Beneficial Effects of Maternal Physical Activity during Pregnancy on Fetal, Newborn, and Child Health: Guidelines for Interventions during the Perinatal Period from the French National College of Midwives

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Beneficial Effects of Maternal Physical Activity during Pregnancy on Fetal, Newborn, and Child Health: Guidelines for Interventions during the Perinatal Period from the French National College of Midwives

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The objective of this work is to synthesize current knowledge about the effects of maternal physical activity during pregnancy on children's health. During the prenatal and postnatal periods, maternal physical activity has protective effects against the risks of macrosomia, obesity, and other associated cardiometabolic disorders. Even though longitudinal studies in humans are still necessary to validate them, these effects have been consistently observed in animal studies. A remarkable effect of maternal physical activity is its positive role on neurogenesis, language development, memory, and other cognitive functions related to learning.
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INTRODUCTION

Until the 1990s, the data in the literature suggested that physical activity by a pregnant woman might imperil the course of her pregnancy and present a risk for the fetus's development and even for the mother's health. Even today, women and their family and friends often express these fears, and some perinatal professionals seek to reduce or suspend all physical activity by pregnant women, including those who participated in sports or athletic endeavors before their pregnancy.

Nonetheless, recent data in the scientific literature have shown that a woman's regular physical activity during her pregnancy presents few risks[1] and provides real benefits for the mother and child, as well as for the course of the pregnancy and birth. Some observational studies have made it possible to establish associations between maternal physical activity and some health markers during intrauterine life and during child development. This type of study does not provide a level of evidence strong enough to conclude in a causal relation. Nonetheless, it is possible to show a "dose" effect, with the benefit increasing with the level of physical activity and thus strengthening the association identified. Other results have come from the interventional studies known as "randomized controlled trials" (RCTs). These support the hypotheses identified in the observational studies. Finally, experimental studies in animals have made it possible to better understand the mechanisms responsible for the benefits for the child's health of maternal physical activity during the perinatal period. It is nonetheless the methodical synthetic work (ie, systematic reviews and meta-analyses) on the results of different studies that make available the best levels of evidence. Our analysis is based primarily on these syntheses, supplemented by a mechanistic analysis.

The results of systematic reviews and meta-analyses have shown that regular physical activity during pregnancy has numerous beneficial effects for pregnant women[2–4]: they are discussed in this review and are analyzed completely in a recent book.[5]

The objective of this work is to offer an overview of the effects of maternal physical activity during pregnancy on children's health. Nonetheless, before considering these benefits, reported for fetal and then newborn and child health, it is important to highlight recent findings showing the harmful effects of the rest frequently prescribed at the onset of pregnancy. A recent synthesis describes the state of scientific knowledge about the risks associated with physical activity by pregnant women.[1] This is Part 2 of these guidelines for maternal physical activity; Part 1 focused on the maternal benefit of her physical activity in the perinatal period.[6]

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Quick Points

- ✦ Evidence suggests that strict bed rest does not prevent preterm delivery.
- ✦ Inversely, physical activity by women during pregnancy is beneficial for fetal health, development, and well-being.
- ✦ Physical activity during pregnancy contributes to creating a healthy environment in utero during the critical period of organ development and seems to have positive long-term cardiovascular and neurocognitive effects during childhood and adulthood.
- ✦ Further studies are needed to clarify these long-term effects on postnatal health, by controlling for potential biases.

MATERIAL AND METHODS

For this review, we initially searched for publications in PubMed/MEDLINE, completed with different groups of key words and their associated Mesh terms, such as: *Physical activity* or *Physical exercise* or *Sports*, *Mother* or *Maternal* or *Parturient*, *Pregnancy* or *Pregnant* or *Parturient* or *Gestation*, *Child* or *Newborn* or *Fetus*. We obtained all articles published in English on this topic since the origin of these databases through December 2020. This initial research included only human studies. It was partially completed with studies about the mechanisms of the effects identified, especially by considering studies of different animal models. The publications finally selected enabled us to classify the effects of maternal physical activity during pregnancy by stage of development: fetal life, early childhood, and childhood. Primacy was given to synthetic work (ie, reviews and meta-analyses), compared with original studies, except when we could not identify either a narrative or systematic review.

COMMENTED RESULTS

Effects on the Unborn Child of the Prescription of Bed Rest and Physical Inactivity for Pregnant Women

Several meta-analyses[7] have studied the effect of rest with hospitalization during pregnancy for fetal growth restriction,[7] threatened preterm birth among singleton pregnancies,[8] hypertension,[9] threatened miscarriage in the first half of pregnancy,[10] preeclampsia,[11] and multiple pregnancy.[12] The conclusions of each of these meta-analyses were unequivocal: although bed rest either in the hospital or at home is widely used as the first stage of treatment, no evidence supports its utility, especially for fetal growth and for preterm birth.

More specifically, bed rest did not reduce the risk of preterm birth, even in at-risk situations. In a study conducted in 1985,[14] 212 twin pregnancies were randomized into 2 groups: "prophylactic hospitalization (with bed rest) from 32 weeks of gestation" (n = 105) and "outpatient follow-up" (n = 107). The frequency of births before 37 weeks was significantly different between the 2 groups: 30.4% in the hospitalization arm and 18.7% in the outpatient arm. More recently, a study compared 2 groups of women with threatened preterm birth between 24^{+0} and 33^{+4} weeks.[13] They were randomized between "outpatient management immediately after a course of corticosteroids" (n = 50) and "hospitalization until 34 weeks" (n = 51). The proportion of births ≥ 36 weeks did not differ between the 2 groups: 71% of the hospitalized women (who spent a mean of 16 days there) versus 72% of those managed on an outpatient basis ($P = .89$). The frequency of birth ≤34 weeks was also similar: 22% for the outpatients and 24% for the hospitalized women.[13] Similarly, no benefits from bed rest have been demonstrated after premature rupture of the membranes or for placenta previa. Carlan et al.[14] randomized 67 pregnant women with preterm PROM between expectant management at home (n = 27) and in the hospital (n = 28); mean (SD) gestational age at rupture of the membranes was similar: 30.6 (3.7) weeks and 31.7 (3.5) weeks. There was no significant difference for gestational age at birth (33.2 [3.2] weeks for the women at home vs 33.5 [3.4] weeks for those hospitalized), the latency period (18 [22] days vs 12 [13] days, respectively), and the number of women with chorioamnionitis (4 vs 3) and cesareans (3 vs 6). Wing et al.[15] described 53 women with an initial diagnosis of placenta previa who needed hospitalization for vaginal bleeding. They were randomized between expectant management at the hospital with bed rest and minimal walking (n = 27) and expectant management on an outpatient basis (n = 26). Mean gestational age at birth was 34.5 (2.4) weeks for the women in the hospitalization group and 34.6 (2.3) weeks for the women in the outpatient group ($P = .90$). There was no difference for neonatal morbidity (defined by acute respiratory distress syndrome, intracranial hemorrhage, or proven sepsis) between the 2 groups (relative risk [RR], 1.16; 95% CI, 0.66–2.02). There were no neonatal deaths. Thus, in 2012, the American College of Obstetrics and Gynecology (ACOG) indicated that bed rest had not been shown to be effective in preventing preterm birth and should not be routinely recommended.[16] In its 2016 Clinical Practice Guidelines, the French National College of Gynecologists and Obstetricians (CNGOF) also stated that *"prolonged hospitalization (**grade B**) and strict bed rest (**grade C**) are not recommended"* for women with threatened preterm birth.[17]

Finally, from the psychological perspective, bed rest is associated with an increase in the risks of mood disorders, stress related to family separation, ambivalent feelings about the pregnancy, and a sense of guilt when unable to adhere to the prescription.[18–21] These emotional consequences also affect the father (feeling of distress) and siblings (adverse emotional effects with negative reactions).[22,23] All of these psychological consequences can harm early interactions and parent–child attachment and bonding — all necessary for the child's harmonious development.

Effects of Maternal Physical Activity on Fetal Development

The practice of physical activity during pregnancy has long been a source of worry, especially because of subsisting doubts about its possibly harmful effects on fetal health. The scientific literature is nonetheless reassuring on the subject, although some types of practices deserve closer studies.

Effect of Acute and Chronic Exercise on the Uteroplacental Blood Flow

The oldest hypothesis on this topic is that physical activity, by inducing the redistribution of blood to active muscles, might result in a decrease in fetal oxygen and nutrients, thus increasing the risks of acute hypoxia and fetal tachycardia and threatening fetal development.[24] That is, it has long been suggested that the decrease in visceral blood flow observed with exercise is likely to reduce the uteroplacental flow by as much as half of its resting value.[25] The amplitude of the reduction appears to vary according to the exercise (continuous or intermittent; exercise with or without loads; importance of the muscle mass used, etc.), the intensity and duration of the exercise, but also the mother's position (standing, seated, or supine). Although placental perfusion during exercise has not been directly measured in the different studies on this topic, the conclusions of a recent systematic review with meta-analysis are reassuring. According to these authors, an exercise session at moderate intensity has no harmful effect on the blood flow of the umbilical or uterine arteries.[26]

Regular aerobic physical activity of moderate intensity (brisk walking, running, Nordic walking, bicycling, swimming, etc.) even appears to lead to positive chronic adaptation of maternal hemodynamics. In other words, the regular repetition of exercise sessions during pregnancy increases the cardiovascular adaptation induced by pregnancy: thus, among active women, we observe a greater elevation in plasma volume, cardiac output, vascular compliance, placental volume in mid-pregnancy, and blood volume in the intervillous space.[27] This exacerbation of cardiovascular adaptation is assumed to increase placental perfusion at rest. Although training effects on placental perfusion have not been directly measured, the current data suggest that beginning or continuing to practice physical activity regularly during pregnancy could increase uteroplacental blood flow at rest and thereby also elevate the quantity of substrates and oxygen delivered to the fetus.[25]

Overall, an acute exercise session does not appear to cause a clinically significant reduction in uteroplacental blood flow. Endurance training even seems to increase this flow at rest, especially by promoting vascular remodeling and angiogenesis in the umbilical and uterine arteries.

Effect of Physical Exercise on the Fetal Heart Rate (HR)

As a general rule, the fetal response to maternal exercise is a moderate increase in HR by 6 beats per minute,[26] with fetal HR returning to its resting value around 20 minutes after exercise ends. The extent and duration of this increase in fetal HR depend on the intensity and duration of the mother's exercise. This is an adaptive response by the fetus, and its cardiac responses are similar, whether or not the mother performs regular physical activity. These responses are observed for moderate-intensity endurance exercise (brisk walking, bicycling, and swimming). A study focused specifically on the effects of yoga reported no modification of fetal HR after a 2-hour session. Few studies have considered the effects of strength training, and they have not shown any evidence of a significant modification of fetal HR (effect of an exercise session or a training effect), as long as exercises in the dorsal decubitus position are avoided, since these could induce fetal bradycardia.

Overall, the fetus tolerates maternal physical activity well when the pregnancy is uncomplicated and if it is not performed in a supine position (as compression of the aorta can diminish uteroplacental blood flow). The risk of fetal bradycardia or tachycardia is not greater than when the mother is at rest; when these events were identified during exercise, they were transient ($<$2 min) and not considered clinically significant. Only aerobic exercise at very high intensity ($\geq$ 85–90% of the mother's maximum HR) is strongly advised against, because of its association with an increased risk of fetal bradycardia.[28]

In all cases, physical activity appears to have a beneficial effect on the fetus's autonomic cardiac regulation (increased HR variability), which seems to continue in the postnatal years.[29]

Effect of Maternal Exercise on Placental Growth and Development

The regular practice of physical exercise during pregnancy influences placental growth and the anatomical markers of placental functional capacity in a fairly favorable direction in most cases (Case 1: a woman who started and then continued throughout her pregnancy a moderate-intensity physical activity program; Case 2: a woman who continued a high volume program of physical activity during the first trimester and then reduced the volume to 60% in the second half; Case 3: a woman who continued during pregnancy the same program of moderate physical activity that she had had before pregnancy). Only a physical activity program during the first half of pregnancy that is identical or inferior to that before the pregnancy and then increases during the second part of pregnancy with training equal to or greater than that before pregnancy is associated with a diminution of placental volume in mid-pregnancy. Its effects on the functional placental volume at term (probable interaction between the effects of the physical activity regimen and those of the associated diet, for which all studies do not control) vary greatly between women (for a complete review, see Clapp[30]).

Risk of Fetal Hyperthermia with a Teratogenic Effect

Some types of exercise significantly increase body temperature. Neural tube abnormalities related to hyperthermia due to exercise have been reported in animals. These results have not been confirmed in humans; on the contrary, a reduction of the risk of neural tube defects has been reported among women involved in sports compared with those who are inactive. Moreover, no prospective study has shown an association between an exercise-related increase in temperature in women and the risk of congenital malformations.[31]

These differences with animals are probably explained by better temperature regulation in the human species, especially during pregnancy. Moreover, the rise in body temperature associated with exercise (in nonextreme conditions) is not sufficient to increase fetal temperature. Finally, training augments the woman's capacity to dissipate heat, and this adaptation continues when she is pregnant. Overall, women's physical activity is therefore well tolerated by the fetus, whether the activity is acute (effect of an exercise session) or repeated (effects of a physical training program[17]).

Effects of Maternal Physical Activity on the Child's Health and Development

Effects on Fetal Growth and the Newborn's Birth Weight

The existing data about the effects of regular physical activity during pregnancy on the child's birth weight are fairly divergent.[32] One of the principal reasons is that diet during pregnancy can modify the effects of exercise. Moreover, there are major disparities between the different studies in terms of the types of exercise considered.

Three meta-analyses have made it possible to conclude that physical activity during pregnancy does not significantly influence birth weight (women with physical activity during pregnancy vs women without physical activity).[2,33,34] Only women with high-intensity physical activity (between 6.0 and 8.9 METs, defined in Boisseau et al.) during the third trimester may have a stronger probability of giving birth to a child weighing 200–400 g less than children of inactive women, although without increasing their risk of an newborn with fetal growth restriction (birth weight <10th percentile) or who is small for gestational age. A Canadian cohort study published in 2017 also suggests that neonates born to a specific category of pregnant women (those who subsequently develop preeclampsia) weighed a mean of 20 g less for each 1 MET per hour of physical activity performed each week.[35] On the other hand, the results of a meta-analysis also published in 2017 showed a lower probability that women who maintain a leisure-time physical activity during their pregnancy will have children with a weight high for gestational age.[36] This meta-analysis included 30 RCTs and 51 cohort studies. The meta-analysis of the RCTs showed that pregnant women's participation in physical activity during their leisure time was associated with a lower gestational weight gain (OR, 0.82; 95% CI, 0.68–0.99), a low probability of developing gestational diabetes mellitus (GDM) (RR, 0.67; 95% CI, 0.49–0.92) XX and a low probability of giving birth to a child with a weight high for gestational age (RR, 0.51; 95% CI, 0.30–0.87).[36] Overall, physical activity resulted in a slight decrease in fetal weight, but without raising the risk of having a small-for-gestational-age newborn. Inversely, a protective effect was observed for the risk of GDM.

Some effect on birth weight nonetheless appears to result, probably indirectly, from pregnant women's participation in physical activity; its intensity, duration, and timing (first vs third trimester vs throughout pregnancy) deserve to be better understood. Similarly, more specific and detailed measurements of the newborn's body composition can provide useful information about the distribution of the different body masses relative to the mother's physical activities.

Control of Maternal Weight Gain and the Newborn's Birth Weight

Maternal weight and BMI are positively correlated with the child's birth weight.[37] Similarly, children born to women with GDM are at risk of macrosomia (more than 45% have a birth weight $\geq$ 4000 g) and neonatal complications (respiratory distress, hypoglycemia, hyperbilirubinemia, hypertrophic cardiomyopathy, etc.). In the longer term, these children are also at risk of overweight or obesity, of developing diabetes, and of neurodevelopmental disorders.[38] This concept is known as *fetal and neonatal programming*, the DoHAD (developmental origins of health and disease) hypothesis, and "Barker's hypothesis", in honor of the epidemiologist who first suggested that adverse events during intrauterine life may affect organ growth and favor disease later in life.

Regular physical activity during pregnancy: (1) is associated with a lower weight gain during pregnancy, regardless of the woman's preconception BMI, (2) helps to reduce the risk of GDM (especially if associated with physical activity during the year before pregnancy), (3) protects against preeclampsia, and (4) may help to reduce complications during birth (fetal macrosomia and fetal distress) and risks to the child's subsequent health (obesity and diabetes).[39]

Studies are needed to clarify the long-term effects of physical activity during pregnancy on fetal and postnatal development, by controlling for the many potential biases (roles of mother's nutrition, BMI, level of prepregnancy physical activity, etc.). Thus, these studies could make it possible to determine if physical activity during pregnancy can limit the effects of this negative fetal and neonatal programming that favors the onset of subsequent metabolic disorders in the child, with a possibility of persistence into adulthood.

Nonetheless, several studies of children exposed to physical activity *in utero* show a favorable effect on their postnatal development. Although at the age of one year no difference was observed in growth indicators (height, weight, diameters of the head, thorax, and abdomen) between children exposed or not exposed to physical activity *in utero*,[40–42] at the age of 5 years, statistically significant differences appeared, with a lower weight and less body fat in the children exposed *in utero*.[41] Epigenetic factors appear to be involved in this programming of body fat among newborns and children. McCullough et al. were the first to show that epigenetic processes (ie, differentially methylated regions of the PLAGL1 gene) are related to the effects of maternal physical activity in reducing birth weight in humans.[43]

Effects on the Programmability of the Child's Future Physical Activity and Control of the Risk of Obesity and Associated Metabolic Disorders

Experimental studies in animals have made it possible to uncover the programmable nature of the child's physical activity, as a function of the mother's lifestyle during pregnancy.[44,45] The work by Robert Waterland's team at the University of Houston (TX) about the programmability of the energy balance converges to support the primacy of changes in physical activity over those in calorie intake.

The first model this team worked on concerned the intergenerational effects of maternal obesity. The authors used the agouti viable yellow (A^{vy}/a) mouse model, attractive because of its spontaneously hyperphagic character and propensity to become obese in adulthood. From the initial model, the authors passed the obesity-promoting A^{vy} allele through the female germline for 4 generations to obtain isogenic mice. Cross-fostering was used to study young mice from lean (a/a) and obese (Avy/a) females: those born to lean females (a/a) were fostered by obese females (A^{vy}/a) and vice versa. Much was learned as these young mice were followed up into adulthood. In particular, the females born to obese mice presented growth restriction; when suckled by the lean mice, catch-up occurred, with greater body mass and adiposity in adulthood. More important still, although the food intake of these obese offspring did not differ from that of the control group, their levels of physical activity and energy expenditure were lower at weaning, and this decrease in physical activity was maintained into adulthood.[45] The authors concluded from these findings that the energy imbalance was essentially driven by the chronic diminution of spontaneous physical activity in these mice, due to their *in utero* exposure to their mother's sedentariness and physical inactivity.[46]

The second rodent model used by this research team was a mouse model raised in a small litter (4 mice/litter) for the purpose of exposing them to overnutrition during the suckling period. Generally, when rats or mice are raised in a small litter, they are larger by the age of weaning (21 days) and maintain this overweight into adulthood, compared to controls raised in a normal-sized litter (approximately 9 rodents/litter). Metabolic cage studies to assess the relative contribution of calorie intake and energy expenditure in these young rats and mice with an energy imbalance showed that in adulthood the decreased energy expenditure was correlated with a reduction in spontaneous physical activity in this population compared with the control group; both groups were exposed to food *ad libitum*. This reduction in spontaneous physical activity was most marked in females at 180 days.[45]

Based on the initial observations described above, Eclarinal et al.[44] conducted an experiment aiming to examine the role of maternal discretionary physical activity in inducing permanent changes in that of its offspring. Adult female isogenic C57BL/6J mice were randomly assigned to a cage with a functional or blocked running wheel before and during their gestation. Several indicators were measured in mothers and their offspring (at different ages), including weight, body composition, and current wheel activity. It was observed that the offspring of mice in the cage with the working wheel, in particular females (from the age of sexual maturity), were more physically active in adulthood than their peers born to mice confined to cages with blocked wheels before and during gestation. This observation suggests a strong possibility that physical activity behavior is programmed in the next generation. Moreover, still more recent results by a research team at Washington State University (WA, USA)[29] corroborate the conclusions that maternal physical activity might be protective against obesity and its associated metabolic disorders. Son et al.[29] used the same isogenic wild-type C57BL/6J mouse model to show that females' involvement in a physical exercise regimen during pregnancy prevented obesity in their offspring and protected them against metabolic disorders, compared with the offspring of females remaining sedentary during gestation. Maternal physical exercise improved both DNA demethylation at the level of the *PRDM16* promoter gene and brown adipose tissue metabolism. Apeline, a hormone produced during physical exercise, seems to contribute to the positive effects of maternal physical activity on the metabolic outcome of offspring.[29]

All of these new results thus suggest that maternal physical activity during pregnancy has the potential to program the child's physical activity,[44,45] with simultaneous persistent effects on the maintenance of an active lifestyle and the control of obesity and its associated metabolic disorders into adulthood.[29,47] This effect appears stronger among females. Studies in humans are nonetheless necessary to verify these observations.

Effects on Autonomic Cardiac Regulation

An increasing number of studies also suggest that exercise during pregnancy is associated with a lower HR and higher sinus rhythm variability in the fetus (low heart rate sinus variability is a cardiovascular risk marker in adults). The persistence of this effect on sinus rhythm variability, observed after birth,[48,49] is a sign of an adaptive mechanism of autonomous cardiac regulation in children. A dose-effect response (between the quantity of maternal physical activity during pregnancy and the increase in sinus variability) has also been shown, given that all the women involved in these studies adhered to their recommended levels of physical activity.[48,49] This effect on the autonomic nervous system seems to be specifically attributable to *in utero* exposure to maternal physical exercise because no other variable (ie, maternal BMI, age, and education level) was significantly associated with these results.[48,49]

Effects on Neurocognitive Development

Several studies have shown that maternal physical activity during pregnancy has a positive effect on the child's neuromotor development. Higher Brazelton scores have been observed starting on the 5th day of life in children born to active mothers, compared to a matched control group.[50] In an interventional study[51] of a group of pregnant Canadian women, those randomized into the active group were asked to do moderate-intensity aerobic exercise (20 min at maximum aerobic power, at least 3 times/wk). Exercise intensity was assessed by a scale rating perceived exertion (RPE).[52] The study's principal endpoint was the measurement of specific electric activity that is possible to record on newborn EEGs when the infant distinguishes an atypical sound in the midst of a series of sounds (auditory evoked potentials). It tests capacity for sound discrimination and auditory memorization and reflects the degree of cerebral maturation. Significant differences were identified in favor of the active group. These results could explain the better development of language — medium of communication — in children of active mothers.

Other studies suggest that maternal exercise during pregnancy can improve children's cognitive functions at 8 months, 12 months, 2 years, and 3 years.[53–56] This positive effect includes improvement in learning and memory, and the diminution of anxiety-like behaviors[56]; together these comprise the cardinal points of neurodevelopmental disorders, including language delay.[54]

The existing epidemiologic data underline the important role that prenatal physical activity plays in neurodevelopment.[54,57,58] In a Brazilian birth cohort, Domingues et al.[57] observed that women's physical activity during pregnancy was positively associated with scores on different neurodevelopmental tests (eg, quality of interactions, communication, attention, motor skills, and memorization) of the child at 12 months. This result was tangible even after taking into account confounding factors, including family income and parental educational level and smoking, as well as preterm birth.[57] Compared with the children of inactive or sedentary women, those born to women active throughout their pregnancy were 1.51 (95% CI, 1.17-1.94) times more likely to have high scores on neurodevelopmental tests.[57] In 2013, Jukic et al.[54] had already obtained similar results from the British *Avon Longitudinal Study of Parents and Children* (ALSPAC) cohort. The 15-month-old children whose mothers had followed the recommendations for physical activity during their pregnancy were better able to use a variety of words.

Outcome at 5 years of age was compared between the children of women who were physically active and a control group matched for numerous other prenatal and postnatal variables known to influence this outcome. Scores on the Wechsler scale and verbal skills were significantly higher in the children of active mothers.[59] In a cohort study of 538 children conducted in Poland, verbal scores measured by the Bayley III scales were higher in children whose mothers performed moderate-intensity physical activity for more than 2.5 hours per week.[58] In a Spanish population of 1868 children aged 6 to 18 years, boys but not girls had a higher educational level when their mothers had been physically active before and during pregnancy.[60] Moreover, the outcome at 1 year of the children of active mothers was prospectively compared to that of a carefully selected control group. To limit confounding, all women in the study were in good physical condition, aged 25 to 38 years, met defined weight and body fat criteria, and had similar socioeconomic status (family income above the 50th centile, both parents with high school diplomas, and a stable family situation). The Bayley score was assessed by blinded independent examiners. The psychomotor score was higher in the group of children of active women: 108 (1) versus 101 (2), $P = .05$).[61] These various results are consistent with those reported in both of the 2 most recent scientific syntheses,[53,55] which conclude that maternal physical activity during pregnancy positively influences total neurodevelopment and specifically language development in children, in particular in their first 18 months.[55] Moreover, the effects of prenatal physical activity on the improvement of general intelligence seem to increase as the children grow.[53]

By What Mechanisms Does Physical Activity during Pregnancy Improve Children's Health?

Increased neurogenesis has been observed in the offspring of active pregnant rats.[62,63] Although the physiological mechanisms at the origin of this effect still do not appear to be completely understood, it is reasonable to think that maternal physical exercise during pregnancy could: (1) induce favorable effects on the offspring's neurocognitive development by direct placental transfer of peripheral blood factors, such as brain-derived neurotrophic factor (BDNF), involved in hippocampal neurogenesis; (2) induce epigenetic modifications (eg, reduced DNA methylation and increased histone acetylation in the promoter region of exon IV of the BDNF gene, in the hippocampus)[64]; (3) improve maternal behavior by reducing maternal stress, with positive consequences on mother-child interactions.

Higher fetal intake of BDNF is correlated with better memory and greater learning ability.[62] BDNF can pass the placental barrier.[65] Its plasma concentrations are higher among active than sedentary women,[66] and this may affect fetal cerebral development. All of these mechanisms remain to be confirmed in humans.

Another major possibility is that the effect of the pregnant woman's physical activity may be based on the remodeling of her own microbiota. Very recent data have shown differences between the intestinal microbiota of physically active and sedentary women,[67] with an augmentation among active women in the abundance of bacteria favorable to health, such as *Bifidobacterium spp, Roseburia hominis, Akkermensia munciniphila*, and *Faecalibacterium Prausnitzii*.[67] Bacterial colonization can be crucial for good cerebral development (gut-brain axis), through mechanisms involving the production, expression, and renewal of neurotransmitters such as serotonin, gamma-aminobutyric acid (GABA), or BDNF.[68] All of these factors are known to be essential in neurocognitive development, language in particular. Beyond the new knowledge about microbial colonization of the fetus from the placenta,[69] and although important controversies[70] as well as a hot debate are currently underway on this topic, birth is another important moment in the enrichment of the infant microbiota, in particular for vaginal births. That is, the risk of immunometabolic disorders appears higher in children with cesarean compared with vaginal births, because of the low exposure of the former to their mother's vaginal flora.[71–73] Since the frequency of cesareans is lower among women physically active during their pregnancy,[74] one can certainly argue that this involves an indirect effect of physical activity on the newborn's constitution of health capital. This effect may thus be determined by the favorable influence of maternal physical activity on vaginal birth as well as the reorganization of the maternal microbiota that the infant can "inherit." These avenues warrant exploration by complementary studies.

Physical activity in the perinatal period reduces the risk of postpartum depression. The data from the literature are solid, based simultaneously on observational and interventional studies.[75,76] This disease affects 10% to 15% of women after childbirth.[77] The negative effects of postpartum depression include an increased risk of fragile vulnerable attachment, as well as neurodevelopmental disorders including cognitive disorders, language delay, and behavioral problems. The prevention of the risk of postpartum depression by physical activity may also explain the long-term benefits found in children.

CONCLUSION

Numerous observational but also interventional clinical studies, as well as meta-analyses, show that unborn children undergo both harmful effects from maternal sedentariness and beneficial effects from her physical activity during pregnancy. It is possible to show a dose effect, with the benefit increasing with the level of physical activity. This finding strengthens the hypothesis of a causal association. Experimental animal studies have also helped researchers to understand the mechanisms responsible for the neurodevelopmental benefits of physical activity during the perinatal period. Some data from the past 5 years thus suggest that maternal physical activity during pregnancy has the potential to program the child's physical activity, with a persistent effect, simultaneously on the maintenance of an active lifestyle and the control of obesity and its associated metabolic disorders into adulthood. This effect appears stronger among females. Studies in humans should be performed to verify these new observations.

Accordingly, regular physical activity is recommended during pregnancy for the benefit of the unborn child. Alongside factors such as eating and the reduction of exposure to toxic substances and to stress, maternal physical activity is one of the determinants of the child's long-term outcome.

In view of these numerous beneficial effects for the fetus and the newborn, it is recommended that pregnant women:

— Begin or continue physical activity of moderate intensity $\geq$ 150 minutes a week with at least 3 sessions of a duration longer than 30 minutes (grade A).

— Begin or continue strength training involving the large muscle groups once or twice a week) (grade A).

— Limit the time spent being sedentary ($\leq$7 h/d) (expert consensus).

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CONFLICT OF INTEREST

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REFERENCES

1. Verdière S, Guinhouya BC, Salerno D, Deruelle P. L'activité physique devrait-elle être contre-indiquée pendant la grossesse au regard des risques qui lui sont potentiellement associés ? *Gynecol Obstet Fertil Senol*. 2017 45(2):104-11.
2. Kramer MS, McDonald SW. Aerobic exercise for women during pregnancy. *Cochrane Database Syst Rev*. 2006 Jul 19(3):CD000180.
3. Mudd LM, Owe KM, Mottola MF, Pivarnik JM. Health benefits of physical activity during pregnancy: an international perspective. *Med Sci Sports Exerc*. 2013;45(2):268-77.
4. Nascimento SL, Surita FG, Cecatti JG. Physical exercise during pregnancy: a systematic review. *Curr Opin Obstet Gynecol*. 2012;24(6):387-94.
5. Guinhouya BC. L'activité physique chez la femme enceinte et l'accouchée. *Médecine-Sciences Lavoisier*, 2021.
6. Nathalie B. Physical Activity during the Perinatal Period: Guidelines for Interventions during the Perinatal Period from the French National College of Midwives. *J Midwifery Womens Health*. 2022;67(Suppl. 1):S158-S171.
7. Gulmezoglu AM, Hofmeyr GJ. Bed rest in hospital for suspected impaired fetal growth. *Cochrane Database Syst Rev*. 2000(2):CD000034.
8. Sosa CG, Althabe F, Belizan JM, Bergel E. Bed rest in singleton pregnancies for preventing preterm birth. *Cochrane Database Syst Rev*. 2015 Mar 30(3):CD003581.
9. Meher S, Abalos E, Carroli G. Bed rest with or without hospitalisation for hypertension during pregnancy. *Cochrane Database Syst Rev*. 2005 Oct 19(4):CD003514.
10. Aleman A, Althabe F, Belizan J, Bergel E. Bed rest during pregnancy for preventing miscarriage. *Cochrane Database Syst Rev*. 2005 Apr 18(2):CD003576.
11. Meher S, Duley L. Rest during pregnancy for preventing pre-eclampsia and its complications in women with normal blood pressure. *Cochrane Database Syst Rev*. 2006 Apr 19(2):CD005939.
12. Crowther CA, Han S. Hospitalisation and bed rest for multiple pregnancy. *Cochrane Database Syst Rev*. 2010 Jul 7(7):CD000110.
13. Yost NP, Bloom SL, McIntire DD, Leveno KJ. Hospitalization for women with arrested preterm labor: a randomized trial. *Obstet Gynecol*. 2005 Jul;106(1):14-8.
14. Carlan SJ, O'Brien WF, Parsons MT, Lense JJ. Preterm premature rupture of membranes: a randomized study of home versus hospital management. *Obstet Gynecol*. 1993 Jan;81(1):61-4.
15. Wing DA, Paul RH, Millar LK. Management of the symptomatic placenta previa: a randomized, controlled trial of inpatient versus outpatient expectant management. *Am J Obstet Gynecol*. 1996 Oct;175(4 Pt 1):806-11.
16. American College of O, Gynecologists, Committee on Practice B-O. ACOG practice bulletin no. 127: Management of preterm labor. *Obstet Gynecol*. 2012 Jun;119(6):1308-17.
17. CNGOF. Recommandations pour la pratique clinique : Prévention de la prématurité spontanée et des conséquences (hors rupture des membranes). *Collège national des gynécologues et obstétriciens français* 2016:587-608.
18. Gupton A, Heaman M, Ashcroft T. Bed rest from the perspective of the high-risk pregnant woman. *J Obstet Gynecol Neonatal Nurs*. 1997 Jul-Aug;26(4):423-30.
19. Maloni JA, Chance B, Zhang C, Cohen AW, Betts D, Gange SJ. Physical and psychosocial side effects of antepartum hospital bed rest. *Nurs Res*. 1993 Jul-Aug;42(4):197-203.
20. Maloni JA, Kane JH, Suen LJ, Wang KK. Dysphoria among high-risk pregnant hospitalized women on bed rest: a longitudinal study. *Nurs Res*. 2002 Mar-Apr;51(2):92-9.
21. Schroeder CA. Women's experience of bed rest in high-risk pregnancy. *Image J Nurs Sch*. 1996 Fall;28(3):253-8.
22. Maloni JA, Brezinski-Tomasi JE, Johnson LA. Antepartum bed rest: effect upon the family. *J Obstet Gynecol Neonatal Nurs*. 2001 Mar-Apr;30(2):165-73.

23. May KA. Impact of maternal activity restriction for preterm labor on the expectant father. *J Obstet Gynecol Neonatal Nurs*. 1994 Mar-Apr;23(3):246-51.
24. May LE, Scholtz SA, Suminski R, Gustafson KM. Aerobic exercise during pregnancy influences infant heart rate variability at one month of age. *Early Hum Dev*. 2014;90(1):33-8.
25. Clapp JF. Influence of endurance exercise and diet on human placental development and fetal growth. *Placenta*. 2006 Jun-Jul;27(6-7):527-34.
26. Skow RJ, Davenport MH, Mottola MF, et al. Effects of prenatal exercise on fetal heart rate, umbilical and uterine blood flow: a systematic review and meta-analysis. *Br J Sports Med*. 2019 53(2): 124-33.
27. Jackson MR, Gott P, Lye SJ, Ritchie JW, Clapp JF. The effects of maternal aerobic exercise on human placental development: placental volumetric composition and surface areas. *Placenta*. 1995 1995/03//undefined;16(2):179-91.
28. Salvesen KA, Hem E, Sundgot-Borgen J. Fetal wellbeing may be compromised during strenuous exercise among pregnant elite athletes. *Br J Sports Med*. 2012 Mar;46(4):279-83.
29. Son JS, Zhao L, Chen Y, et al. Maternal exercise via exerkine apelin enhances brown adipogenesis and prevents metabolic dysfunction in offspring mice. *Sci Adv*. 2020;6(16):eaaz0359.
30. Clapp JF, 3[rd]. Influence of endurance exercise and diet on human placental development and fetal growth. *Placenta*. 2006 27(6-7):527-34.
31. McMurray RG, Katz VL, Meyer-Goodwin WE, Cefalo RC. Thermoregulation of pregnant women during aerobic exercise on land and in the water. *Am J Perinatol*. 1993 Mar;10(2):178-82.
32. Charlesworth S, Foulds HJ, Burr JF, Bredin SS. Evidence-based risk assessment and recommendations for physical activity clearance: pregnancy. *Appl Physiol Nutr Metab*. 2011;36(Suppl 1):S33-S48.
33. Lokey EA, Tran ZV, Wells CL, Myers BC, Tran AC. Effects of physical exercise on pregnancy outcomes: a meta-analytic review. *Med Sci Sports Exerc*. 1991 Nov;23(11):1234-9.
34. Leet T, Flick L. Effect of exercise on birthweight. *Clin Obstet Gynecol*. 2003 Jun;46(2):423-31.
35. Bisson M, Croteau J, Guinhouya BC, et al. Physical activity during pregnancy and infant's birth weight: results from the 3D Birth Cohort. *BMJ Open Sport Exerc Med*. 2017 3(1):e000242.
36. da Silva SG, Ricardo LI, Evenson KR, Hallal PC. Leisure-Time Physical Activity in pregnancy and maternal-child health: A Systematic Review and Meta-Analysis of Randomized Controlled Trials and Cohort Studies. *Sports Med*. 2017 47(2):295-31.
37. Ludwig DS, Currie J. The association between pregnancy weight gain and birthweight: a within-family comparison. *Lancet*. 2010 Sep 18;376(9745):984-90.
38. Metzger BE, Lowe LP, Dyer AR, et al. Hyperglycemia and adverse pregnancy outcomes. *N Engl J Med*. 2008;358:1991-2002.
39. Metzger BE, Lowe LP, Dyer AR, et al. Hyperglycemia and adverse pregnancy outcomes. *N Engl J Med*. 2008;358:1991-2002.
40. Clapp JF, 3rd. The changing thermal response to endurance exercise during pregnancy. *Am J Obstet Gynecol*. 1991 Dec;165(6 Pt 1):1684-9.
41. Clapp JF, 3rd. Morphometric and neurodevelopmental outcome at age five years of the offspring of women who continued to exercise regularly throughout pregnancy. *J Pediatr*. 1996 Dec;129(6): 856-63.
42. Clapp JF, 3rd, Simonian S, Lopez B, Appleby-Wineberg S, Harcar-Sevcik R. The one-year morphometric and neurodevelopmental outcome of the offspring of women who continued to exercise regularly throughout pregnancy. *Am J Obstet Gynecol*. 1998 Mar;178(3):594-9.
43. McCullough LE, Mendez MA, Miller EE, Murtha AP, Murphy SK, Hoyo C. Associations between prenatal physical activity, birth weight, and DNA methylation at genomically imprinted domains in a multiethnic newborn cohort. *Epigenetics*. 2015;10(7):597-606.
44. Eclarinal JD, Zhu S, Baker MS, et al. Maternal exercise during pregnancy promotes physical activity in adult offspring. *FASEB J*. 2016 30(7):2541-8.
45. Zhu S, Eclarinal J, Baker MS, Li G, Waterland RA. Developmental programming of energy balance regulation: is physical activity more 'programmable' than food intake? *Proc Nutr Soc*. 2016 75(1):73-7.
46. Baker MS, Li G, Kohorst JJ, Waterland RA. Fetal growth restriction promotes physical inactivity and obesity in female mice. *Int J Obesity*. 2015;39:98-104.
47. Son JS, Liu X, Tian Q, et al. Exercise prevents the adverse effects of maternal obesity on placental vascularization and fetal growth. *J Physiol*. 2019 597(13):3333-47.
48. May LE, Glaros A, Yeh HW, Clapp JF, 3rd, Gustafson KM. Aerobic exercise during pregnancy influences fetal cardiac autonomic control of heart rate and heart rate variability. *Early Hum Dev*. 2010 Apr;86(4):213-7.
49. May LE, Scholtz SA, Suminski R, Gustafson KM. Aerobic exercise during pregnancy influences infant heart rate variability at one month of age. *Early Hum Dev*. 2014 Jan;90(1):33-8.
50. Clapp JF, 3[rd], Lopez B, Harcar-Sevcik R. Neonatal behavioral profile of the offspring of women who continued to exercise regularly throughout pregnancy. *Am J Obstet Gynecol*. 1999 180(1 Pt 1): 91-4.
51. Labonte-Lemoyne E, Curnier D, Ellemberg D. Exercise during pregnancy enhances cerebral maturation in the newborn: A randomized controlled trial. *J Clin Exp Neuropsychol*. 2017 39(4):347-54.
52. Borg GAV. Psychosocial bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14:377-81.
53. Álvarez-Bueno C, Cavero-Redondo I, Sánchez-López M, Garrido-Miguel M, Martínez-Hortelano JA, Martínez-Vizcaíno V. Pregnancy leisure physical activity and children's neurodevelopment: a narrative review. *BJOG*. 2018; 125(10):1235-42.
54. Jukic AMZ, Lawlor DA, Juhl M, et al. Physical activity during pregnancy and language development in the offspring *Paediatr Perinat Epidemiol*. 2013;27(3):283-93.
55. Niño Cruz GI, Ramirez Varela A, da Silva ICM, Hallal PC, Santos IS. Physical activity during pregnancy and offspring neurodevelopment: A systematic review. *Paediatr Perinat Epidemiol*. 2018 32(4):369-79.
56. Robinson AM, Bucci DJ. Maternal exercise and cognitive functions of the offspring. *Cogn Sci (Hauppauge)*. 2012;7(2):187-205.
57. Domingues MR, Matijasevich A, Barros AJ, Santos IS, Horta BL, Hallal PC. Physical activity during pregnancy and offspring neurodevelopment and IQ in the first 4 years of life. *PLoS One*. 2014 9(10):e110050.
58. Polańska K, Muszyński P, Sobala W, Dziewirska E, Merecz-Kot D, Hanke W. Maternal lifestyle during pregnancy and child psychomotor development - Polish Mother and Child Cohort study. *Early Hum Dev*. 2015 91(5):317-25.
59. Clapp JF, 3rd. Morphometric and neurodevelopmental outcome at age five years of the offspring of women who continued to exercise regularly throughout pregnancy. *J Pediatr*. 1996;129(6):856-63.
60. Esteban-Cornejo I, Martinez-Gomez D, Tejero-González CM, et al. Maternal physical activity before and during the prenatal period and the offspring's academic performance in youth. The UP&DOWN study. *J Matern Fetal Neonatal Med*. 2016;29(9):1414-20.
61. Clapp JF, 3rd, Simonian S, Lopez B, Appleby-Wineberg S, Harcar-Sevcik R. The one-year morphometric and neurodevelopmental outcome of the offspring of women who continued to exercise regularly throughout pregnancy. *Am J Obstet Gynecol*. 1998 178(3): 594-9.
62. Akhavan MM, Emami-Abarghoie M, Safari M, et al. Serotonergic and noradrenergic lesions suppress the enhancing effect of maternal exercise during pregnancy on learning and memory in rat pups. *Neuroscience*. 2008;151(4):1173-83.

63. Kim H, Lee SH, Kim SS, Yoo JH, Kim CJ. The influence of maternal treadmill running during pregnancy on short-term memory and hippocampal cell survival in rat pups. *Int J Dev Neurosci*. 2007;25(4):243-9.
64. Gomez-Pinilla F, Zhuang Y, Feng J, Ying Z, Fan G. Exercise impacts brain-derived neurotrophic factor plasticity by engaging mechanisms of epigenetic regulation. *Eur J Neurosci*. 2011;33(3):383-90.
65. Kodomari I, Wada E, Nakamura S, Wada K. Maternal supply of BDNF to mouse fetal brain through the placenta. *Neurochem Int*. 2009 54(2):95-8.
66. Rojas-Vega S, Kleinert J, Sulprizio M, Hollmann W, Bloch W, Strüder HK. Responses of serum neurotrophic factors to exercise in pregnant and postpartum women. *Psychoneuroendocrinology*. 2011 36(2):220-7.
67. Bressa C, Bailén-Andrino M, Pérez-Santiago J, et al. Differences in gut microbiota profile between women with active lifestyle and sedentary women. *PLoS One*. 2017 12(2):e0171352.
68. Yang Y, Tian J, Yang B. Targeting gut microbiome: A novel and potential therapy for autism. *Life Sci*. 2018 194:111-9.
69. Antony KM, Ma J, Mitchell KB, Racusin DA, Versalovic J, Aagaard K. The preterm placental microbiome varies in association with excess maternal gestational weight gain. *Am J Obstet Gynecol*. 2015 212(5):653.e1-e16.
70. Gschwind R, Fournier T, Kennedy S, et al. Evidence for contamination as the origin for bacteria found in human placenta rather than a microbiota. *PLoS One*. 2020;15(8):e0237232.
71. Adlercreutz EH, Wingren CJ, Vincente RP, Merlo J, Agardh D. Perinatal risk factors increase the risk of being affected by both type 1 diabetes and coeliac disease. *Acta Paediatr*. 2015;104(2):178-84.
72. Black M, Bhattacharya S, Philip S, Norman JE, McLernon DJ. Planned Cesarean delivery at term and adverse outcomes in childhood health. *JAMA*. 2015;314(21):2271-9.
73. Kuhle S, Tong OS, Woolcott CG. Association between Caesarean section and childhood obesity: a systematic review and meta-analysis. *Obes Rev*. 2015;16(4):295-303.
74. Domenjoz I, Kayser B, Boulvain M. Effect of physical activity during pregnancy on mode of delivery. *Am J Obstet Gynecol*. 2014;211(401):e1-e11.
75. Shakeel N, Richardsen KR, Martinsen EW, Eberhard-Gran M, Slinning K, Jenum AK. Physical activity in pregnancy and postpartum depressive symptoms in a multiethnic cohort. *J Affect Disord*. 2018 236:93-100.
76. Vargas-Terrones M, Barakat R, Santacruz B, Fernandez-Buhigas I, Mottola MF. Physical exercise programme during pregnancy decreases perinatal depression risk: a randomised controlled trial. *Br J Sports Med*. 2019 53(6):348-53.
77. O'Hara MW, McCabe JE. Postpartum depression: current status and future directions. *Annu Rev Clin Psychol*. 2013;9:379-407.
78. Barasinski C, Zaros C, Bercherie J, et al. Intervention during the Perinatal Period: Synthesis of the Clinical Practice Guidelines from the French National College of Midwives. *J Midwifery Womens Health*. 2022;67(Suppl. 1):S2-S16.