



The Multifaceted Influence of Sleep Deprivation on Cognitive and Physical Performance: A Comprehensive Review of Dietary, Behavioral, and Physiological Factors

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Abstract

Background: Sleep is a fundamental physiological process essential for maintaining health and cognitive function. Sleep deprivation has been linked to various health issues, including cognitive deficits, impaired physical performance, and increased susceptibility to chronic diseases. Understanding the multifaceted influences on sleep quality is crucial, particularly in contemporary society where sleep disorders are on the rise.

Methods: This narrative review synthesizes findings from observational studies, experimental trials, and meta-analyses published between 2012 and 2023, focusing on the effects of dietary factors, physical activity, and stimulant consumption on sleep quality. Databases including Medline and Web of Science were utilized to gather relevant literature.

Results: The review indicates that inadequate sleep duration, particularly less than 7 hours per night, is associated with increased risks of obesity, hypertension, cardiovascular diseases, and mental health disorders. Dietary components, such as macronutrient composition, caffeine, and alcohol intake, significantly impact sleep quality. Moreover, the role of the glymphatic system in removing neurotoxic waste during sleep underscores the importance of sufficient sleep for neurological health.

Conclusion: Enhanced understanding of the complex interactions between sleep, nutrition, and lifestyle factors can inform public health strategies aimed at improving sleep quality and overall health outcomes. Interventions focusing on optimizing diet and physical activity, alongside minimizing stimulant consumption, are recommended to mitigate the adverse effects of sleep deprivation.

Keywords: Sleep deprivation, cognitive performance, dietary influence, physical activity, health outcomes.

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1. Introduction

Sleep is a natural and reversible state regulated mostly by neurobiological mechanisms, essential for the preservation of health and well-being. Sleep is linked to diminished awareness of environmental stimuli and the cessation of motor functions [1]. The quality of sleep is affected by several variables, including nutrition, physical activity, genetics, and environmental conditions [2-4]. Sleep has a multifaceted influence on the body: it decreases energy expenditure, enhances the replenishment of energy reserves in the brain, modulates both adaptive and innate immunological responses, and facilitates memory consolidation (the stabilization of learned information in the brain) [2,5-8]. Sleep disturbances are linked to the beginning and progression of several illnesses, including cardiovascular disease, depression, and cancer [9-11]. Sleep disturbances increase the risk of infectious illnesses [12-15].

In contemporary society, the notable rise in noncommunicable illnesses and sleep disorders underscores the critical relevance of knowing the elements that enhance sleep quality. This narrative review aims to examine the variables influencing sleep quality, including diet, stimulants, and physical exercise.

2. Stages of Sleep and Their Duration

Sleep continuity is evaluated by the total sleep duration, the latency to sleep onset (i.e., the interval between turning out the lights and achieving sleep), and the quality and quantity of sleep during the sleep period [14,16]. Physiological sleep has two primary phases: the REM (rapid eye movement) phase and the NREM (non-rapid eye movement) phase, which recur throughout the sleep cycle. The REM phase is linked to the activation of the sympathetic nervous system, resulting in elevated temperature, blood pressure, and heart rate [17]. During the REM sleep phase, there is a reduction in muscular tone and activation in the limbic areas, indicating that REM contributes to emotional regulation. The NREM phases are prolonged and correlate with the activity of the parasympathetic nervous system, while the REM phase is characterized by reductions in body temperature, blood pressure, and heart rate. The NREM sleep phase facilitates memory consolidation, metabolic control, and cerebral repair [17,19].

Sleep problems linked to inadequate or absent NREM phases are a growing public health concern that impacts total bodily function [17]. Adults typically allocate around 20–25% of their entire sleep duration to the REM phase and 75–80% to the NREM phase, experiencing four to five NREM cycles. Significant inter- and intraindividual variations exist in sleep duration among individuals [18]. A study of monozygotic and dizygotic twins demonstrates the heritability of sleep duration [19]. The length of sleep is affected by heredity to a degree of 31 to 55%, indicating a substantial genetic effect on sleep duration [19]. This research demonstrates that both the length of sleep and factors such as insomnia, habitual sleep time, midday sleep, and subjective sleep quality may be inherited across identical and fraternal twins [19]. Alongside genetic characteristics, environmental elements, including job time and kind, commuting distance, professional and familial obligations, and social interactions, can affect sleep requirements. To facilitate "healthy" sleep, it is essential to provide sufficient length, consistency, quality, and the absence of sleep disruptions.

The duration of sleep in healthy individuals diminishes with age: a newborn requires 14–17 hours of sleep daily, adults need 7–9 hours, and elderly persons require 7–8 hours. Inadequate sleep of less than 7 hours correlates with diminished wellbeing and compromised health. Moreover, those who experience insufficient sleep are at an elevated risk of several ailments (e.g., melancholy, mental disorders, coronary heart disease, metabolic syndrome, hypertension) compared to those who have an adequate amount of sleep (7–8 hours) daily [10,12,20].

3. Insomnia and Its Associated Risk Factors

Insomnia is a clinical illness marked by challenges in initiating or sustaining sleep, accompanied by daytime fatigue and irritation. It cannot be ascertained only by the quantity of sleep hours each day. Insomnia problems are prevalent in around 10–20% of the adult population, based on current information [21]. They are affected by variables like prolonged sleep length, wakefulness after sleep, respiratory problems during sleep, reduced sleep duration, and sleep fragmentation [22]. Insomnia results in heightened alertness

during wakefulness, sleep accompanied by an elevated metabolic rate, and higher concentrations of adrenocorticotrophic hormone and cortisol in the first sleep phase [23].

The predominant symptoms linked to insomnia are sleep disturbances (affecting around 50–70% of individuals), difficulties in initiating sleep, and inadequate restorative sleep. Sleep problems may be categorized as secondary (e.g., medications) or main (e.g., psychological illnesses) [23]. Sleep disturbances may present as early awakening, irrespective of bedtime, leading to diminished productivity and focus, increased irritation, heightened risk of errors and accidents, and a decline in quality of life [24]. Insomnia in children results in diminished focus, hence hindering academic achievement. This may be contingent upon certain circumstances and actions, such as weighing the infant before bedtime or administering bottle feeding. If there is no stimulation before to bedtime, the youngster may struggle to go asleep [24].

Insomnia is a contributing factor that elevates the risk of several disorders, including asthma, gastric reflux, hypertension, cardiovascular diseases, and type 2 diabetes [24]. The misalignment of the hypothalamic-pituitary axis in chronic insomnia affects thyroid hormone levels by elevating cortisol, corticotropin-releasing hormone, and thyrotropin concentrations [24]. A meticulous diagnosis is essential to identify or exclude insomnia, given the multitude of sleep disorders that patients may confuse with it, including sleep apnea, restless legs syndrome, or nocturnal cramps [24]. Restless legs syndrome (RLS), commonly referred to as Willis-Ekbom illness, is defined by involuntary movements resulting from discomfort and agony in the legs. The symptoms diminish with physical activity [25]. Insomnia is often associated with other conditions, such as obstructive sleep apnea and nocturnal cramps, underscoring the need of a comprehensive diagnosis. The objective of insomnia therapy is to enhance both the quality and quantity of sleep, therefore improving the patient's wellness and quality of life [23].

The diagnosis of insomnia hinges on the efficacy of sleep, specifically the ratio of total sleep duration to time spent in bed. Prolonged time spent in bed while attempting to fall asleep is a primary issue for those with insomnia. Sleep problems impact the onset of anxiety during and before to sleep onset, thus contributing to the emergence of insomnia [26]. Cognitive behavioral therapy is beneficial since it seeks to address insomnia by altering perceptions, attitudes, and beliefs around sleep. This treatment seeks to diminish negative sleep cognitions, enhance sleep hygiene, and decrease time spent in bed, hence improving sleep efficacy [26].

Annually, an increasing number of individuals report a decline in their sleep quality, along with issues such as insomnia, persistent sleep disturbances, nocturnal awakenings, and extended dreaming. The decline in sleep quality and the prevalence of insomnia are seen in the overall population, with a higher frequency among women and those aged 65 and older. Numerous variables contribute to the onset and progression of insomnia, including coffee use, occupational stress, bereavement, divorce, domestic violence, and irregular work schedules. Individuals exhibiting perfectionism, neuroses, a repressed personality, or heightened vulnerability to anxiety are more prone to sleep problems [25].

Sleep issues may also manifest in youngsters. They may be affected, for instance, by postponed developmental milestones, separation anxiety, and hyperactivity [25]. Children's sleep disturbances may result from the absence of certain objects (such as cherished plush toys), insufficient stimulation (such as bedtime storytelling, reading, or swinging), and the parents' departure from the room. These variables may result in heightened anxiety in youngsters, potentially leading to sleeplessness [25].

The sleep-wake cycle may be influenced by stimulants, including alcohol, coffee, and smoke, as well as the use of technological gadgets [26]. The use of electronics in the bedroom diminishes sleep duration and results in constant exposure to external stimuli (such as a ringing telephone) and a decrease in melatonin secretion (due to strong screen light) [27].

4. Roles of Sleep

Two effector systems govern the regulation of the immune response (innate and adaptive): the sympathetic nervous system and the hypothalamic–pituitary–adrenal axis, both of which are affected by sleep. Insufficient sleep leads to a diminished production of antibodies by the immune system, which are crucial

for the body's defensive responses [28,29]. During sleep, the secretion of cortisol, norepinephrine, and adrenaline diminishes. The levels of hormones influencing cell development, including growth hormones, melatonin, and prolactin, rise. Prolactin and growth hormone affect the differentiation and development of new T cells and enhance the activity of type 1 cytokines that regulate the antigenic response of lymphocytes [29].

Sleep decreases energy expenditure (the basal metabolic rate declines) since it lowers body temperature, among other factors. The glucose used by the brain diminishes: during slow sleep, glucose consumption is twice that of the awake state (brain cells exhibit a decreased glucose need). This reduction is not attributable to an extremely low blood glucose level, since it remains consistent with the level seen during wakefulness [2]. During the REM phase, the metabolic rate increases, leading to heightened glucose consumption relative to the NREM sleep phase [2].

The glymphatic system is a macroscopic network that utilizes perivascular canal networks to eliminate certain chemicals from the central nervous system [30]. The glymphatic system functions to eliminate poisons generated in the brain during cellular respiration. During sleep, there is an enhanced mass flow facilitating the excretion of poisons from the brain [2]. The glymphatic system also facilitates the transfer of glucose, amino acids, lipids, and certain neurotransmitters [29]. As the body ages or fails to get sufficient sleep, the elimination of toxins may diminish, resulting in the accumulation of amyloid plaques, often seen in several neurological disorders, including Alzheimer's disease [31].

Sleep and insomnia affect several neural pathways in the brain. During sleep, a spontaneous fusion occurs between glial cells and neurons at the synapses, resulting in the development of cellular networks. The characteristics of the network are modified by synapses and signaling molecules. During sleep, obsolete memories are eliminated, new ones are consolidated, and neuromuscular cycles are reinforced.

Hypertension is a condition of modern society that serves as the primary risk factor for the onset of other cardiovascular disorders. The duration of sleep influences high blood pressure. Research indicates that sleep deprivation (≤ 5 hours/day) and insomnia elevate the risk of hypertension by a factor of five. The likelihood of hypertension is elevated in those who rise early in the morning (e.g., due to late bedtimes) and who have challenges in sustaining sleep [10,14].

A clear correlation exists between inadequate sleep, cardiovascular disorders, and the onset of inflammation in the body. The highest risk of acquiring cardiovascular disease is shown in those who sleep for less than 5 hours each day. Individuals who sleep for less than 7 hours are at an elevated risk of cardiovascular illnesses and death due to dysfunction within this system. The length of sleep should thus be a minimum of 7 hours [13,14].

Inadequate sleep results in elevated levels of inflammatory markers, including C-reactive protein (CRP), which are believed to be associated with the occurrence of breast cancer and lung tumors [14]. Individuals engaged in prolonged night shifts have a heightened risk of developing malignancies, including breast cancer, colon cancer, and non-Hodgkin's lymphoma [32].

Sleep problems and insomnia may manifest as symptoms of depression. Research indicates that individuals with sleep difficulties have a twofold greater risk of depression [33]. Elevated inflammatory markers, sometimes resulting from inadequate sleep duration, are often seen in individuals experiencing depression. Experimental findings demonstrating active inflammation in the body indicate that depressive symptoms correlate with heightened brain activity, particularly in regions important for regulating negative and positive emotions [9,11,14,33].

5. Search Methodology

To compile the scientific reports during the last decade (2012–2023), the electronic databases Medline and Web of Science were examined. Research on sleep quality concerning diet, stimulants, and physical activity was compiled from observational research, experimental trials, and meta-analyses. This investigation

included both human research and animal tests. In some instances, research pertinent to this study that fall beyond the designated search period are discussed.

6. Optimal nutrition

Optimal nutrition entails supplying all essential nutrients to sustain health and well-being. The meals individuals eat may affect both their daytime alertness and the quality of their sleep. Sleep is affected not only by the dietary energy efficiency but also by the composition of macronutrients, including proteins, carbs, and fats [34]. Inadequate protein consumption may hinder sleep quality, but excessive protein intake may cause challenges in sustaining sleep.

A significant correlation has been shown between the quality of consumed carbohydrates (fiber content and food processing level) and sleep quality [35]. The glycemic index, along with meal frequency and timing, is affected not just by carbohydrate consumption but also by the quality of the carbohydrates ingested [35]. Excessive intake of noodles, confections, and sugary beverages, along with the neglect of breakfast and irregular meal patterns, correlates with inadequate sleep, while a diet abundant in fish, shellfish, and vegetables promotes restorative sleep. The insufficient consumption of macronutrients, high caloric intake, and late dining lead to diminished sleep quality and may affect the onset of insomnia [35].

Consuming meals rich in tryptophan, melatonin, and serotonin enhances sleep quality. In adults, the consumption of tryptophan-rich meals has been associated with prolonged rest, enhanced performance, and increased total sleep duration [36]. Vitamins and minerals (e.g., B vitamins, zinc) affect sleep quality, and when deficiencies were rectified, enhancements in sleep duration and overall sleep quality were seen [37].

A growing trend of sleeping fewer than 6 hours per night is being noted in the general population, leading to heightened use of coffee, which includes caffeine. The normal half-life of caffeine ranges from 2 to 10 hours, however it may extend to 20 hours. Caffeine undoubtedly enhances performance; nevertheless, it also has adverse consequences, particularly on sleep quality. Individuals who ingest substantial quantities of caffeine are more prone to morning drowsiness compared to those who take moderate amounts.

Many adults use alcohol, with some asserting that it aids in inducing sleep. Nonetheless, alcohol adversely impacts sleep, disrupts the electrical architecture of sleep, influences biorhythms, and exacerbates insomnia. Research using mild alcohol dosages (<1 g/kg body weight) indicated a reduction in the REM sleep phase, mostly occurring in the latter part of the sleep cycle [39].

Nutrition significantly impacts sleep wellbeing. The dietary pathways affecting sleep regulation are complex. Specific dietary components might directly affect sleep; for instance, coffee may extend the time required to fall asleep while diminishing both the total length and quality of sleep [40]. Numerous dietary metabolites may play a crucial role in sleep regulation by influencing associated variables. Foods may also affect the commensal microbiota, perhaps resulting in the production of metabolites [41]. Chronic inadequate nutrition may lead to inflammation, which is strongly associated with sleeplessness [42]. Proper diet, abundant in fruits, vegetables, and whole grains, positively influences sleep [43].

7. Sleep and Energy Consumption

Overweight and obesity constitute an escalating issue in both developed and developing nations. Excess weight and obesity affect several associated disorders, including type II diabetes, cancer, and cardiovascular conditions. Substandard sleep practices and insufficient sleep hygiene may be associated with overweight and obesity [44]. Data indicate that up to 95% of students in upper secondary school fail to satisfy the criteria for sufficient sleep duration [45]. Over the last century, sleep duration has decreased by one hour across all age demographics [46]. The findings indicate a reduction in sleep duration of 10–15 minutes in recent years, with an increase in the proportion of those sleeping fewer than 6 hours [47]. Insufficient sleep has been shown to increase the risk of obesity development. Inadequate sleep results in heightened food consumption, thereby causing a surplus caloric intake. Research indicates a correlation between inadequate sleep duration and physiological alterations in appetite [44].

Inadequate sleep correlates with hormonal alterations in the body, including the secretion of leptin, ghrelin, cortisol, and growth hormone. Hormonal fluctuations may lead to diminished tissue insulin sensitivity. These alterations include unsuitable meal choices, modifications in energy control, excessive consumption of food, and decreased physical activity [48,49]. Individuals who have reduced sleep duration exhibit a diminished REM phase, perhaps contributing to the association between weight gain and inadequate sleep. Research including 335 participants revealed substantial disparities in sleep phases between overweight children and those of normal body weight [50]. Individuals with excessive body weight exhibited worse sleep performance, an extended latency to the first REM phase, decreased REM duration, and less REM activity [51].

Leptin and ghrelin are hormones that regulate hunger. Ghrelin induces hunger, while leptin induces satiety. In individuals with inadequate sleep lengths, leptin levels decrease, whilst ghrelin levels, which induce a sensation of hunger, elevate [52,53]. Inadequate sleep hygiene, coupled with inadequate sleep duration, adversely affects dietary decisions, leading to larger portions, heightened caloric intake, amplified hunger sensations, and more consumption of sugary beverages and foods [49]. Current evidence indicates a correlation between sleep quality and obesity. Individuals who are overweight or obese exhibit worse sleep quality compared to those of normal body weight, irrespective of sleep duration, as shown by factors such as the frequency of awakenings within 5 minutes, overall sleep performance, delayed onset of sleep, and premature awakening.

Excessive energy and fat intake, compulsive eating, and nocturnal snacking contribute to sleep difficulties, which may subsequently disrupt sensations of fullness and hunger. Individuals who sleep for shorter durations tend to choose high-calorie foods and frequent snacking, while also exhibiting a greater propensity to miss meals [54].

Sleep problems substantially affect individuals' quality of life. Optimal diet may significantly enhance sleep quality. An optimal diet must include all essential minerals, vitamins, and amino acids. Inadequate nutrition may precipitate sleeplessness, which subsequently contributes to the emergence of other significant ailments, including hypertension, type 2 diabetes, and cardiovascular illnesses. Food-borne chemicals might adversely affect sleep quality, either via inflammation or hormonal regulatory changes.

8. Dietary Lipids and Sleep Quality

Nuts, vegetable oils, and olive oil are distinguished by elevated levels of unsaturated fatty acids and reduced levels of saturated fatty acids. The intake of these goods is below the recommended levels for most of the population that supports saturated fats. The overconsumption of foods high in saturated fatty acids promotes the onset of noncommunicable diseases (NCDs) [55-57]. Research indicates that individuals with insomnia exhibit greater intake of high-fat meals compared to those without sleep difficulties [35].

Consuming fatty fish (exceeding 5% fat, including salmon, mackerel, and trout) positively influences sleep regulation. Fatty fish are an excellent source of omega-3 and omega-6 fatty acids, in addition to vitamin D. These nutrients may affect the control of serotonin secretion and, therefore, the regulation of sleep [58]. Consuming fatty fish enhances sleepiness, resulting in improved sleep and greater daytime performance. Current research indicates that the intake of fatty fish may positively influence daily functioning and sleep [58].

Polyunsaturated omega-3 fatty acids constitute a crucial dietary component. Diets deficient in omega-3 fatty acids may disrupt nocturnal sleep due to an internal disruption of the circadian rhythm and a decrease in melatonin production. Research on omega-3 deficient hamsters has shown an alteration in the rhythm of melatonin release and persistent locomotor hyperactivity [59,60]. Animal fats mostly consist of saturated fatty acids. Foods fried in hydrogenated oil provide a significant source of saturated fatty acids [59]. Research indicates that the intake of saturated fatty acids results in an increased frequency of nocturnal awakenings and diminishes the length of slow-wave sleep, the phase essential for bodily recovery [59]. The habitual intake of saturated fatty acids facilitates the development of diabetes, often linked to sleep disturbances [61].

9. Discussion

Research indicates a significant reduction in sleep duration across all age demographics, with sleep disorders and insomnia being recognized in individuals of all ages. Numerous studies indicate that sleep problems and insomnia increase the risk of cardiovascular disease, obesity, depression, cancer, and infectious illnesses [9-12,50,54]. A decreased duration of sleep adversely affects dietary selections, including the omission of breakfast, the consumption of processed meals with lower vitamin content, and the ingestion of overly fatty foods, resulting in an increased caloric intake. A significant issue is the rise in overweight and obesity in children and adolescents. Research indicates that this demographic often fails to get sufficient sleep duration [45,46]. Preventing sleep disturbances and insomnia is essential to avert noncommunicable illnesses, which often originate in early infancy.

Numerous studies indicate that adequate diet, regular physical exercise, and reduced stimulant intake positively influence sleep quality. Poor nutrition may ultimately result in inflammation, which is intimately linked to sleeplessness. Nutritional variables influencing sleep may operate via many ways of action [35]. Sleep may be influenced by specific components (e.g., caffeine) or by a combination of dietary metabolites. Foods may also affect the commensal microbiota, perhaps resulting in the production of certain bioactive metabolites [41]. Gamma-aminobutyric acid (GABA), a byproduct of bacteria, may enhance sleep quality and facilitate sleep.

Research indicates that a balanced diet positively influences sleep quality [64-66]. Foods and meals rich in protein, carbs, and lipids are crucial for sustaining sleep quality [57,58]. The quality of nutrients is as significant as their amount. An adequate quantity of the amino acid tryptophan, the precursor of melatonin, positively influences sleep. Scientific research indicates that omega-3 fatty acids may favorably affect the control of serotonin production [58]. To enhance sleep quality, people are advised to consume carbohydrate-rich meals characterized by low glycemic indices, low glycemic loads, and high fiber content. To guarantee sufficient sleep quality, one should avoid processed meals that are heavy in saturated fatty acids and refined carbs but low in fiber.

10. Conclusions

Sleep-related difficulties constitute a vast subject for more investigation, particularly since sleep disturbances may play a role in the development of several chronic illnesses. Research examining the correlation between sleep, nutrition, physical activity, and population health should be undertaken on a diverse cohort, particularly among those at risk for noncommunicable illnesses.

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التأثيرات المتعددة للحرمان من النوم على الأداء المعرفي والجسدي: مراجعة شاملة للعوامل الغذائية والسلوكية والفسولوجية

الملخص

الخلفية: يُعد النوم عملية فسيولوجية أساسية للحفاظ على الصحة والوظائف المعرفية. وقد ارتبط الحرمان من النوم بمشكلات صحية متنوعة، بما في ذلك العجز المعرفي، وضعف الأداء الجسدي، وزيادة القابلية للإصابة بالأمراض المزمنة. يُعد فهم التأثيرات المتعددة على جودة النوم أمراً بالغ الأهمية، خاصة في المجتمع المعاصر الذي يشهد ارتفاعاً في اضطرابات النوم.

الطرق: تجمع هذه المراجعة السريرية بين النتائج المستخلصة من الدراسات الرصدية، التجارب التجريبية، والتحليلات التلوية المنشورة بين عامي 2012 و2023، مع التركيز على تأثير العوامل الغذائية، النشاط البدني، واستهلاك المنشطات على جودة النوم. تم استخدام قواعد بيانات مثل Medline وWeb of Science لجمع الأدبيات ذات الصلة.

النتائج: تشير المراجعة إلى أن قلة مدة النوم، خاصة أقل من 7 ساعات في الليلة، ترتبط بزيادة مخاطر السمنة، وارتفاع ضغط الدم، وأمراض القلب والأوعية الدموية، واضطرابات الصحة النفسية. كما تؤثر المكونات الغذائية مثل تركيبة المغذيات الكبيرة، والكافيين، وتناول الكحول بشكل كبير على جودة النوم. علاوة على ذلك، يبرز دور النظام الغليفاوي في إزالة الفضلات العصبية السامة أثناء النوم أهمية النوم الكافي لصحة الجهاز العصبي.

الاستنتاج: يمكن أن تسهم الفهم المحسن للتفاعلات المعقدة بين النوم، التغذية، وعوامل نمط الحياة في إثراء الاستراتيجيات الصحية العامة التي تهدف إلى تحسين جودة النوم والنتائج الصحية العامة. توصي التدخلات التي تركز على تحسين النظام الغذائي والنشاط البدني، إلى جانب تقليل استهلاك المنشطات، لتخفيف الآثار السلبية للحرمان من النوم.

الكلمات المفتاحية: الحرمان من النوم، الأداء المعرفي، التأثير الغذائي، النشاط البدني، النتائج الصحية.