotáková, A., Grün, V., & Válková, H. (2021b). Comparison of forward and backward gait in males with and without intellectual disabilities. *Journal of intellectual disability research : JIDR, 65*(10), 922–929. https://doi.org/10.1111/jir.12873

Gimunová, M., Kolářová, K., Vodička, T., Bozděch, M., & Zvonař, M. (2022a). How barefoot and conventional shoes affect the foot and gait characteristics in toddlers. *PloS one, 17*(8), e0273388. https://doi.org/10.1371/journal.pone.0273388

Gimunová, M., Paludo, A. C., Bernaciková, M., & Bienertova-Vasku, J. (2024). The effect of space travel on human reproductive health: a systematic review. *NPJ microgravity*, *10*(1), 10. https://doi.org/10.1038/s41526-024-00351-1

Gimunová, M., Paulínyová, A., Bernaciková, M., & Paludo, A. C. (2022b). The Prevalence of Menstrual Cycle Disorders in Female Athletes from Different Sports Disciplines: A Rapid Review. *International journal of environmental research and public health*, *19*(21), 14243. https://doi.org/10.3390/ijerph192114243

Gimunová, M., Sebera, M., Bozděch, M., Kolářová, K., Vodička, T., & Zvonař, M. (2021a). The Impact of Different Periods of Walking Experience on Kinematic Gait Parameters in Toddlers. *International journal of environmental research and public health, 19*(1), 58. https://doi.org/10.3390/ijerph19010058

Gimunová, M., Sebera, M., Kasović, M., Svobodová, L., & Vespalec, T. (2022b). Spatio-Temporal Gait Parameters in Association with Medications and Risk of Falls in the Elderly. *Clinical interventions in aging, 17*, 873–883. https://doi.org/10.2147/CIA.S363479

Gimunová, M., Zvonař, M., & Mikeska, O. (2018). The effect of aging and gender on plantar pressure distribution during the gait in elderly. *Acta of bioengineering and biomechanics, 20*(4), 139–144.

Gimunová, M., Zvonař, M., Sebera, M., Turčínek, P., & Kolářová, K. (2020). Special footwear designed for pregnant women and its effect on kinematic gait parameters during pregnancy and postpartum period. *PloS one, 15*(5), e0232901. https://doi.org/10.1371/journal.pone.0232901

Glenn, J. M., Vincenzo, J., Canella, C. K., Binns, A., & Gray, M. (2015). Habitual and Maximal Dual-Task Gait Speeds Among Sedentary, Recreationally Active, and Masters Athlete Late Middle-Aged Adults, *Journal of Aging and Physical Activity*, *23*(3), 433–437.

Guéguen N. (2012). Gait and menstrual cycle: ovulating women use sexier gaits and walk slowly ahead of men. *Gait & posture*, *35*(4), 621–624. https://doi.org/10.1016/j.gaitpost.2011.12.011

Guimarães, I., & Póvoa, A. M. (2020). Primary Dysmenorrhea: Assessment and Treatment. Dismenorreia primária: Avaliação e tratamento. *Revista brasileira de ginecologia e obstetricia : revista da Federacao Brasileira das Sociedades de Ginecologia e Obstetricia*, *42*(8), 501–507. https://doi.org/10.1055/s-0040-1712131

Güler, Ö., Bingöl, A. D., Şahin, F. N., & Ersöz, G. (2020). Evaluation of the effects of menstrual cycle on postural stability in active young women. *International Journal of Applied Exercise Physiology, 9*(10), 44–49.

Guven Yorgun, Y., & Ozakbas, S. (2019). Effect of hormonal changes on the neurological status in the menstrual cycle of patient with multiple sclerosis. *Clinical neurology and neurosurgery*, *186*, 105499. https://doi.org/10.1016/j.clineuro.2019.105499

Hailemeskel, S., Demissie, A., & Assefa, N. (2016). Primary dysmenorrhea magnitude, associated risk factors, and its effect on academic performance: evidence from female university students in Ethiopia. *International journal of women's health*, *8*, 489–496. https://doi.org/10.2147/IJWH.S112768

Hamacher, D., Rudolf, M., Lohmann, C., & Schega, L. (2016). Pain severity reduction in subjects with knee osteoarthritis decreases motor-cognitive dual-task costs. *Clinical biomechanics (Bristol, Avon), 39*, 62–64. https://doi.org/10.1016/j.clinbiomech.2016.09.009

Hennegan, J., OlaOlorun, F. M., Oumarou, S., Alzouma, S., Guiella, G., Omoluabi, E., & Schwab, K. J. (2021). School and work absenteeism due to menstruation in three West African countries: findings from PMA2020 surveys. *Sexual and reproductive health matters*, *29*(1), 1915940. https://doi.org/10.1080/26410397.2021.1915940

Herssens, N., Verbecque, E., Hallemans, A., Vereeck, L., Van Rompaey, V., & Saeys, W. (2018). Do spatiotemporal parameters and gait variability differ across the lifespan of healthy adults? A systematic review. *Gait & posture, 64*, 181–190. https://doi.org/10.1016/j.gaitpost.2018.06.012

Hertel, J., Williams, N.I., Olmsted-Kramer, L.C. et al. Neuromuscular performance and knee laxity do not change across the menstrual cycle in female athletes. *Knee Surg Sports Traumatol Arthr* 14, 817–822 (2006). https://doi.org/10.1007/s00167-006-0047-4

Herzberg, S. D., Motu'apuaka, M. L., Lambert, W., Fu, R., Brady, J., & Guise, J. M. (2017). The Effect of Menstrual Cycle and Contraceptives on ACL Injuries and Laxity: A Systematic Review and Meta-analysis. *Orthopaedic journal of sports medicine*, *5*(7), 2325967117718781. https://doi.org/10.1177/2325967117718781

Hirtz, R., Hars, C., Naaresh, R., Laabs, B. H., Antel, J., Grasemann, C., Hinney, A., Hebebrand, J., & Peters, T. (2022). Causal Effect of Age at Menarche on the Risk for Depression: Results From a Two-Sample Multivariable Mendelian Randomization Study. *Frontiers in genetics, 13*, 918584. https://doi.org/10.3389/fgene.2022.918584

Hita-Contreras, F., Martínez-Amat, A., Lomas-Vega, R., Álvarez, P., Mendoza, N., Romero-Franco, N., & Aránega, A. (2013). Relationship of body mass index and body fat distribution with postural balance and risk of falls in Spanish postmenopausal women. *Menopause (New York, N.Y.)*, *20*(2), 202–208. https://doi.org/10.1097/gme.0b013e318261f242

Hita-Contreras, F., Zagalaz-Anula, N., Martínez-Amat, A., Cruz-Díaz, D., Sánchez-Montesinos, I., Aibar-Almazán, A., & Lomas-Vega, R. (2018). Sleep quality and its association with postural stability and fear of falling among Spanish postmenopausal women. *Menopause (New York, N.Y.), 25*(1), 62–69. https://doi.org/10.1097/GME.0000000000000941

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and science in sports and exercise*, *41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Horvat, M., Croce, R., Tomporowski, P., & Barna, M. C. (2013). The influence of dual-task conditions on movement in young adults with and without Down syndrome. *Research in developmental disabilities, 34*(10), 3517–3525. https://doi.org/10.1016/j.ridd.2013.06.038

Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Doré, J., Marceau, P., Marceau, S., Tremblay, A., & Teasdale, N. (2007). Body weight is a strong predictor of postural stability. *Gait & posture*, *26*(1), 32–38. https://doi.org/10.1016/j.gaitpost.2006.07.005

Hunnell, N. A., Rockcastle, N. J., McCormick, K. N., Sinko, L. K., Sullivan, E. L., & Cameron, J. L. (2007). Physical activity of adult female rhesus monkeys (Macaca mulatta) across the menstrual cycle. *American journal of physiology. Endocrinology and metabolism*, *292*(6), E1520–E1525. https://doi.org/10.1152/ajpendo.00497.2006

Iacovides, S., Avidon, I., & Baker, F. C. (2015). What we know about primary dysmenorrhea today: a critical review. *Human reproduction update*, *21*(6), 762–778. https://doi.org/10.1093/humupd/dmv039

Iosa, M., De Bartolo, D., Morone, G., Boffi, T., Mammucari, E., Vannozzi, G., Bini, F., Marinozzi, F., Antonucci, G., & Paolucci, S. (2019). Gait phase proportions in different locomotion tasks: The pivot role of golden ratio. *Neuroscience letters*, *699*, 127–133. https://doi.org/10.1016/j.neulet.2019.01.052

Janse de Jonge, X., Thompson, B., & Han, A. (2019). Methodological Recommendations for Menstrual Cycle Research in Sports and Exercise. *Medicine and science in sports and exercise*, *51*(12), 2610–2617. https://doi.org/10.1249/MSS.0000000000002073

Johnson, A., Roberts, L., & Elkins, G. (2019). Complementary and Alternative Medicine for Menopause. *Journal of evidence-based integrative medicine, 24*, 2515690X19829380. https://doi.org/10.1177/2515690X19829380

Kacem, M., Borji, R., Sahli, S., & Rebai, H. (2021). The Disturbing Effect of Neuromuscular Fatigue on Postural Control Is Accentuated in the Premenstrual Phase in Female Athletes. *Frontiers in physiology*, *12*, 736211. https://doi.org/10.3389/fphys.2021.736211

Kao, P. C., & Pierro, M. A. (2021). Dual-task treadmill walking at self-paced versus fixed speeds. *Gait & posture, 89*, 92–101. https://doi.org/10.1016/j.gaitpost.2021.07.001

Karapanou, O., & Papadimitriou, A. (2010). Determinants of menarche. *Reproductive biology and endocrinology : RB&E*, *8*, 115. https://doi.org/10.1186/1477-7827-8-115

Kędziorek, J., & Błażkiewicz, M. (2020). Nonlinear Measures to Evaluate Upright Postural Stability: A Systematic Review. *Entropy (Basel, Switzerland)*, *22*(12), 1357. https://doi.org/10.3390/e22121357

Keklicek, H., Sermenli Aydin, N., Can, H. B., Dönmez Aydin, D., Yilmazer Kayatekin, A. Z., & Uluçam, E. (2021). Primary dysmenorrhea and postural control: Is it a problem only during menstruation?. *Gait & posture*, *85*, 88–95. https://doi.org/10.1016/j.gaitpost.2021.01.019

Kim, K. W., & Lim, B. O. (2014). Effects of menarcheal age on the anterior cruciate ligament injury risk factors during single-legged drop landing in female artistic elite gymnasts. *Archives of orthopaedic and trauma surgery*, *134*(11), 1565–1571. https://doi.org/10.1007/s00402-014-2055-z

Koshino, Y., Samukawa, M., Chida, S., Okada, S., Tanaka, H., Watanabe, K., Chijimatsu, M., Yamanaka, M., & Tohyama, H. (2020). Postural Stability and Muscle Activation Onset during Double- to Single-Leg Stance Transition in Flat-Footed Individuals. *Journal of sports science & medicine*, *19*(4), 662–669.

Kristunas, C. A., Hemming, K., Eborall, H., Eldridge, S., & Gray, L. J. (2019). The current use of feasibility studies in the assessment of feasibility for stepped-wedge cluster randomised trials: a systematic review. *BMC medical research methodology, 19*(1), 12. https://doi.org/10.1186/s12874-019-0658-3

Krzykała, M., Karpowicz, K., Karpowicz, M., Bartkowiak, S., Demuth, A., Czerniak, U., & Janowski, J. (2023). Somatic characteristic, morphological asymmetry and postural stability of youth male canoeists compared to control. A cross-sectional study. *PloS one*, *18*(5), e0285997. https://doi.org/10.1371/journal.pone.0285997

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: are there changes in attentional requirements related to normal aging?. *Experimental aging research, 22*(2), 185–198. https://doi.org/10.1080/03610739608254006

Lalys, L., & Pineau, J. C. (2014). Age at menarche in a group of French schoolgirls. *Pediatrics international : official journal of the Japan Pediatric Society*, *56*(4), 601–604. https://doi.org/10.1111/ped.12296

Latash, M. L. (c2008). *Neurophysiological basis of movement* (2nd ed). Human Kinetics.

Le Noan-Lainé, M., Artaud, F., Ndoadoumgue, A. L., Ozguler, A., Cœuret-Pellicer, M., Ringa, V., Elbaz, A., & Canonico, M. (2023). Characteristics of reproductive history, use of exogenous hormones and walking speed among women: Data from the CONSTANCES French Cohort Study. *Maturitas*, *170*, 42–50. https://doi.org/10.1016/j.maturitas.2023.01.008

Leal-Junior, A., Frizera-Neto, A. (2022). Chapter 3 – Gait analysis: overview, trends, and challenges. Editor(s): Arnaldo Leal-Junior, Anselmo Frizera-Neto, Optical Fiber Sensors for the Next Generation of Rehabilitation Robotics, Academic Press, 2022, Pages 53–64, ISBN 9780323859523, https://doi.org/10.1016/B978-0-32-385952-3.00011-1

Lee, B. J., Cho, K. H., & Lee, W. H. (2017). The effects of the menstrual cycle on the static balance in healthy young women. *Journal of physical therapy science*, *29*(11), 1964–1966. https://doi.org/10.1589/jpts.29.1964

Lee, H., & Petrofsky, J. (2018). Differences Between Men and Women in Balance and Tremor in Relation to Plantar Fascia Laxity During the Menstrual Cycle. *Journal of athletic training*, *53*(3), 255–261. https://doi.org/10.4085/1062-6050-2-17

Lee, H., & Yim, J. (2016). Increased Postural Sway and Changes in the Neuromuscular Activities of the Ankle Stabilizing Muscles at Ovulation in Healthy Young Women. *The Tohoku journal of experimental medicine*, *240*(4), 287–294. https://doi.org/10.1620/tjem.240.287

Lee, H., Petrofsky, J. S., Daher, N., Berk, L., Laymon, M., & Khowailed, I. A. (2013). Anterior cruciate ligament elasticity and force for flexion during the menstrual cycle. *Medical science monitor : international medical journal of experimental and clinical research*, *19*, 1080–1088. https://doi.org/10.12659/MSM.889393

Levine, D., Richards, J., & Whittle, M.W. (2012). *Whittle's gait analysis. Fifth edition*. Elsevier.

Li, K. Z., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: age-related differences in compensatory behavior. *Psychological science, 12*(3), 230–237. https://doi.org/10.1111/1467-9280.00341

Liang, H. W., Chi, S. Y., Tai, T. L., Li, Y. H., & Hwang, Y. H. (2022). Impact of age on the postural stability measured by a virtual reality tracker-based posturography and a pressure platform system. *BMC geriatrics, 22*(1), 506. https://doi.org/10.1186/s12877-022-03195-0

Lipowicz, A., Bugdol, M. N., Szurmik, T., Bibrowicz, K., Kurzeja, P., & Mitas, A. W. (2019). Body balance analysis of children and youth with intellectual disabilities. *Journal of intellectual disability research : JIDR, 63*(11), 1312–1323. https://doi.org/10.1111/jir.12671

Liu, Y. C., Yang, Y. R., Tsai, Y. A., & Wang, R. Y. (2017). Cognitive and motor dual task gait training improve dual task gait performance after stroke – A randomized controlled pilot trial. *Scientific reports*, *7*(1), 4070. https://doi.org/10.1038/s41598-017-04165-y

Løvendahl, P., & Chagunda, M. G. (2010). On the use of physical activity monitoring for estrus detection in dairy cows. *Journal of dairy science*, *93*(1), 249–259. https://doi.org/10.3168/jds.2008-1721

Magnus, M. C., Guyatt, A. L., Lawn, R. B., Wyss, A. B., Trajanoska, K., Küpers, L. K., Rivadeneira, F., Tobin, M. D., London, S. J., Lawlor, D. A., Millard, L. A. C., & Fraser, A. (2020). Identifying potential causal effects of age at menarche: a Mendelian randomization phenome-wide association study. *BMC medicine, 18*(1), 71. https://doi.org/10.1186/s12916-020-01515-y

Malina R. M. (1983). Menarche in athletes: a synthesis and hypothesis. *Annals of human biology*, *10*(1), 1–24. https://doi.org/10.1080/03014468300006141

Marques, P., Skorupskaite, K., Rozario, K.S., Anderson, R.A., George J.T. (2000). Physiology of GnRH and Gonadotropin Secretion. In: Feingold KR, Anawalt B, Blackman MR, et al., editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; Available from: https://www.ncbi.nlm.nih.gov/books/NBK279070/

Martin, D., Timmins, K., Cowie, C., Alty, J., Mehta, R., Tang, A., & Varley, I. (2021). Injury Incidence Across the Menstrual Cycle in International Footballers. *Frontiers in sports and active living*, *3*, 616999. https://doi.org/10.3389/fspor.2021.616999

Mather, G., & Murdoch, L. (1994). Gender discrimination in biological motion displays based on dynamic cues. *Proceedings of the Royal Society B: Biological Sciences, 258*, 273–279.

Maylor, E. A., & Wing, A. M. (1996). Age differences in postural stability are increased by additional cognitive demands. *The journals of gerontology. Series B, Psychological sciences and social sciences*, *51*(3), P143–P154. https://doi.org/10.1093/geronb/51b.3.p143

McGawley, K., Sargent, D., Noordhof, D., Badenhorst, C. E., Julian, R., & Govus, A. D. (2023). Improving menstrual health literacy in sport. *Journal of science and medicine in sport*, *26*(7), 351–357. https://doi.org/10.1016/j.jsams.2023.06.007

McGee, E. A., & Hsueh, A. J. (2000). Initial and cyclic recruitment of ovarian follicles. *Endocrine reviews*, *21*(2), 200–214. https://doi.org/10.1210/edrv.21.2.0394

McNulty, K. L., Elliott-Sale, K. J., Dolan, E., Swinton, P. A., Ansdell, P., Goodall, S., Thomas, K., & Hicks, K. M. (2020). The Effects of Menstrual Cycle Phase on Exercise Performance in Eumenorrheic Women: A Systematic Review and Meta-Analysis. *Sports medicine (Auckland, N.Z.)*, *50*(10), 1813–1827. https://doi.org/10.1007/s40279-020-01319-3

Medina-Perucha, L., López-Jiménez, T., Jacques-Aviñó, C., Holst, A. S., Valls-Llobet, C., Munrós-Feliu, J., Martínez-Bueno, C., Pinzón-Sanabria, D., Vicente-Hernández, M. M., & Berenguera, A. (2023). Menstruation and social inequities in Spain: a cross-sectional online survey-based study. *International journal for equity in health*, *22*(1), 92. https://doi.org/10.1186/s12939-023-01904-8

Meignié, A., Duclos, M., Carling, C., Orhant, E., Provost, P., Toussaint, J. F., & Antero, J. (2021). The Effects of Menstrual Cycle Phase on Elite Athlete Performance: A Critical and Systematic Review. *Frontiers in physiology*, *12*, 654585. https://doi.org/10.3389/fphys.2021.654585

Meng, H., O'Connor, D. P., Lee, B. C., Layne, C. S., & Gorniak, S. L. (2017). Alterations in over-ground walking patterns in obese and overweight adults. *Gait & posture*, *53*, 145–150. https://doi.org/10.1016/j.gaitpost.2017.01.019

Miao, B., Liu, X., & Zhu, T. (2021). Automatic mental health identification method based on natural gait pattern. *PsyCh journal*, *10*(3), 453–464. https://doi.org/10.1002/pchj.434

Michalak, J., Troje, N. F., Fischer, J., Vollmar, P., Heidenreich, T., & Schulte, D. (2009). Embodiment of sadness and depression – gait patterns associated with dysphoric mood. *Psychosomatic medicine*, *71*(5), 580–587. https://doi.org/10.1097/PSY.0b013e3181a2515c

Minkin M. J. (2019). Menopause: Hormones, Lifestyle, and Optimizing Aging. *Obstetrics and gynecology clinics of North America, 46*(3), 501–514. https://doi.org/10.1016/j.ogc.2019.04.008

Mokošáková, M., Senko, T., Okuliarová, M., Kršková, L., Hlavačka, F., & Zeman, M. (2018). Effect of oral contraceptives intake on postural stability in young healthy women throughout the menstrual cycle. *General physiology and biophysics*, *37*(5), 581–588. https://doi.org/10.4149/gpb_2018015

Montalvo, A. M., Schneider, D. K., Webster, K. E., Yut, L., Galloway, M. T., Heidt, R. S., Jr, Kaeding, C. C., Kremcheck, T. E., Magnussen, R. A., Parikh, S. N., Stanfield, D. T., Wall, E. J., & Myer, G. D. (2019). Anterior Cruciate Ligament Injury Risk in Sport: A Systematic Review and Meta-Analysis of Injury Incidence by Sex and Sport Classification. *Journal of athletic training*, *54*(5), 472–482. https://doi.org/10.4085/1062-6050-407-16

Montero-Odasso, M., Verghese, J., Beauchet, O., & Hausdorff, J. M. (2012). Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *Journal of the American Geriatrics Society, 60*(11), 2127–2136. https://doi.org/10.1111/j.1532-5415.2012.04209.x

Morris, N. M., & Udry, J. R. (1970). Variations in pedometer activity during the menstrual cycle. *Obstetrics and gynecology*, *35*(2), 199–201.

Mujdeci, B., Turkyilmaz, D., Yagcioglu, S., & Aksoy, S. (2016). The effects of concurrent cognitive tasks on postural sway in healthy subjects. *Brazilian Journal of Otorhinolaryngology*, *82*(1), 3–10.

Muniandy, Y., Xuan, C. S., Singh , S., Krishnan Vasanthi, R., Srinivasan, V., Kumar, P., & Suganthirababu, P. (2023). A Comparative Study on Dynamic Balance During Menstrual and Non-Menstrual Period Among Female University Students. *National Journal of Community Medicine*, *14*(07), 452–456. https://doi.org/10.55489/njcm.140720232963

Nelson H. D. (2008). Menopause. *Lancet (London, England)*, *371*(9614), 760–770. https://doi.org/10.1016/S0140-6736(08)60346-3

Nirenberg, M., Vernon, W., & Birch, I. (2018). A review of the historical use and criticisms of gait analysis evidence. *Science & justice : journal of the Forensic Science Society, 58*(4), 292–298. https://doi.org/10.1016/j.scijus.2018.03.002

Nurwulan, N. R., Jiang, B. C., & Iridiastadi, H. (2015). Posture and Texting: Effect on Balance in Young Adults. *PloS one*, *10*(7), e0134230. https://doi.org/10.1371/journal.pone.0134230

N-Wihlbäck, A. C., Sundström-Poromaa, I., & Bäckström, T. (2006). Action by and sensitivity to neuroactive steroids in menstrual cycle related CNS disorders. *Psychopharmacology*, *186*(3), 388–401. https://doi.org/10.1007/s00213-005-0185-2

O'Kane, J. W., Tencer, A., Neradilek, M., Polissar, N., Sabado, L., & Schiff, M. A. (2016). Is Knee Separation During a Drop Jump Associated With Lower Extremity Injury in Adolescent Female Soccer Players?. *The American journal of sports medicine*, *44*(2), 318–323. https://doi.org/10.1177/0363546515613076

Okayama, A., Nakayama, N., Kashiwa, K., Horinouchi, Y., Fukusaki, H., Nakamura, H., & Katayama, S. (2022). Prevalence of Sarcopenia and Its Association with Quality of Life, Postural Stability, and Past Incidence of Falls in Postmenopausal Women with Osteoporosis: A Cross-Sectional Study. *Healthcare (Basel, Switzerland), 10*(2), 192. https://doi.org/10.3390/healthcare10020192

Onland-Moret, N. C., Peeters, P. H., van Gils, C. H., Clavel-Chapelon, F., Key, T., Tjønneland, A., Trichopoulou, A., Kaaks, R., Manjer, J., Panico, S., Palli, D., Tehard, B., Stoikidou, M., Bueno-De-Mesquita, H. B., Boeing, H., Overvad, K., Lenner, P., Quirós, J. R., Chirlaque, M. D., Miller, A. B., … Riboli, E. (2005). Age at menarche in relation to adult height: the EPIC study. *American journal of epidemiology*, *162*(7), 623–632. https://doi.org/10.1093/aje/kwi260

Onofrei, R. R., Amaricai, E., Suciu, O., David, V. L., Rata, A. L., & Hogea, E. (2020). Smartphone Use and Postural Balance in Healthy Young Adults. *International journal of environmental research and public health*, *17*(9), 3307. https://doi.org/10.3390/ijerph17093307

Opala-Berdzik, A., Błaszczyk, J. W., Bacik, B., Cieślińska-Świder, J., Świder, D., Sobota, G., & Markiewicz, A. (2015). Static Postural Stability in Women during and after Pregnancy: A Prospective Longitudinal Study. *PloS one, 10*(6), e0124207. https://doi.org/10.1371/journal.pone.0124207

Orlowski, M., Sarao, M.S. (2023). Physiology, Follicle Stimulating Hormone. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; Available from: https://www.ncbi.nlm.nih.gov/books/NBK535442/

Ortega-Bastidas, P., Gómez, B., Aqueveque, P., Luarte-Martínez, S., & Cano-de-la-Cuerda, R. (2023). Instrumented Timed Up and Go Test (iTUG)-More Than Assessing Time to Predict Falls: A Systematic Review. *Sensors (Basel, Switzerland), 23*(7), 3426. https://doi.org/10.3390/s23073426

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan-a web and mobile app for systematic reviews. *Systematic reviews*, *5*(1), 210. https://doi.org/10.1186/s13643-016-0384-4

Owen M. (2013). Physiological signs of ovulation and fertility readily observable by women. *The Linacre quarterly*, *80*(1), 17–23. https://doi.org/10.1179/0024363912Z.0000000005

Özer Kaya, D., & Toprak Çelenay, Ş. (2016). Fluctuations of state anxiety, spinal structure, and postural stabilityacross the menstrual cycle in active women. *Turkish journal of medical sciences*, *46*(4), 977–984. https://doi.org/10.3906/sag-1501-13

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical research ed.)*, *372*, n71. https://doi.org/10.1136/bmj.n71

Pakzad, M., Fung, J., & Preuss, R. (2016). Pain catastrophizing and trunk muscle activation during walking in patients with chronic low back pain. *Gait & posture, 49*, 73–77. https://doi.org/10.1016/j.gaitpost.2016.06.025

Palm, H. G., Strobel, J., Achatz, G., von Luebken, F., & Friemert, B. (2009). The role and interaction of visual and auditory afferents in postural stability. *Gait & posture*, *30*(3), 328–333. https://doi.org/10.1016/j.gaitpost.2009.05.023

Paludo, A. C., Paravlic, A., Dvořáková, K., & Gimunová, M. (2022). The Effect of Menstrual Cycle on Perceptual Responses in Athletes: A Systematic Review With Meta-Analysis. *Frontiers in psychology*, *13*, 926854. https://doi.org/10.3389/fpsyg.2022.926854

Park, J. W., Baek, S. H., Sung, J. H., & Kim, B. J. (2022). Predictors of Step Length from Surface Electromyography and Body Impedance Analysis Parameters. *Sensors (Basel, Switzerland)*, *22*(15), 5686. https://doi.org/10.3390/s22155686

Peterka, R. J., & Loughlin, P. J. (2004). Dynamic regulation of sensorimotor integration in human postural control. *Journal of neurophysiology, 91*(1), 410–423. https://doi.org/10.1152/jn.00516.2003

Peters, A., Mahdy, H. (2022). Symptothermal Contraception. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; PMID: 33231986.

Petrofsky, J., & Lee, H. (2015). Greater Reduction of Balance as a Result of Increased Plantar Fascia Elasticity at Ovulation during the Menstrual Cycle. *The Tohoku journal of experimental medicine*, *237*(3), 219–226. https://doi.org/10.1620/tjem.237.219

Pierce, M. B., & Leon, D. A. (2005). Age at menarche and adult BMI in the Aberdeen children of the 1950s cohort study. *The American journal of clinical nutrition, 82*(4), 733–739. https://doi.org/10.1093/ajcn/82.4.733

Plummer, P., Eskes, G., Wallace, S., Giuffrida, C., Fraas, M., Campbell, G., Clifton, K. L., Skidmore, E. R., & American Congress of Rehabilitation Medicine Stroke Networking Group Cognition Task Force (2013). Cognitive-motor interference during functional mobility after stroke: state of the science and implications for future research. *Archives of physical medicine and rehabilitation, 94*(12), 2565–2574.e6. https://doi.org/10.1016/j.apmr.2013.08.002

Pollard, T. M., & Wagnild, J. M. (2017). Gender differences in walking (for leisure, transport and in total) across adult life: a systematic review. *BMC public health*, *17*(1), 341. https://doi.org/10.1186/s12889-017-4253-4

Preston, R. R., & Wilson, T. E. (2013). *Physiology*. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins. Lippincott's illustrated reviews. ISBN 978-1-4511-7567-7.

Provost, M. P., Quinsey, V. L., & Troje, N. F. (2008). Differences in gait across the menstrual cycle and their attractiveness to men. *Archives of sexual behavior*, *37*(4), 598–604. https://doi.org/10.1007/s10508-007-9219-7

Rahim, M. J., Schwebel, D. C., Hasan, R., Griffin, R., & Sen, B. (2023). Cost-benefit analysis of a distracted pedestrian intervention. *Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention, 29*(1), 62–67. https://doi.org/10.1136/ip-2022-044740

Ravi, S., Kujala, U. M., Tammelin, T. H., Hirvensalo, M., Kovanen, V., Valtonen, M., Waller, B., Aukee, P., Sipilä, S., & Laakkonen, E. K. (2020). Adolescent Sport Participation and Age at Menarche in Relation to Midlife Body Composition, Bone Mineral Density, Fitness, and Physical Activity. *Journal of clinical medicine, 9*(12), 3797. https://doi.org/10.3390/jcm9123797

Reed, B. G., & Carr, B. R. (2018). The Normal Menstrual Cycle and the Control of Ovulation. In: Feingold KR, Anawalt B, Blackman MR, et al., editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; Available from: https://www.ncbi.nlm.nih.gov/books/NBK279054/

Ren, J., Chen, Y., Li, F., Xue, C., Yin, X., Peng, J., Liang, J., Feng, Q., & Wang, S. (2021). Road Injuries Associated With Cellular Phone Use While Walking or Riding a Bicycle or an Electric Bicycle: A Case-Crossover Study. *American journal of epidemiology, 190*(1), 37–43. https://doi.org/10.1093/aje/kwaa164

Resch, J. E., May, B., Tomporowski, P. D., & Ferrara, M. S. (2011). Balance performance with a cognitive task: a continuation of the dual-task testing paradigm. *Journal of athletic training, 46*(2), 170–175. https://doi.org/10.4085/1062-6050-46.2.170

Reschechtko, S., Nguyen, T. N., Tsang, M., Giltvedt, K., Kern, M., & Hooshmand, S. (2023). Postural sway is not affected by estrogen fluctuations during the menstrual cycle. *Physiological reports*, *11*(10), e15693. https://doi.org/10.14814/phy2.15693

Rezende, A. P. R., Alvarenga, F. R., Ramos, M., Franken, D. L., Dias da Costa, J. S., Pattussi, M. P., & Paniz, V. M. V. (2022). Prevalence of Premenstrual Syndrome and Associated Factors Among Academics of a University in Midwest Brazil. Prevalência de síndrome pré-menstrual e fatores associados entre acadêmicas de uma Universidade no Centro-Oeste do Brasil. *Revista brasileira de ginecologia e obstetricia : revista da Federacao Brasileira das Sociedades de Ginecologia e Obstetricia*, *44*(2), 133–141. https://doi.org/10.1055/s-0041-1741456

Rizzato, A., Paoli, A., Andretta, M., Vidorin, F., & Marcolin, G. (2021). Are Static and Dynamic Postural Balance Assessments Two Sides of the Same Coin? A Cross-Sectional Study in the Older Adults. *Frontiers in physiology, 12*, 681370. https://doi.org/10.3389/fphys.2021.681370

Roberts, S. C., Havlicek, J., Flegr, J., Hruskova, M., Little, A. C., Jones, B. C., Perrett, D. I., & Petrie, M. (2004). Female facial attractiveness increases during the fertile phase of the menstrual cycle. *Proceedings. Biological sciences*, *271 Suppl 5*(Suppl 5), S270–S272. https://doi.org/10.1098/rsbl.2004.0174

Rosende-Bautista, C., Munuera-Martínez, P. V., Seoane-Pillado, T., Reina-Bueno, M., Alonso-Tajes, F., Pérez-García, S., & Domínguez-Maldonado, G. (2021). Relationship of Body Mass Index and Footprint Morphology to the Actual Height of the Medial Longitudinal Arch of the Foot. *International journal of environmental research and public health*, *18*(18), 9815. https://doi.org/10.3390/ijerph18189815

Rosso, V., Agostini, V., Takeda, R., Tadano, S., & Gastaldi, L. (2019). Influence of BMI on Gait Characteristics of Young Adults: 3D Evaluation Using Inertial Sensors. *Sensors (Basel, Switzerland)*, *19*(19), 4221. https://doi.org/10.3390/s19194221

Rowe, E., Beauchamp, M. K., & Astephen Wilson, J. (2021). Age and sex differences in normative gait patterns. *Gait & posture*, *88*, 109–115. https://doi.org/10.1016/j.gaitpost.2021.05.014

Rubio Barañano, A., Faisal, M., Barrett, B. T., & Buckley, J. G. (2022). Using a smartphone on the move: do visual constraints explain why we slow walking speed?. *Experimental brain research*, *240*(2), 467–480. https://doi.org/10.1007/s00221-021-06267-6

Ruedl, G., Ploner, P., Linortner, I., Schranz, A., Fink, C., Sommersacher, R., Pococco, E., Nachbauer, W., & Burtscher, M. (2009). Are oral contraceptive use and menstrual cycle phase related to anterior cruciate ligament injury risk in female recreational skiers?. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *17*(9), 1065–1069. https://doi.org/10.1007/s00167-009-0786-0

Saibaba, G., Srinivasan, M., Priya Aarthy, A., Silambarasan, V., & Archunan, G. (2017). Ultrastructural and physico-chemical characterization of saliva during menstrual cycle in perspective of ovulation in human. *Drug discoveries & therapeutics*, *11*(2), 91–97. https://doi.org/10.5582/ddt.2017.01008

Salihu, A. T., Hill, K. D., & Jaberzadeh, S. (2022). Effect of cognitive task complexity on dual-task postural stability: a systematic review and meta-analysis. *Experimental brain research, 240*(3), 703–731. https://doi.org/10.1007/s00221-021-06299-y

Saraiva, M., Castro, M. A., & Vilas-Boas, J. P. (2023). Influence of cognitive and motor tasks using smartphone during gait: EMG and gait performance analysis – Dual-task study. *Human movement science, 89*, 103097. https://doi.org/10.1016/j.humov.2023.103097

Schaefer, S., Jagenow, D., Verrel, J., & Lindenberger, U. (2015). The influence of cognitive load and walking speed on gait regularity in children and young adults. *Gait & posture, 41*(1), 258–262. https://doi.org/10.1016/j.gaitpost.2014.10.013

Schmalenberger, K. M., Tauseef, H. A., Barone, J. C., Owens, S. A., Lieberman, L., Jarczok, M. N., Girdler, S. S., Kiesner, J., Ditzen, B., & Eisenlohr-Moul, T. A. (2021). How to study the menstrual cycle: Practical tools and recommendations. *Psychoneuroendocrinology*, *123*, 104895. https://doi.org/10.1016/j.psyneuen.2020.104895

Schoep, M. E., Nieboer, T. E., van der Zanden, M., Braat, D. D. M., & Nap, A. W. (2019). The impact of menstrual symptoms on everyday life: a survey among 42,879 women. *American journal of obstetrics and gynecology*, *220*(6), 569.e1–569.e7. https://doi.org/10.1016/j.ajog.2019.02.048

Scholz, T., Zech, A., Wegscheider, K., Lezius, S., Braumann, K. M., Sehner, S., & Hollander, K. (2017). Reliability and Correlation of Static and Dynamic Foot Arch Measurement in a Healthy Pediatric Population. *Journal of the American Podiatric Medical Association*, *107*(5), 419–427. https://doi.org/10.7547/16-133

Sell, T. C., Lovalekar, M. T., Nagai, T., Wirt, M. D., Abt, J. P., & Lephart, S. M. (2018). Gender Differences in Static and Dynamic Postural Stability of Soldiers in the Army's 101st Airborne Division (Air Assault). *Journal of sport rehabilitation, 27*(2), 126–131. https://doi.org/10.1123/jsr.2016-0131

Şenol, D., Uçar, C., Toy, Ş., Kısaoğlu, A., Özbağ, D., Ersoy, Y., & Yıldız, S. (2021). Analysis of the effects of hypothalamic-pituitary-adrenal axis activity in menstrual cycle on ankle proprioception, dynamic balance scores and visual-auditory reaction times in healthy young women. *Journal of musculoskeletal & neuronal interactions*, *21*(1), 85–92.

Shen, J., Liu, J., Liang, F., Liu, X., Liu, X., Fan, B., Lv, Z., & Zhang, C. (2023). Correlation analysis between body mass index and foot length in Chinese adolescents: a regional study. *Ergonomics*, 1–9. Advance online publication. https://doi.org/10.1080/00140139.2023.2166683

Shultz, S. J., Wideman, L., Montgomery, M. M., Beasley, K. N., & Nindl, B. C. (2012). Changes in serum collagen markers, IGF-I, and knee joint laxity across the menstrual cycle. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, *30*(9), 1405–1412. https://doi.org/10.1002/jor.22093

Sibley, K. M., Beauchamp, M. K., Van Ooteghem, K., Paterson, M., & Wittmeier, K. D. (2017). Components of Standing Postural Control Evaluated in Pediatric Balance Measures: A Scoping Review. *Archives of physical medicine and rehabilitation, 98*(10), 2066–2078.e4. https://doi.org/10.1016/j.apmr.2017.02.032

Silsupadol, P., Shumway-Cook, A., Lugade, V., van Donkelaar, P., Chou, L. S., Mayr, U., & Woollacott, M. H. (2009). Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. *Archives of physical medicine and rehabilitation*, *90*(3), 381–387. https://doi.org/10.1016/j.apmr.2008.09.559

Smith, J. A., Stabbert, H., Bagwell, J. J., Teng, H. L., Wade, V., & Lee, S. P. (2022). Do people with low back pain walk differently? A systematic review and meta-analysis. *Journal of sport and health science, 11*(4), 450–465. https://doi.org/10.1016/j.jshs.2022.02.001

Spence, J. E. (1997). Anovulation and monophasic cycles. *Ann N Y Acad Sci, 816*, 173–176. https://doi.org/10.1111/j.1749-6632.1997.tb52141.x

Steinberg, N., Tenenbaum, S., Zeev, A., Pantanowitz, M., Waddington, G., Dar, G., & Siev-Ner, I. (2021). Generalized joint hypermobility, scoliosis, patellofemoral pain, and physical abilities in young dancers. *BMC musculoskeletal disorders*, *22*(1), 161. https://doi.org/10.1186/s12891-021-04023-z

Su, H. W., Yi, Y. C., Wei, T. Y., Chang, T. C., & Cheng, C. M. (2017). Detection of ovulation, a review of currently available methods. *Bioengineering & translational medicine, 2*(3), 238–246. https://doi.org/10.1002/btm2.10058

Sullivan, E. V., Rose, J., Rohlfing, T., & Pfefferbaum, A. (2009). Postural sway reduction in aging men and women: relation to brain structure, cognitive status, and stabilizing factors. *Neurobiology of aging, 30*(5), 793–807. https://doi.org/10.1016/j.neurobiolaging.2007.08.021

Sung, E. S., & Kim, J. H. (2018). The influence of ovulation on postural stability (Biodex Balance System) in young female. *Journal of exercise rehabilitation*, *14*(4), 638–642. https://doi.org/10.12965/jer.1836266.133

Tagawa, N., Okamura, K., Araki, D., Sugahara, A., & Kanai, S. (2024). Influence of the menstrual cycle on static and dynamic kinematics of the foot medial longitudinal arch. *Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association*, *29*(2), 609–614. https://doi.org/10.1016/j.jos.2023.01.009

Takahashi, T. A., & Johnson, K. M. (2015). Menopause. *The Medical clinics of North America, 99*(3), 521–534. https://doi.org/10.1016/j.mcna.2015.01.006

Takeda, T., Imoto, Y., Nagasawa, H., Takeshita, A., & Shiina, M. (2016). Stress fracture and premenstrual syndrome in Japanese adolescent athletes: a cross-sectional study. *BMJ open*, *6*(10), e013103. https://doi.org/10.1136/bmjopen-2016-013103

Tanen, L., Docherty, C. L., Van Der Pol, B., Simon, J., & Schrader, J. (2014). Prevalence of chronic ankle instability in high school and division I athletes. *Foot & ankle specialist*, *7*(1), 37–44. https://doi.org/10.1177/1938640013509670

Taraborrelli S. (2015). Physiology, production and action of progesterone. *Acta obstetricia et gynecologica Scandinavica*, *94 Suppl 161*, 8–16. https://doi.org/10.1111/aogs.12771

Thakkar, H. H., & Senthil Kumar, E. (2017). Static and dynamic postural stability in subjects with and without chronic low back pain. *International Journal of Research in Medical Sciences*, *3*(9), 2405–2409. https://doi.org/10.18203/2320-6012.ijrms20150639

Tramontano, M., Morone, G., Curcio, A., Temperoni, G., Medici, A., Morelli, D., Caltagirone, C., Paolucci, S., & Iosa, M. (2017). Maintaining gait stability during dual walking task: effects of age and neurological disorders. *European journal of physical and rehabilitation medicine*, *53*(1), 7–13. https://doi.org/10.23736/S1973-9087.16.04203-9

Troje, N. F., Westhoff, C., & Lavrov, M. (2005). Person identification from biological motion: Effects of structural and kinematic cues. *Perception & Psychophysics* **67**, 667–675. https://doi.org/10.3758/BF03193523

Uchida, Y., & Izumizaki, M. (2022). The use of wearable devices for predicting biphasic basal body temperature to estimate the date of ovulation in women. *Journal of thermal biology*, *108*, 103290. https://doi.org/10.1016/j.jtherbio.2022.103290

Vickers, J., Reed, A., Decker, R., Conrad, B. P., Olegario-Nebel, M., & Vincent, H. K. (2017). Effect of investigator observation on gait parameters in individuals with and without chronic low back pain. *Gait & posture*, *53*, 35–40. https://doi.org/10.1016/j.gaitpost.2017.01.002

Voss, S., Joyce, J., Biskis, A., Parulekar, M., Armijo, N., Zampieri, C., Tracy, R., Palmer, A. S., Fefferman, M., Ouyang, B., Liu, Y., Berry-Kravis, E., & O'Keefe, J. A. (2020). Normative database of spatiotemporal gait parameters using inertial sensors in typically developing children and young adults. *Gait & posture, 80*, 206–213. https://doi.org/10.1016/j.gaitpost.2020.05.010

Werneck, A. O., Oyeyemi, A. L., Cyrino, E. S., Ronque, E. R. V., Szwarcwald, C. L., Coelho-E-Silva, M. J., & Silva, D. R. (2018). Association between age at menarche and blood pressure in adulthood: is obesity an important mediator?. *Hypertension research : official journal of the Japanese Society of Hypertension, 41*(10), 856–864. https://doi.org/10.1038/s41440-018-0079-4

WHO Multicentre Growth Reference Study Group (2006). WHO Motor Development Study: windows of achievement for six gross motor development milestones. *Acta paediatrica (Oslo, Norway: 1992). Supplement*, *450*, 86–95. https://doi.org/10.1111/j.1651-2227.2006.tb02379.x

Wojtys, E. M., Huston, L. J., Boynton, M. D., Spindler, K. P., & Lindenfeld, T. N. (2002). The effect of the menstrual cycle on anterior cruciate ligament injuries in women as determined by hormone levels. *The American journal of sports medicine*, *30*(2), 182–188. https://doi.org/10.1177/03635465020300020601

Wronka I. (2010). Association between BMI and age at menarche in girls from different socio-economic groups. *Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur, 68*(1), 43–52. https://doi.org/10.1127/0003-5548/2010/0066

Wu, T., Mendola, P., & Buck, G. M. (2002). Ethnic differences in the presence of secondary sex characteristics and menarche among US girls: the Third National Health and Nutrition Examination Survey, 1988–1994. *Pediatrics*, *110*(4), 752–757. https://doi.org/10.1542/peds.110.4.752

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. The Quarterly journal of experimental psychology. A, *Human experimental psychology, 54*(4), 1143–1154. https://doi.org/10.1080/713756012

Yamazaki, T., Maruyama, S., Sato, Y., Suzuki, Y., Shimizu, S., Kaneko, F., Ikezu, M., Matsuzawa, K., & Edama, M. (2021). A preliminary study exploring the change in ankle joint laxity and general joint laxity during the menstrual cycle in cis women. *Journal of foot and ankle research*, *14*(1), 21. https://doi.org/10.1186/s13047-021-00459-7

Yang, Y., Wang, S., & Cong, H. (2023). Association between age at menarche and bone mineral density in postmenopausal women. *Journal of orthopaedic surgery and research*, *18*(1), 51. https://doi.org/10.1186/s13018-023-03520-2

Yim, J., Petrofsky, J., & Lee, H. (2018). Correlation between Mechanical Properties of the Ankle Muscles and Postural Sway during the Menstrual Cycle. *The Tohoku journal of experimental medicine*, *244*(3), 201–207. https://doi.org/10.1620/tjem.244.201

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement disorders : official journal of the Movement Disorder Society, 23*(3), 329–472. https://doi.org/10.1002/mds.21720

Yonkers, K. A., O'Brien, P. M., & Eriksson, E. (2008). Premenstrual syndrome. *Lancet (London, England)*, *371*(9619), 1200–1210. https://doi.org/10.1016/S0140-6736(08)60527-9

Zhao, X., Gu, Y., Yu, J., Ma, Y., & Zhou, Z. (2020). The Influence of Gender, Age, and Body Mass Index on Arch Height and Arch Stiffness. *The Journal of foot and ankle surgery : official publication of the American College of Foot and Ankle Surgeons*, *59*(2), 298–302. https://doi.org/10.1053/j.jfas.2019.08.022

Zulkifli, S. S., & Loh, W. P. (2020). A state-of-the-art review of foot pressure. *Foot and ankle surgery : official journal of the European Society of Foot and Ankle Surgeons, 26*(1), 25–32. https://doi.org/10.1016/j.fas.2018.12.005

Żurawiecka, M., & Wronka, I. (2021). Association between age at menarche and body mass index, waist circumference, waist to hip ratio, and waist to height ratio in adult women. *American journal of human biology : the official journal of the Human Biology Council*, *33*(6), e23523. https://doi.org/10.1002/ajhb.23523

Żurawiecka, M., & Wronka, I. (2022). Association of age at menarche with adult height and sitting height in young Polish females. *Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur*, *79*(1), 1–10. https://doi.org/10.1127/anthranz/2021/1264

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