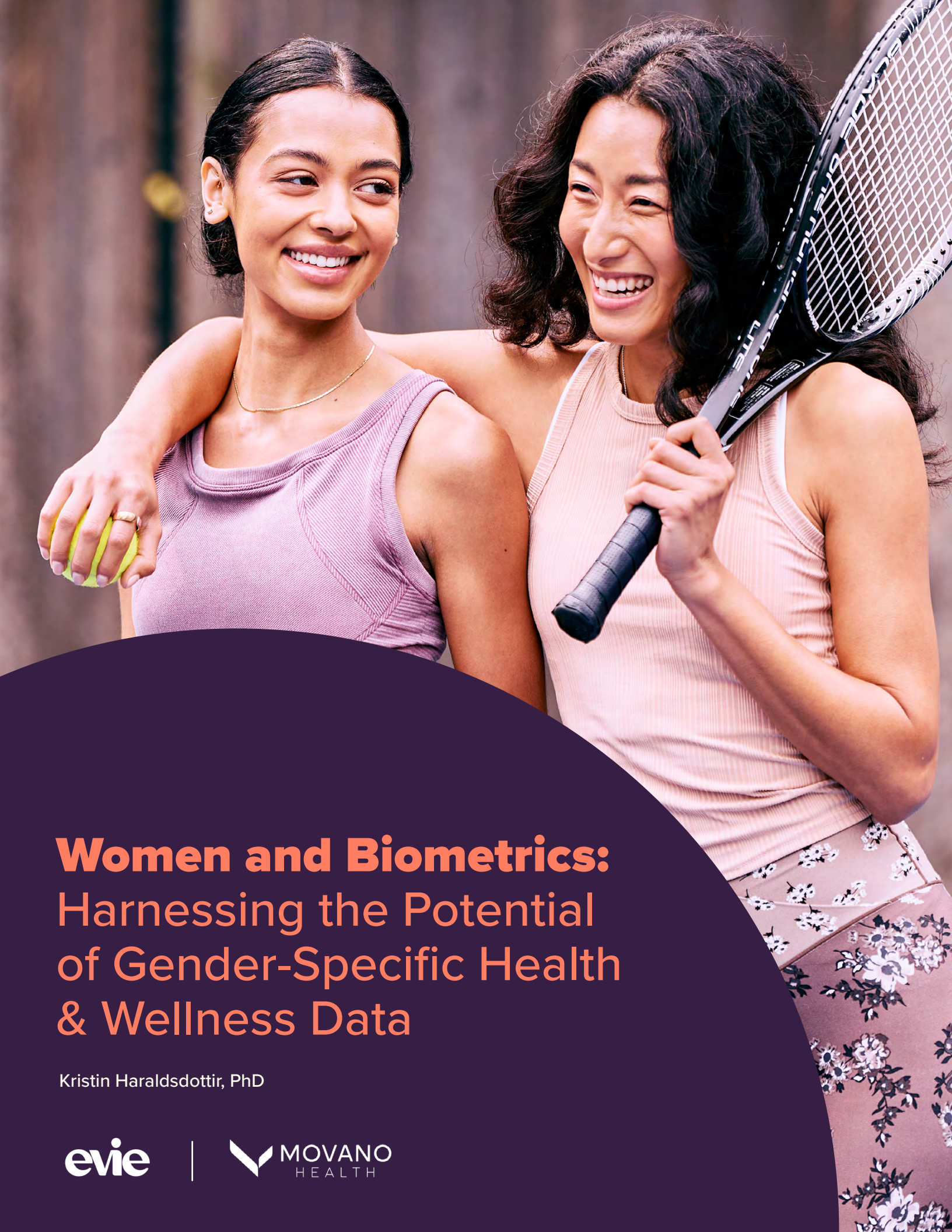

Women and Biometrics: Harnessing the Potential of Gender-Specific Health & Wellness Data

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Women deserve a wearable that understands women.

The inclusion of health and wellness data in wearable health technology has the potential to transform how we manage our health. Biometric health data, which includes blood oxygen saturation (SpO_2), heart rate variability (HRV), heart rate (HR), blood pressure, body temperature, and respiration rate in the context of this paper — are important measures of health and disease states, and are biological data points captured directly from sensors or cuffs on the skin. They are also increasingly recognized as valid predictors of disease risk. Traditionally, when health statistics and guidelines have been presented to the general population, women's guidelines are not delineated from men's, and rarely are women-specific biological phases taken into consideration, such as menstrual phase, pregnancy, post-partum, and menopause status. Yet gender and sex-specific factors affect nearly every health-related data point.

There are many knowledge gaps when it comes to women's health that can be largely attributed to two factors. First, the cyclical changes in women's hormone levels at various stages of life introduce complexity that is simply greater than in men's health, which has resulted in research that does not take into account a woman's menstrual phase, pregnancy status, or menopause status. Second, there is a well recognized and historic gender-based bias against women's inclusion in research studies, which has resulted in both fewer studies focused on women, and an overall significantly lower representation of women in research studies. For these reasons, we at Movano Health are reviewing the literature on women's physiology and biometrics to show that there is a need for different interpretations of certain health and wellness data for women. This paper focuses on studies that present data on women, even if these studies don't offer specific definitions for gender or sex. We also acknowledge that trans women and men and non-binary individuals are sorely underrepresented in the literature. Although limited, we've taken some of that research to add to this report. Finally, we conclude by offering guidance on how to make healthier behavior choices using data gleaned from biosensors.

Introduction

Our biometrics are unique to us, and tell a story about how we are doing, both physically and mentally.

Tracking one's health and wellness has never been more accessible. Thanks to wearable devices and their rising popularity, there is more interest in understanding the subtle—and sometimes not so subtle—hints that our bodies are trying to tell us about our health. However, despite the improved access to health data, there is little guidance around what our health metrics mean and how to contextualize them, particularly for women. Our biometrics are unique to us, and tell a story about how we are doing, both physically and mentally. Our personal health history, genetics, goals, age, gender, sex, body composition, lifestyle, and even career affect our biometrics. For women, the added layers of biological cycles such as menstrual phase, pregnancy, menopause status, and other hormonal factors, impact their body composition, cardiovascular function, and the nervous system. Furthermore, there are psychosocial factors from societal gender norms and biases that contribute to every biomarker's potential insights and meaning for women.

With a renewed interest in health and wellness in the past decade, there are a plethora of products offered today to help track biometrics, such as counting steps, measuring sleep and HR, and more. Many of these products drive awareness about the state of the user's body. But few, if any, provide differentiated insights for women and men despite there being clear differences in biology. In this report, we present literature that demonstrates how women's biomarkers tell a different story than men's. We argue why wearable devices must take into consideration the fluctuations in biological markers that accompany a woman's hormonal makeup and psychosocial demands and why we cannot ignore the inarguable role that sex hormones, the nervous system, the menstrual cycle, chronic pain, and body composition play in women's health data and behaviors.

The Underrepresentation of Women in Healthcare Research

A primary reason for the lack of distinction between women's and men's health and wellness data is that the body of knowledge about women's health is limited. Medical research has historically focused on male health (Mazure & Jones, 2015; Steinberg et al., 2021). Until recently, women were often excluded from clinical trials, even when the clinical trials were for diseases disproportionately affecting women. This exclusion occurred for reasons such as:

- Ensuring homogeneity of treatment effect;
- Increased risk associated with studying women during pregnancy;
- Perceived difficulty of controlling for menstrual phase in research

In clinical trials used to inform guidelines for cardiovascular disease prevention in women, female participation was just 30%.

Melloni et.al., 2010

As a result, women have experienced well-documented suboptimal health care and medical outcomes (Bartlett et al., 2005). Because of the underrepresentation of women in healthcare research, there are fewer available treatments for diseases specific to women, such as endometriosis, pregnancy complications, and some autoimmune diseases. In 1993, stricter laws began requiring National Institutes of Health (NIH)-funded research to include women. Thanks to this change, today women account for just over half of all enrollees in NIH-funded clinical research (Clayton & Collins, 2014).

While women's health has become a larger focus of research, most research today that includes female participants still does not control for the menstrual cycle phase. And there continues to be an underwhelming body of literature on the effect of female sex hormones, menstrual cycle phase, pregnancy, menopause, and women's psychosocial demands on women's health.

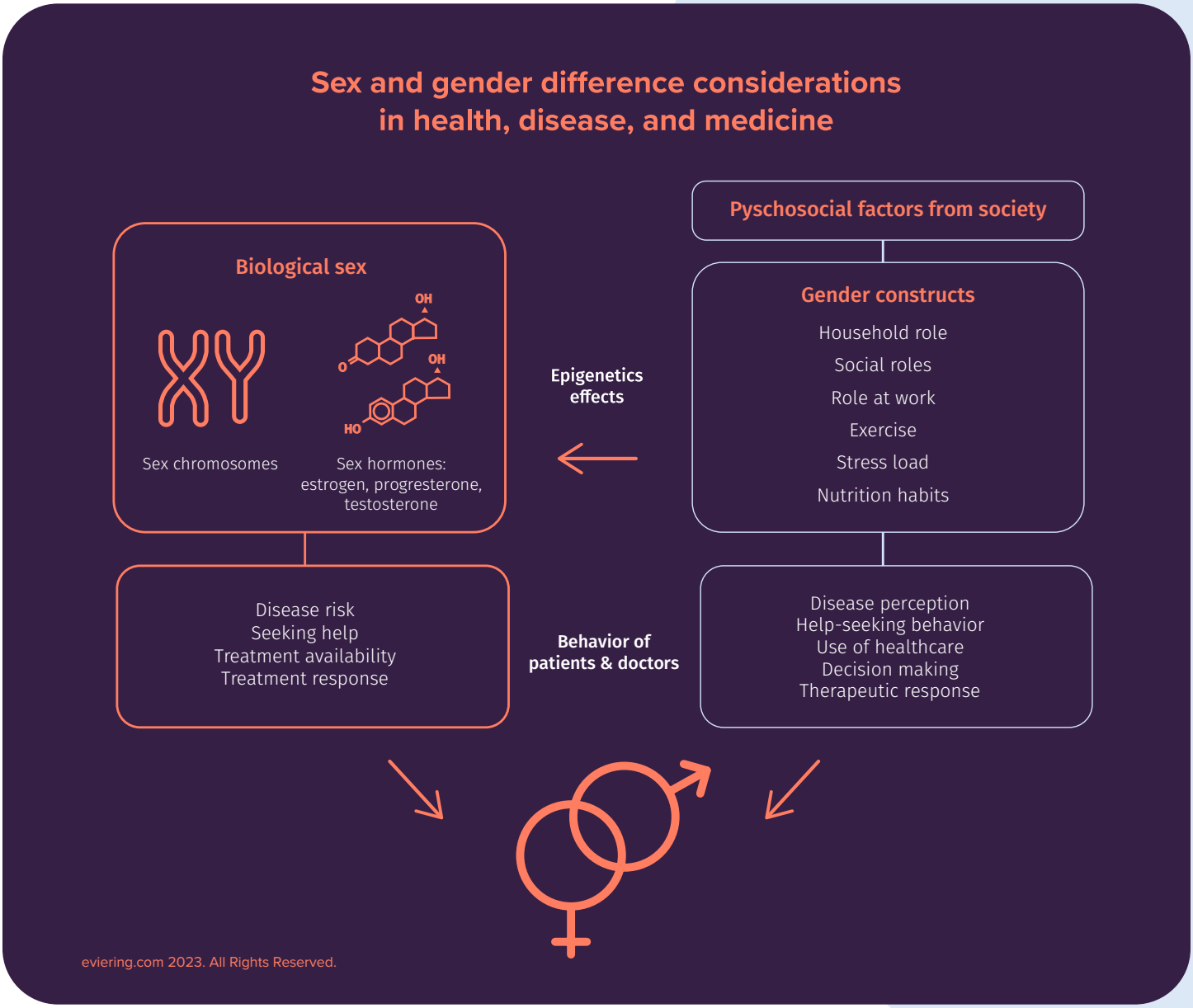
By increasing access to health data through wearable devices, women will have more control over their own health. It will also increase the accessibility of information for researchers looking to study women's health.

Women's Health: Physiology and Disease

Sex and gender-specific differences in health exist largely due to genetic and hormonal influences of biological sex. These differences influence physiology and disease, and thus biometrics.

There is a long history of gender-related social and cultural constructs surrounding the treatment of women's health. Despite the recent progress in women's health research, the number of studies including only males in biological research outnumber female-only studies, particularly in physiology, where the ratio is 4 to 1. Furthermore, when studies include both sexes, only approximately one-third of these studies have factored sex into their analyses (Beery & Zucker, 2011).

Many features of women's physiology differ significantly from men's. This includes body composition and the regulation of major systems in the body including the cardiovascular system, nervous system, and endocrine system. Yet there are few resources for women to understand these differences and how they may affect their health. We have searched the literature on women's health research and consolidated aspects of health that are different between women and men.



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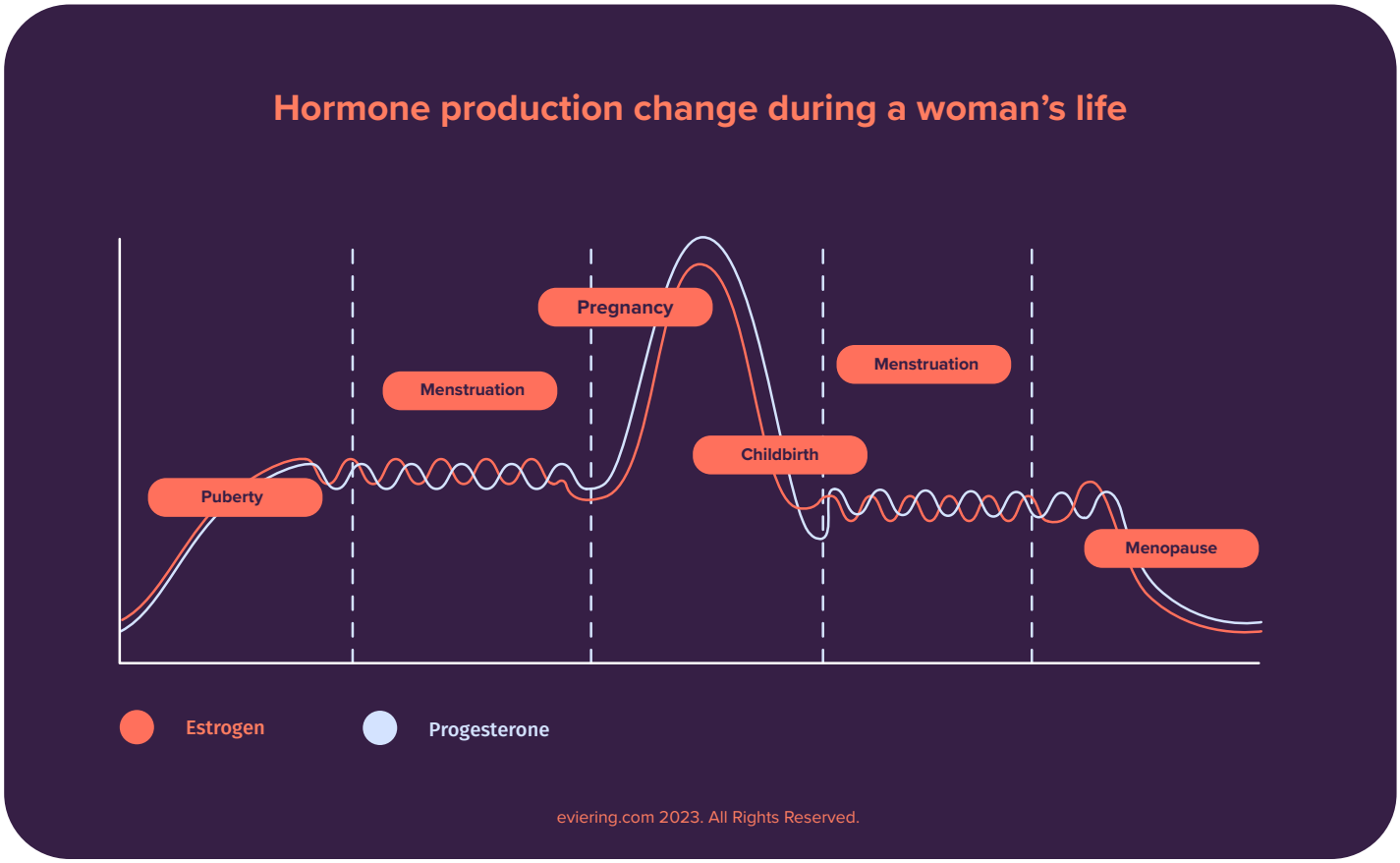
Beery & Zucker, 2011

Sex hormones

The differences between women and men when it comes to health metrics are in large part influenced by the downstream effects of sex hormones. Hormones are unique messengers in the body that impact many important aspects of development and homeostasis like cardiovascular function, mood, reproduction, metabolism, development, and body composition. They also impact women's susceptibility to disease, nervous system regulation, and mental health. Adrenal glands and gonads (ovaries in women, testes in men) produce sex hormones, which are often called reproductive hormones due to their important role in puberty, fertility, and reproduction. Estrogen and progesterone are the main female sex hormones driving the fluctuations throughout the menstrual cycle, and they both drop in production during perimenopause. In addition to driving physiological changes during the menstrual cycle, pregnancy, and menopause, female sex hormones have a significant effect on many biomarkers, including sleep, resting HR, and HRV, to name a few.

When we think about sex hormones, we often think of physical differences between biological females and males based on body shape, strength, and reproduction. However, sex hormones also have a significant impact on many aspects of physiology beyond the reproductive system, including bone structure and composition, muscle, skin, hair, mucous membranes, the urinary tract, breast tissue, and the brain. To further complicate the matter, in younger women, female hormones are dynamically fluctuating throughout the monthly menstrual cycle. During peri- and post-menopause, a woman's sex hormone profile changes drastically, once again changing a woman's physiology and disease risk. The drop in sex hormones during peri- and post-menopause can lead to changes in body fat distribution, and adverse changes to lipid and lipoprotein levels, and vascular structure and function (El Khoudary et al., 2020).

By ignoring, or not fully understanding, the many factors that differentiate women and men's biology, we are likely to miss key signals that can have major influences on women's health and well-being.



Non-binary and genderqueer

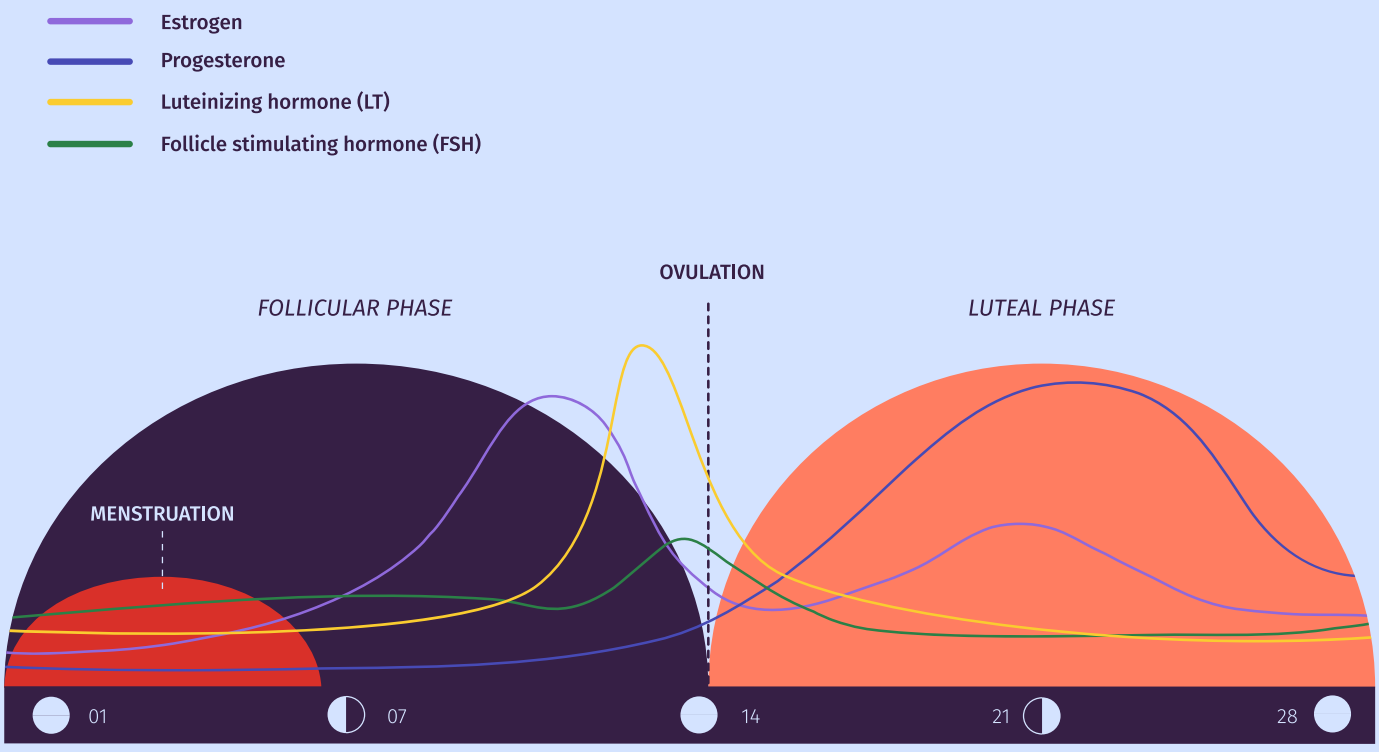
In populations that do not fall into the normative woman/female and man/male categories, such as non-binary and genderqueer people, hormone therapy is common. There is a documented higher risk of cardiovascular disease and myocardial infarction in transgender individuals, possibly due to increased social stressors, health disparity, lower socioeconomic status, and substance abuse (Alzahrani et al., 2019).

Menstrual cycle, menopause, and fertility

From puberty through menopause, women's hormones fluctuate monthly, and this cyclical nature of estrogen and progesterone results in women's biomarkers constantly adjusting to a changing hormonal profile. Hormones also change through fertility treatments, throughout pregnancies, and make a large shift during menopause. In comparison, healthy men's hormonal profile remains relatively constant from puberty.

Health indicators change in response to fluctuations in a woman's hormonal profile, usually corresponding to progesterone and estrogen levels rising and falling throughout the menstrual cycle, pregnancy, and menopause. For example, researchers have discovered that certain health data metrics change as progesterone surges following ovulation. This includes an increase in body temperature and resting HR and a decrease in sleep quality and HRV. Similar changes to biometrics occur during menopause and as a pregnancy progresses.

Hormones during the menstrual cycle



(Phase lengths are based on an average 28-day cycle)

Thanks to this discovery, continuous body temperature monitoring has become a method of detecting ovulation (Goeckenjan, Schiwek, & Wimberger, 2020). Under normal, healthy conditions, there is a noticeable increase of approximately 0.5 to 1.0 degrees Fahrenheit shortly after ovulation, indicating a "window" of higher fertility. There has been a good amount of research success surrounding methods of skin temperature tracking. And there is promise that this method could be used in the future to help identify signs of both fertility and infertility (Zhu et al., 2021).

Body composition

Body composition refers to the weight and proportions of body fat, bone mass, and lean mass (muscle and organs) in the body, and it differs significantly between women and men. Differing sex hormone profiles in women and men impact the way the body builds lean muscle and accumulates and stores fat. Men tend to have a higher ratio of lean mass to total mass than women of a similar Body Mass Index (BMI)[1], whereas women tend to have a higher ratio of body fat to whole body mass than men of similar BMI. And men tend to predominantly accumulate adipose tissue around their trunk and abdomen while women tend to accumulate it around their hips and thighs (Bredella, 2017). This can be largely attributed to differences in sex hormones, rather than lifestyle. In general, it is healthier to have a higher percentage of lean mass to total body weight, and thus a lower percentage of body fat. However, the actual healthy range for body fat percentage is different in women and men, due to differences in body composition attributed largely to hormonal differences. While higher body fat can increase the risk of heart disease, stroke, type 2 diabetes, sleep disturbances, high blood pressure, metabolic syndrome, and some cancers (NIH), there are many nuances that play a stronger role in risk profile. For example, the male pattern of fat distribution is associated with higher cardiovascular disease risk than the female pattern of fat distribution. Conversely, when women's estrogen levels drop in menopause, they can accumulate more visceral adipose tissue, which increases their disease risk profile. It is important to note that in general, higher body fat percentage above healthy ranges is associated with lower HRV, which is associated with higher risk of many diseases (Triggiani et al., 2019).

Women also tend to have lower skeletal muscle mass than men. The average percentage of muscle to body weight in men is 38.4% compared to 30.6% in women (Bredella, 2017; Janssen, Heymsfield, Wang, & Ross, 2000). This difference can be somewhat attributed to lifestyle choices, such as time spent developing muscle mass. But in addition to genetic factors, there is an underlying sex hormonal difference that causes muscle mass to develop more in men than women. Testosterone, the main sex hormone in men, is a pro-muscle hypertrophy hormone. In other words, it increases muscle mass through multiple mechanisms. Although testosterone is also present in women, its levels are significantly lower than in men.

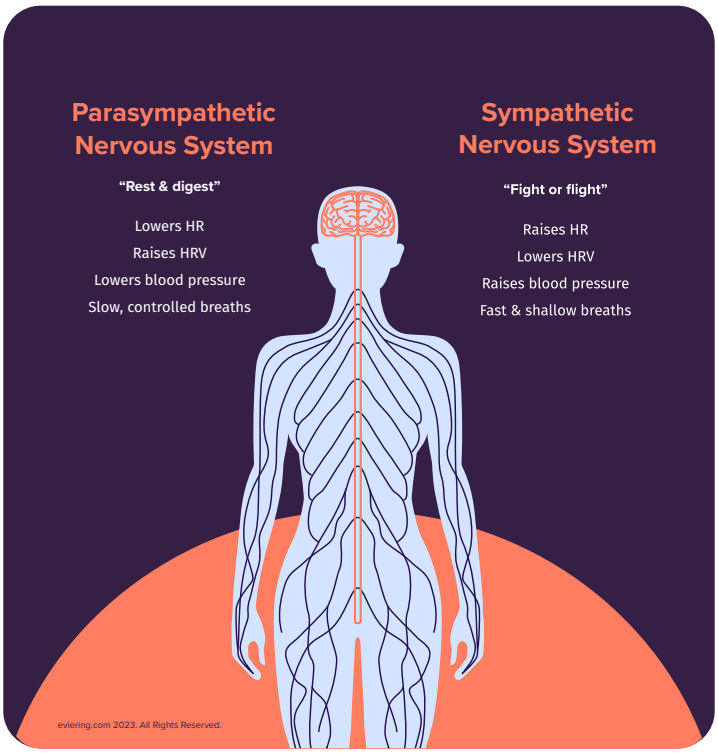
Bone density is also a component of body composition that tends to be significantly different in women and men, where women have disproportionately lower bone density than men. Osteoporosis involves a decrease in bone density that results in micro-architectural deterioration of the bones which can lead to fractures. As a result of bone density differences, osteoporosis is four times more common in women than men (Alswat, 2017). The impact of diet and exercise on bone density strongly suggests that a healthier diet and high activity levels can reduce the risk of osteoporosis (Anderson, Rondano, & Holmes, 1996; Levis & Lagari, 2012).

1. BMI has been acknowledged as a poor marker of body composition or health on an individual level and should not be used to assess body composition or health of an individual. While it is an effective tool as a blunt descriptor of body composition on a population level, it can be misleading, particularly for certain racial groups.

Nervous system

Another major body system affecting health data is the nervous system. The human nervous system divides into two branches. The first is the central nervous system, which consists of the brain and the spinal cord. The second is the peripheral nervous system, which is made up of nerves that branch off from the central nervous system and communicate with the rest of the body.

The autonomic nervous system, which is part of the peripheral nervous system, handles all involuntary actions like heart rate, breathing, respiratory rate, digestion, blood pressure, contractility of the heart, sweating, urination, and more. The autonomic nervous system divides into two separate sides:



1. **Parasympathetic nervous system** (also known as "rest and digest")

2. **Sympathetic nervous system** (also known as "fight or flight")

Working behind the scenes, these two sides exist in tandem to make necessary changes to heart rate, blood pressure, perspiration, and more to keep the body at equilibrium (Joyner, Charkoudian, & Wallin, 2010; Kleiger, Stein, & Bigger, 2005). They ensure that the body relaxes when it needs rest or responds to stress when needed at a moment's notice. The body will adjust blood pressure according to whether it needs to respond to stress, such as exercise, or relaxation, like lying down (Mancia & Grassi, 2014). It will then adjust the heart rate and how hard the heart pumps during each heartbeat in response to similar scenarios (Gordan, Gwathmey, & Xie, 2015).

Scientists have noted structural differences in the nervous system between women and men, where some studies found sex differences in the gray matter volume of specific brain regions. For example, females tend to have greater volume in the prefrontal cortex, orbitofrontal cortex, superior temporal cortex, lateral parietal cortex, and insula (Liu, Seidlitz, Blumenthal, Clasen, & Raznahan, 2020). We need more research to fully understand the implications of these differences. But what we do know is that gray matter volume aligns with functional systems for face processing, and some of these brain regions are strongly associated with specific biological processes.

There are diseases related to the nervous system for which it is critical to have a better understanding. Cognitive impairment diseases such as Alzheimer's disease and dementia disproportionately affect women, and women also provide the most caregiving to people with dementia (Winblad et al., 2016). While the causes and risk factors for these diseases range from genetic to psychosocial domains, there is an urgency to develop a better understanding of these diseases and why they affect women more than men.

Cardiovascular system

The cardiovascular system, also known as the circulatory system in the body, originates and ends in the heart. Its primary function is to deliver oxygenated blood from the lungs to tissues in the body and then to deliver waste gasses, such as carbon dioxide and back to the lungs to be exhaled. At first, it may not appear that the cardiovascular system differs between women and men, but women tend to have smaller hearts and heart chambers, leading to lower stroke volume, or volume of blood pumped per heart beat, and smaller lungs and lung volumes. There are also several mechanisms heavily influenced by sex hormones and the nervous system, leading to differences in resting HR, HR during exercise, HRV, blood pressure, and respiratory rate.

Heart disease is the leading cause of death among adult women in the U.S., accounting for approximately 1 in every 5 female deaths (Centers for Disease Control and Prevention, 2022). Many factors contribute to heart disease risk, including:

- Genetics
- Diabetes
- Being overweight or obese
- Eating an unhealthy diet
- Physical inactivity
- Drinking too much alcohol
- And receiving more recent attention, the loss of the protective role of female sex hormones due to menopause (El Khoudary et al., 2020)

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>
> Centers for Disease Control and Prevention, 2022

A large, precedent-setting study in 1986 found that women have a significantly lower risk of heart disease before menopause. This is largely due to differences in hormonal makeup. In recent years, a significant body of research has established that women have a lower risk of heart disease before menopause than men (Baig et al., 2022; El Khoudary et al., 2020; Prabhavathi, Selvi, Poornima, & Sarvanan, 2014). However, after menopause, the risk of heart disease is nearly equal between men and women. These studies show that female sex hormones play a protective role in women's cardiovascular health (Lerner & Kannel, 1986). It's also worth noting that women's heart attack symptoms differ from men's. This, along with a lower incidence of heart attacks in younger women, means that women's heart attacks are more likely to go unrecognized compared to men (34% vs 27%, respectively).

While cardiovascular disease is, on its own, a significant cause of death in women, there are comorbidities that elevate the risk of cardiovascular disease, including diabetes. Diabetes affects 11.3% of the U.S. population (Centers for Disease Control and Prevention, 2022) and about 1 in every 9 adult women. Not only does a diagnosis of diabetes significantly alter a woman's health and lifestyle, but it also increases her risk of developing heart disease, stroke, high blood pressure, dementia, and narrowing blood vessels. Furthermore, altered glucose metabolism as a result of diabetes can lead to cardiac autonomic neuropathy, resulting in lower HRV, higher resting HR, and lower SpO_2 (Laursen et al.)

Chronic pain is one of the most prevalent human conditions, affecting over 25% of the world's population.* And women significantly represent a higher percentage of those with chronic pain.

Bartley & Fillingim, 2013

*Institute of Medicine Committee on Advancing Pain Research & Education, 2011

Pain

There is increasing evidence that stark sex differences exist in the experience of pain, including pain sensitivity, the prevalence of acute and chronic pain, and analgesic responses. Chronic pain is one of the most prevalent human conditions, affecting over 25% of the world's population (Institute of Medicine Committee on Advancing Pain Research & Education, 2011). And women significantly represent a higher percentage of those with chronic pain (Bartley & Fillingim, 2013). Several chronic pain conditions can only occur in females, including:

- **Endometriosis** (affecting roughly 10-15% of reproductive-age women and girls globally (Smolarz, Szyłło, & Romanowicz, 2021))
- **Vulvodynia** (experienced by 8.3% of women from a large sample of women in Michigan (Reed et al., 2012))
- **Menstrual pain** (84% of women report pain and 34.2% report severe pain (Kural, Noor, Pandit, Joshi, & Patil, 2015))

Other common chronic pain disorders, including chronic fatigue syndrome, fibromyalgia, interstitial cystitis, and temporomandibular disorder, occur overwhelmingly more often in women (over 80%) than men (Mogil, 2012). Chronic pain could impact several health metrics in women, including:

- **Lower HRV** (Koenig, Loerbroks, Jarczok, Fischer, & Thayer, 2016)
- **Worse sleep** (Finan, Goodin, & Smith, 2013)
- **Higher blood pressure** (Saccò et al., 2013)

Women & Biometrics

Health-related biometrics allow us to track a wide range of data about our bodies. But on their own, without taking into account the nuances of sex and gender, these data points tell an incomplete story. Think of health metrics as small pieces of a puzzle. Only when interpreted together, as part of the larger context of the human body, can they paint a clear picture of someone's health.

In previous sections, we described why it's important to consider women's biological and psychosocial makeup when interpreting health data. Below, we describe factors that affect health and wellness data in women, and outline some of the health metrics women can track on their own outside the medical setting.

Biometrics in Women

SpO_2

SpO_2, also known as blood oxygen saturation, is a measure of the amount of oxygen that red blood cells are carrying relative to their total capacity. Oxygen in the blood is critical to survival. The body needs oxygen to maintain function in all of the major organ systems in the body, such as the brain, heart, and kidneys.

For most people, an SpO_2 of 96 to 100% is normal. And research has found that resting SpO_2 decreases on average by 0.2% per decade (Vold, Aasebø, Wilsgaard, & Melbye, 2015). Low oxygen saturation is a sign that the blood is not carrying as much oxygen as it could be. This means there could be an underlying issue, such as respiratory illness, disease, or another condition that affects the oxygen transport from the lungs to the bloodstream. For example, SpO_2 can be indicative of a sleep condition, such as sleep apnea or heart disease. In pregnant women with pre-eclampsia, low SpO_2 (lower than 93%) results in a higher likelihood of worse outcomes than in women with normal SpO_2 (Millman et al., 2011).

Heart rate variability

Heart rate variability (HRV) is one of the best-kept secrets to managing our overall health and understanding the body's stress level. The variation between heartbeats is a strong indicator of our body's general readiness, adaptability, and well-being. It can suggest the presence of heart conditions, anxiety, and other potential health problems. It's now a common metric used by everyone from elite athletes tracking their recovery to doctors assessing patients' risk profiles for certain diseases, such as heart disease in post-menopausal women (Baig et al., 2022).

Reproductive hormones in women, particularly estrogen and progesterone, significantly affect cardiovascular function, which in turn affect HRV. This causes fluctuations in HRV throughout the menstrual cycle, including higher HRV during the proliferative phase of the cycle or around the first 14 days of the cycle (Brar, Singh, & Kumar, 2015). However, because there are so many biological factors that affect HRV, it is inadvisable to compare HRV between women and men. For example, HRV in pre-menopausal women tends to be lower than in men. This is a trend generally associated with lower parasympathetic tone, higher sympathetic activity, and greater stress. But at the same time, research has demonstrated that women have a more active parasympathetic nervous system.

This further emphasizes why it's not advisable to compare HRV between women and men (Koenig et al., 2016). After menopause, HRV declines in women, which is correlated with the significant declines in estrogen and progesterone (Voss, Schroeder, Heitmann, Peters, & Perz, 2015). Since increased cardiovascular disease risk and cognitive decline are also associated with menopause (Ramesh et al., 2022), HRV can be an important marker to help identify when to take action to improve health outcomes in women. There is also emerging evidence that HRV could be a promising predictor of breast cancer tumor stage, where advanced-stage patients have significantly lower HRV compared to benign and early-stage patients (Wu, Chen, Wang, Shi, & Zhou, 2021).

Resting heart rate

A lower resting HR is generally associated with better health behaviors and outcomes, higher fitness, healthier body composition, and lower general stress and risk of disease (Reimers, Knapp, & Reimers, 2018). Resting HR is generally best used to track trends over time, and is a good metric for women to be familiar with when it comes to their health.

Interestingly, women tend to have higher resting HRs than men. The average adult male resting HR is 70 to 72 beats per minute (bpm) and the average adult female resting HR is 78 to 82 bpm (Prabhavathi et al., 2014). Research shows that resting HR is higher in women after drinking alcohol, during sickness, and when undergoing stress (Altini & Plews, 2021). In general, a high resting HR is a risk factor for cardiovascular disease (Koenig et al., 2016) and diabetes in women (Zhang et al., 2010). However, there are instances where increases in heart rate are not causes for concern. For example, resting maternal

heart rate increases throughout a healthy pregnancy (Loerup et al., 2019). And one study notes that resting HR is significantly higher in the ovulatory and luteal phases of the menstrual cycle compared to the menstrual and follicular phases (Moran, Leathard, & Coley, 2000).

Blood pressure

Pre-menopausal women are less likely to have high blood pressure, or hypertension, than men. This is largely due to differences in the renin-angiotensin system and nitric oxide systems in the body. These differences result from the protective effect of female sex hormones on blood vessel tension (Regitz-Zagrosek & Kararigas, 2017). But after menopause, this protective effect of sex hormones starts to disappear, and after the age of 65, a higher percentage of women than men have hypertension (Roger et al., 2011). Given that high blood pressure is a major risk factor for heart disease in women, it is important to track cardiovascular health in order to intervene early if a woman's risk profile is high.

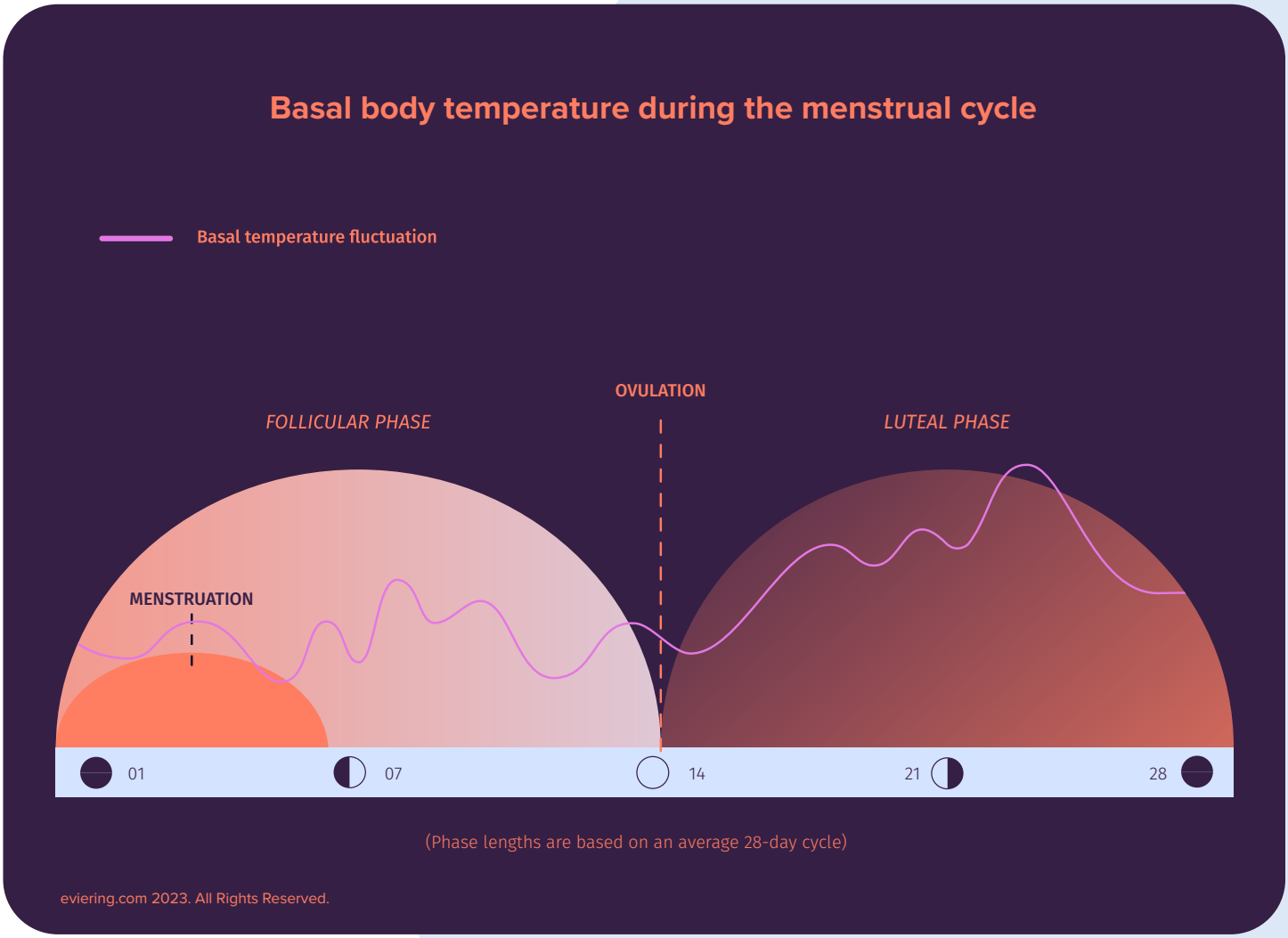
Approximately 40% of strokes, 39% of myocardial infarctions, and 28% of end-stage renal diseases are largely attributed to hypertension (Gudmundsdottir, 2020). Early intervention can delay mortality and improve quality of life. Finding ways to detect early signs of high blood pressure is critical. The ability of the blood vessels to adapt and respond quickly to changes in blood flow and pressure is an important protective mechanism against cardiovascular disease. The measurement used to determine this is called flow-mediated dilation. Women have significantly higher flow-mediated dilation than men during both the follicular and luteal phases of the menstrual cycle. But their flow-mediated dilation is nearly identical to men's during menstruation (Hashimoto et al., 1995). This means that women's physiological response to the demands of exercise or other stressors could vary throughout the menstrual cycle. Health and wellness data from wearable devices can predict and track risk factors for cardiovascular disease by identifying when HRV is lower and resting HR is higher than historic trends in women with hypertension (Cooney et al., 2010). They could also help women not only track the phase of the menstrual cycle they're in, but also help identify trends in their biometrics compared to expected norms and their own historical data to support their health.

Body temperature

Normal basal body temperature varies by person, age, activity, genetics, and time of day. The average body temperature is between 97.0 and 98.6 degrees Fahrenheit (Geneva, Cuzzo, Fazili, & Javaid, 2019).

In women, core body temperature changes with the rise and fall of progesterone during the menstrual cycle. Body temperature increases immediately following ovulation, and continues to stay high during the luteal phase (Baker, Siboza, & Fuller, 2020) before dropping to its lowest point during menstruation and the follicular phase. The thermogenic effect of progesterone and the temperature-reducing effect of estrogen creates this relatively stable and predictable cycle of body temperature. As a result, body temperature is commonly used by healthcare professionals, and increasingly by individuals, in pregnancy planning or prevention (Bull et al., 2019). And among women in perimenopause (the menopause transition), elevations in core body temperature often precede incidents of hot flashes (Freedman, Norton, Woodward, & Cornélissen, 1995). Recent research has found that using wearable technology to continuously measure skin temperature may be a more accurate or sensitive method to track basal body temperature compared to single points of measurement such as those obtained using an oral thermometer (Zhu et al., 2021).

There is also increasing evidence that fluctuations in women's body temperature may impact their ability to thermoregulate in extreme heat and during exercise. This suggests that women should pay even closer attention to hydration and monitor body heat regulation during the second half of the menstrual cycle, menopause, and while ill.



Respiratory rate

The respiratory system is the super highway for oxygen to reach the bloodstream, and respiratory rate constantly fluctuates in response to the needs of the body. Several sex differences in its structure and function can affect our respiratory rate, lung capacity, and oxygen consumption. For example, women tend to have smaller airways, lungs, and a more "prismatic" shape of the ribcage than men (Dominelli & Molgat-Seon, 2022). As a result, baseline respiratory rate is generally higher in women than in men (Molgat-Seon et al., 2018). It is also well established that an increased respiratory rate can lower HRV, as it stimulates the sympathetic nervous system, or vice versa, and that slow, intentional breathing can increase parasympathetic tone and HRV (Russo, Santarelli, & O'Rourke, 2017). Given the close correlation between respiratory rate and cardiac vagal (parasympathetic) tone, a high respiratory rate has been closely correlated with adverse health conditions, such as cardiac events, pneumonia, COVID-19, and other clinical deteriorations (Chatterjee et al., 2021; Nicolò, Massaroni, Schena, & Sacchetti, 2020). The fact that respiratory rate can predict adverse health outcomes is a big reason why this is a key metric in health wearables. It's important to not only include it, but also factor into the interpretation of data the context that women have significantly higher resting respiratory rates than men.

Biometric tracking is the first step in developing a better awareness of our bodies and the signals they are sending. With a greater availability of data, we are beginning to better understand our health and identify areas that could use improvement, along with potential red flags for health complications. The next step is understanding what actions we can take to improve trends. In the following section, we identify lifestyle behaviors that have a significant impact on health-related biometrics.

How to Improve Your Health by Tracking Biometrics

Physical activity

Regular physical activity is one of the most important pro-health behaviors among adults. There are both short and long-term benefits of an active lifestyle, a consistent workout schedule, and even a single bout of physical activity. Adequate physical activity can prevent, delay, or manage the development of a myriad of diseases (Ward, Schiller, & Goodman, 2014). Physical activity can lower the risk of all-cause and cardiovascular disease and mortality in women. This means that active women are more likely to live longer, healthier lives (Hu et al., 2005).

From childhood, girls fall behind boys in minutes per day of physical activity (Nader, Bradley, Houts, McRitchie, & O'Brien, 2008). This trend continues into adulthood. Adult women are generally more sedentary than men, where 29.4% of women over 50 in the U.S. are inactive compared to 25.5% of men (Watson, 2016), but there are many reasons for women's higher rates of inactivity. Research demonstrates that many of the barriers to higher physical activity among females are psychosocial, rather than physical (Edwards & Sackett, 2016). For example, researchers have found that when it comes to exercise, women have lower self-efficacy, perceived competence, social support, and motivation to exercise, and higher levels of perceived barriers than men (Edwards & Sackett, 2016). Women also report several gender-specific psychosocial barriers to greater physical activity, including body image, enjoyment, motivation, lack of social support, subjective gender norms, perceived competency, outcome expectations, attitudes, and enjoyment of physical activity (Pan et al., 2009).

The World Health Organization recommends that adults engage in at least 150 to 300 minutes of moderate-intensity aerobic physical activity or 75 to 150 minutes of vigorous-intensity aerobic physical activity throughout each week. Additionally, it recommends that adults should engage in muscle-strengthening activities at moderate or greater intensity two or more days per week. However, only 1 in 4 adults meet these guidelines.

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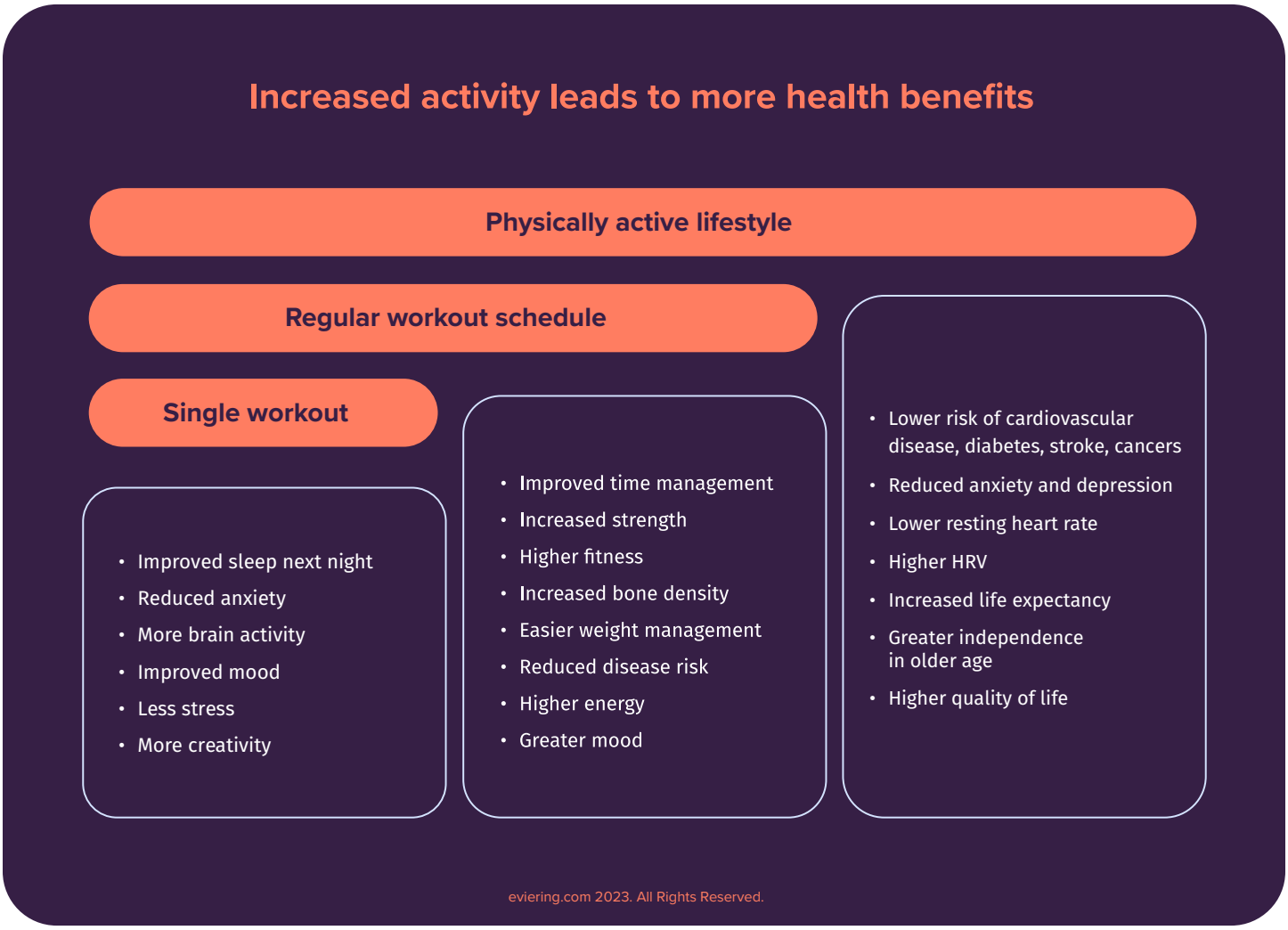
Watson, 2016



The health implications of lower physical activity among women can have far-reaching negative effects on women's health. Given the barriers and health implications that women face, it's imperative to improve women's physical activity rates. But to do so it's important to tailor physical activity feedback and recommendations to women's specific motivations and context preferences. For example, in a large study investigating older adults' motivators for participating in physical activity, researchers found that the majority of women's motivating factors for physical activity included appearance, weight, and social factors. The type of activity, timing, exercise format, and social setting also made a difference (van Uffelen, Khan, & Burton, 2017). In contrast, men were more motivated to engage in physical activities that require skill and practice, vigorous intensity, and competition.

With more regular physical activity, women can improve countless aspects of their quality of life. Researchers have demonstrated a positive correlation between daily active minutes and the quality of sleep in women (Sullivan Bisson, Robinson, & Lachman, 2019). In fact, a recent study found that young adults who underwent a 15-week exercise training regimen pursued healthier dietary preferences and were more likely to regulate their food intake (Joo, Williamson, Vazquez, Fernandez, & Bray, 2019). In short, by taking control of their health and tracking their health-related biometrics, women are more likely to make healthier choices to see improvements in their health.

Mental health

There is also a gender gap in mental health disorders. Women have a higher lifetime prevalence of mood or anxiety disorders than men, and unfortunately, there is little understanding as to what causes these differences (Riecher-Rössler, 2010). It could be that changes in sex hormones increase the vulnerability to mood disorders in women (Brzezinski-Sinai & Brzezinski, 2020). Diagnosed postpartum depression affects between 10 to 20% of new mothers, and there are estimates that over 50% of women with postpartum depression go undiagnosed (Payne & Maguire, 2019).

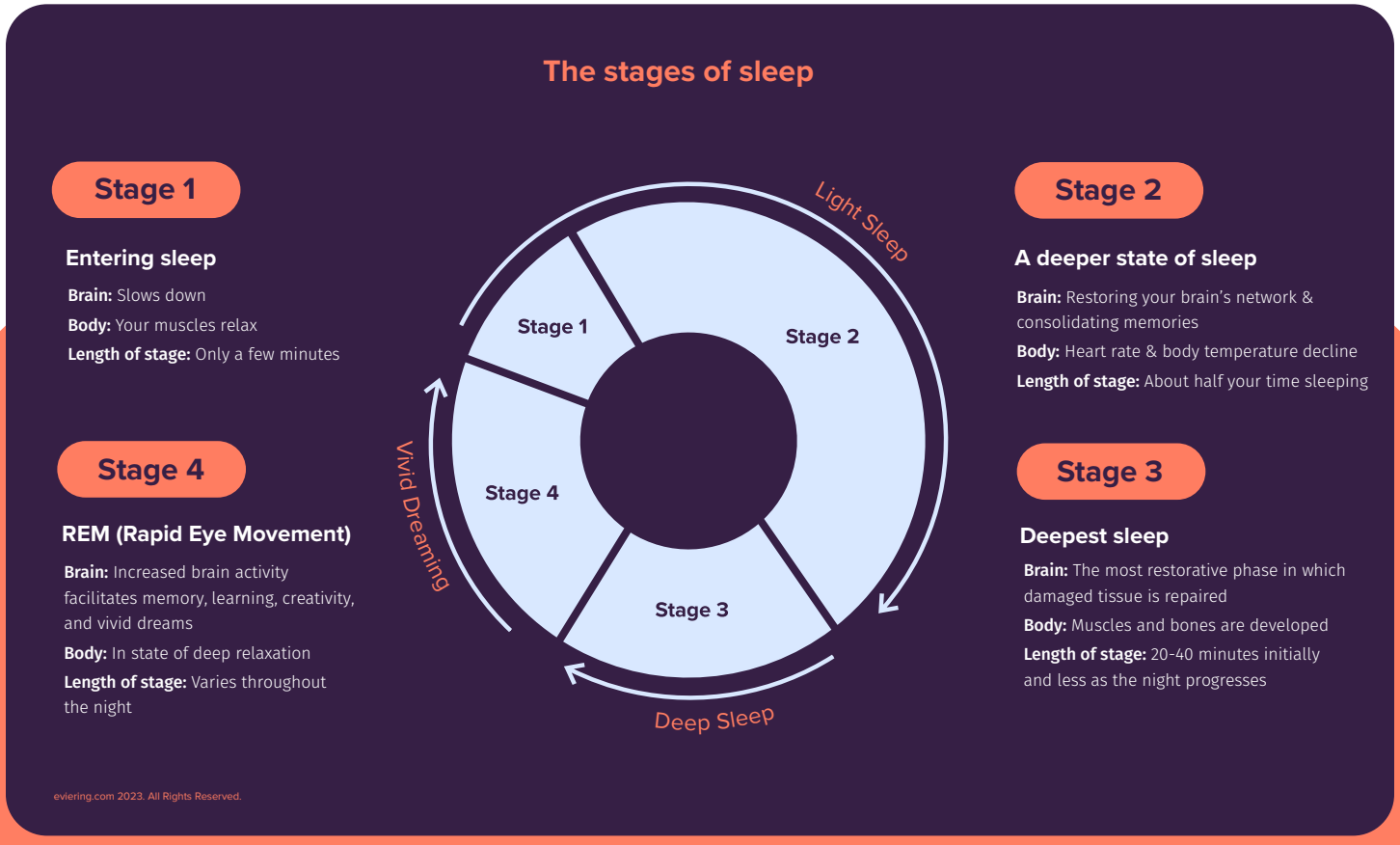
Mental health plays a significant role in the feedback loop of health, impacting the nervous system, endocrine system, lifestyle behaviors, and biometrics. While mood may not seem like it's correlated with your health, it is closely linked to many health-related outcomes (Peluso & Andrade, 2005). In fact, anxiety and depression are associated with lower HRV, higher resting HR, higher blood pressure, and worse sleep (Gorman & Sloan, 2000). Because of the intrinsic link between mental and physical health, engaging in behaviors that improve some of these biometrics could help reduce symptoms of anxiety and depression. Improvements in mood can occur, for example, by practicing physical activity, breathing exercises, and mindfulness (Busch et al., 2012). These actions could help increase HRV, improve sleep, and lower resting HR.

> **While mood may not seem like it's correlated with your health, it is closely linked to many health-related outcomes.**
>
> Peluso & Andrade, 2005

> **In fact, anxiety and depression are associated with lower HRV, higher resting HR, higher blood pressure, and worse sleep.**
>
> Gorman & Sloan, 2000

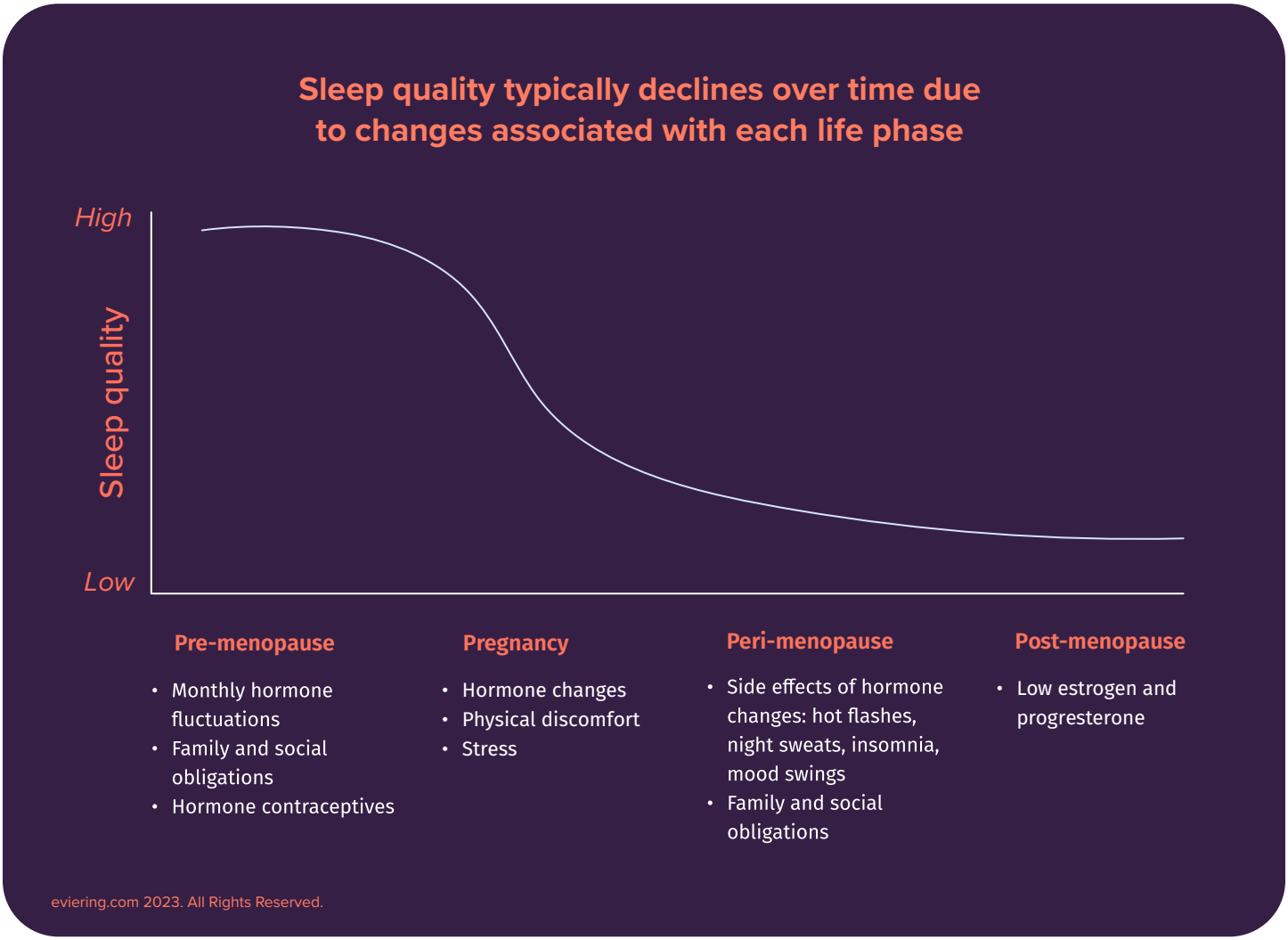
Sleep

Sleep is one of the most important aspects of maintaining physical and mental health. The human body cycles through two main phases of sleep: rapid eye movement (REM) and non-rapid eye movement (NREM). NREM sleep divides into three stages, each of which is progressively deeper sleep. During sleep, the body cycles through all of these stages on average between 4 to 6 times each night. Each phase and stage of sleep includes variations in muscle tone, brain wave patterns, and eye movements. The balance of these stages can affect how rested women feel during waking hours (Patel, Reddy, & Araujo, 2022). The problem is that women face many obstacles when it comes to getting quality sleep. Compared to men, women's sleep is often of a lower standard. Women are more likely to experience sleep deficits due to family and social obligations that compete with sleep (Staessen et al., 1992). The continually fluctuating hormone levels throughout women's lives—especially in estrogen, progesterone, melatonin, cortisol, and testosterone—have a significant impact on their ability to get a good night's rest (Pengo, Won, & Bourjeily, 2018).



Since progesterone is so closely related to sleep quality, women often experience sleep quality and duration very differently throughout their lives due to hormonal fluctuations. Before menopause, research suggests that women experience less REM sleep during the follicular and ovulation phases of their cycle and more REM sleep during the luteal phase. During pregnancy, sleep disturbances are common and tend to worsen as pregnancy progresses. Most obviously, the physical changes that occur during pregnancy can result in discomfort and therefore a worse night's sleep. Additionally, hormone changes can result in more fragmented sleep and less deep sleep. During and after menopause, women stop producing estrogen and progesterone, which have major impacts on sleep. Drops in progesterone can lead to the development of sleep apnea since it relaxes upper airways and causes lapses in breathing (Andersen, Bittencourt, Antunes, & Tufik, 2006).

Tracking biometrics allows for close monitoring of both sleep quality and duration. Tracking sleep habits can improve sleep by helping women understand if they are sleeping less or more poorly than they could or should be. By paying special attention to biometrics that can signal parasympathetic nervous system activity, and thereby relaxation, women can make behavior changes that will help improve their sleep hygiene. For example, monitoring heart rate and HRV can help women engage in activities that lower heart rate and increase HRV, both of which can improve sleep quality and duration.



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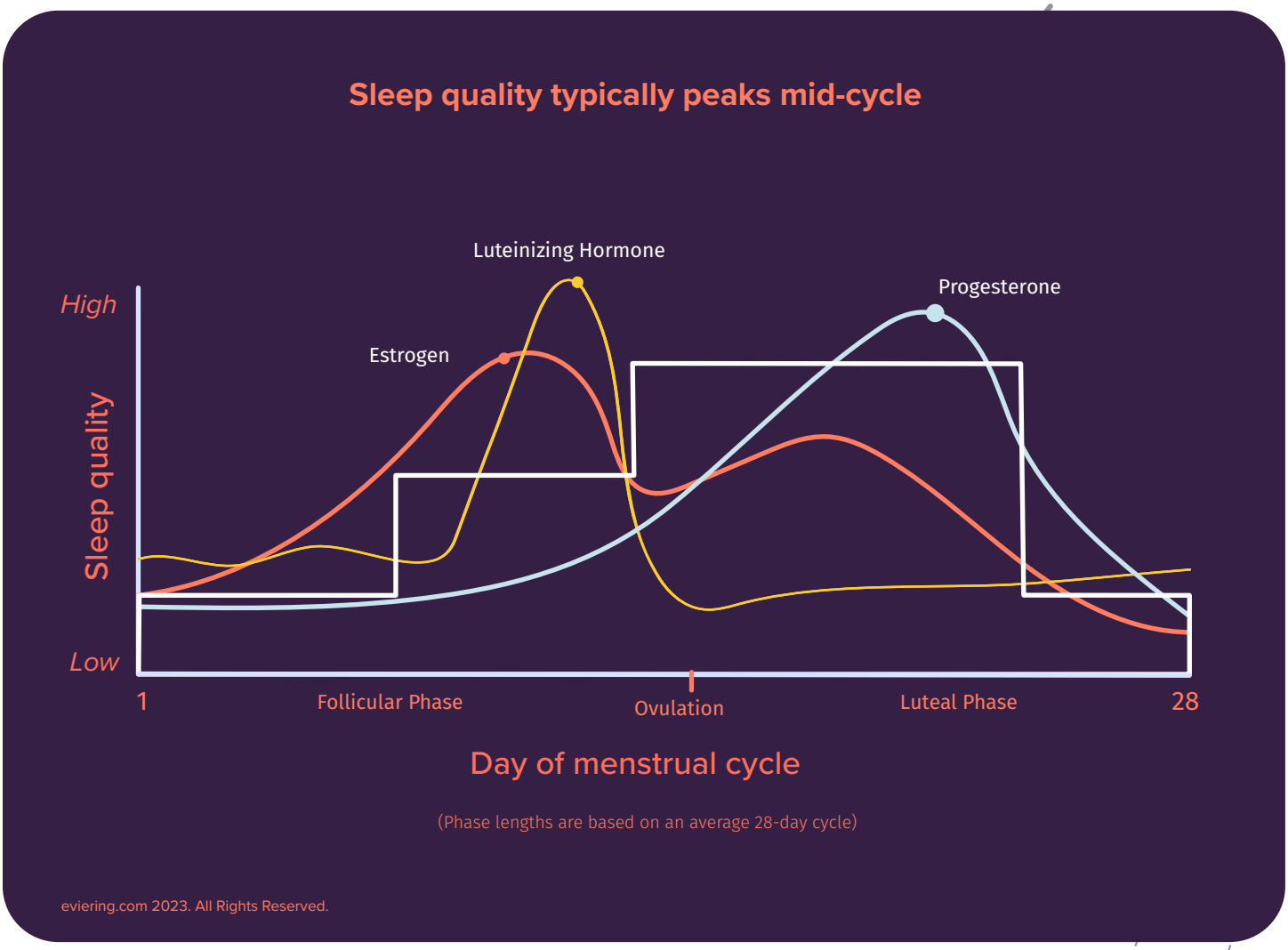

Diet

Diet also plays an integral role in physiological function. The contents of one's diet can affect the composition of electrolytes and sodium in the blood, inflammation in the body, healthy bacteria in the gut microbiome, and more. Effects of the diet, like inflammation, blood glucose levels, and obesity, can also impact HRV (Singh et al., 2000). In fact, research has demonstrated that weight loss can lead to improvements in HRV. In a study exploring the efficacy of a 12-week dietary weight loss program on cardiovascular health in postmenopausal women, weight loss was correlated with improvements in HRV and cholesterol (Mouridsen et al., 2013).

Tracking health and wellness data doesn't directly result in an improved diet. But researchers have found that the simple act of tracking data can lead to pro-health behaviors, such as eating a healthier diet and exercising more regularly (Sullivan & Lachman, 2016). By wearing a tracker that provides feedback, women develop a stronger sense of control over their health. And research shows that a sense of control can have a positive influence on physical and mental health behaviors (Hong et al., 2021).

The importance of women tracking their health metrics

Since the mandatory inclusion of women in NIH-funded clinical trials thirty years ago, the knowledge base surrounding women's health has grown substantially. However, health and wellness products and education still rely heavily on information sources that have not adequately taken into consideration the intricacies of women's physiology. Given that a woman's hormonal profile changes daily during pre-menopause and then undergoes a drastic change in pregnancy, perimenopause and postmenopause, it is unwise to compare her data to men's. Or even to compare her data against another period in her life or another phase in her menstrual cycle.

It's important to offer women more insights into their health based on their metrics, while also taking into account the critical data concerning their hormonal profile. Only by doing this can we empower women to make healthy behavior changes in real-time to improve their quality of life, and live longer, healthier lives.

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