Impact of physical activity levels on infant measures and maternal health

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Abstract

Five hundred and four pregnant women participated in this study. The objective was to examine the association between selected sociocultural characteristics and physical activity on the course of pregnancy, labor, delivery infant measures and maternal health. The participants were from the European (71%), Maori (20%) and Pacific communities (9%) in New Zealand. On average, pregnant women spent 20 hours each day in sedentary activities, such as sleeping, sitting, and standing. Urban women were found to be more sedentary than rural women. There was no difference in the activity patterns by ethnicity. During the seventh month of pregnancy the low income group and beneficiaries were found to be more sedentary than others.

The need for some birth interventions was found to increase with time spent in sedentary activity. Sedentary activity was significantly related to the need for an episiotomy. The results also showed that the more active the women the lesser the need for pain relief. The need for syntocin and epidural anesthesia almost halved as the number of minutes spent in moderate high activity increased. The more the number of minutes spent in sedentary activity in the seventh month, the longer the duration of labor. However, the duration of sleeping was associated with a shorter duration of labor.

Duration of physical activity did not affect birth weight, but time spent in sedentary activity was found to impact on the gestational age of the baby. The more sedentary mothers had a shorter gestational term and the more active the subjects the more likely they were to go full term. Sedentary activity during pregnancy was found to affect weight gain between the fourth to seventh months of pregnancy. The more time women spent on moderate low to moderate high activity, the less was the weight gain. Thus standing and sitting were not beneficial for a good pregnancy outcome. It was very clear that pregnant women would need to get more active. Furthermore, physical activity during pregnancy did not affect post partum weight retention. There may be other lifestyle characteristics

such as diet both during and after pregnancy, or change in activity patterns postpartum that may have affected post partum weight retention.

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Introduction

Pregnancy is a time in a woman's life when her body undergoes many changes. Although routine lifestyle patterns are affected, healthy pregnant women continue to engage in extensive physical activity. This includes the physical demands associated with continued daily work activities. The extreme can be heavy manual labor, especially in rural areas. In addition, there are a growing number of women who continue their leisure time and sport activities throughout their period of pregnancy.

In a woman's life cycle most of the weight gain and weight retention occurs during the childbearing period. Excessive weight gain can be detrimental to the mother and the infant. The obese gravida is at an increased risk of developing gestational diabetes, pregnancy-induced hypertension, and fetal growth restriction and cesarean delivery. The positive energy balance necessary for weight gain may be achieved by an increase in energy intake. This relationship, however, can be modified by a decrease or increase in physical activity, an increase in work efficiency, changes in basal metabolism, an increase in efficiency with which energy is used to synthesize new tissue, or some combination of these factors.

Exercise is recognized as an important lifestyle factor necessary for the prevention of excessive weight gain and also for the treatment of a variety of diseases. The benefits of exercise are manifold, so some women continue to exercise even throughout pregnancy. However, traditionally and due to cultural beliefs most women may discontinue exercise during pregnancy for fear of a miscarriage and poor pregnancy outcome.

The reasons for this are varied and there is concern that the thermal, cardiovascular, metabolic and biophysical changes, which accompany physical activity, may have unfavorable pregnancy outcomes. Some research in animals and humans has shown that exercise and physical work during pregnancy is a predisposing factor to premature labor, low birth weight babies and increased infant mortality rates. Moreover, in animal studies the adverse effects of exercise during pregnancy and lactation include irreversible growth retardation with inter-generational effects in rats. Recommending physical activity in pregnancy, is therefore, done with caution and moderation is advised.

On the other hand several other studies have shown that continuing to exercise at intensities of 60% of maximum aerobic capacity does not impair fetal well-being and has maternal benefits. The reasons for this include a reduction in the magnitude of the potentially harmful responses. Despite much research, the question of whether women should exercise during pregnancy remains controversial. Moreover, in New Zealand there have been very few studies on physical activity during pregnancy and its impact on maternal health, the birth process and infant measures, in the main ethnic groups. Thus this study has been undertaken. A review of the relevant literature is presented in the following chapter.

1.1 Pregnancy and weight gain

Cross sectional studies have shown a positive relationship between body weight and parity (1). In a longitudinal 5-year follow-up study conducted to study the association between pregnancy and persistent changes in adiposity, it was found that women gained weight and body fat usually after the first pregnancy and that these changes were persistent (1). As compared to the prepregnancy body weight, Ohlin et al found a mean increase of 0.5 kg 1year postpartum in the study, but 14% of the subjects gained more than 5 kg or more (2).

The prevalence of morbid obesity is increasing steadily among women of reproductive age and the proportion of overweight women in the age group 20-39 years is between 20 and 35%(3). Obesity in later years has been associated with weight gain in early adulthood (1). One of the components contributing to this weight gain is weight retention following pregnancy. Obesity is harmful to the mother and has been associated with poor perinatal and neonatal outcomes (4). Several studies report an increased incidence of gestational diabetes, pregnancy-induced hypertension, fetal growth restriction, increased risk of cesarean births and postoperative morbidity in the morbidly obese gravida (5,6,7,8,9,10). Heredity plays a very important role in the development of obesity. Moreover, the interaction of environmental factors such as food intake, physical activity levels and smoking also affect the development of obesity (11). In those with a genetic predisposition to developing obesity, a high fat diet and a sedentary lifestyle, have an obesity promoting effect (11). 'The Stockholm Pregnancy and Weight Development Study' conducted to identify risk factors for postpartum weight retention such as dietary habits, physical activity and socio-demographic factors, reported that women who increased their energy intake during and after pregnancy, or increased their snack eating after pregnancy to 3 or more snacks/day, and decreased their lunch frequency starting during or after the pregnancy, had greater weight retention one year postpartum (11). Women who had retained 5 kg or more 1-year postpartum, were more seldom physically active in their leisure time throughout the study period compared with women with a smaller weight gain (11).

Underweight is equally not beneficial to the pregnant gravida. A pre-pregnancy weight of less than 54kg has been associated with a relative risk of 1.25 for delivering preterm (12). A review examining the relationship between gestational weight gain and preterm delivery reported that of the thirteen studies reviewed eleven showed a positive association between maternal weight gain and risk of preterm delivery (13). Moreover, studies examining pattern of weight gain noted that a low rate of gain during the latter part of pregnancy was associated with an increased risk of preterm delivery of approximately 50-100% (13,14). Reduced pregnancy weight gain in women who were poorly nourished in early pregnancy has been found to be associated with higher blood pressure in their offspring (15). Thus maternal nutritional status both before and during pregnancy is an important determinant of birth outcomes.

The Institute of Medicine (14), therefore recommends that underweight women (BMI < 19.8) should gain between 12-18kg, normal weight women (BMI 19.9-26.0) should gain between 11.5-16kg, and overweight women (BMI > 26.0-29.0) should gain between 7-11.5kg and not more than 7kg for obese women (BMI > 29.0) (16). This rate of weight gain will minimize fat gain in the obese women and maximize fat gain in the underweight women. A cohort study of 196 pregnant women found that a majority of women do not gain as recommended during pregnancy (16). Thirty-nine percent gained more than recommended and 26% gained less than recommended.

In order to minimize fat gain in pregnancy most women continue to exercise in pregnancy. Almost 10% of Australian women of childbearing age perform vigorous exercise (17). Prescribing exercise during pregnancy is done with caution, as there is concern that its physiological effects may have an adverse impact on pregnancy outcome. Some of the concerns are discussed below.

1.2 Physiological effects of pregnancy

Pregnancy is associated with alterations in body structure, metabolism, and cardiovascular and endocrine function (18,19). As a result of these changes, there are large increases in blood volume, cardiac output, and vascular conductance in association with a decrease in arterial pressure and suppression in the vascular tone. Blood flow to the reproductive tract increases 10-fold, and there is a substantial increase in the flow through the cutaneous and renal circulation (20). There is an increase in the rate of metabolism, minute ventilation, and the respiratory exchange ratio as well as insulin resistance (21). These changes along with increased hepatic and renal clearance and the increased contribution of peptides and steroids from the placenta bring about an alteration in the blood levels of most circulating hormones, substrates and catabolites (19,21).

1.2.1 Cardiovascular system

In the first trimester of pregnancy cardiac output during rest increases, and reaches a maximum of about 40% above the non-pregnant value in the second trimester, and then remains stable (22,23). This increase in cardiac output is due to an increase in both stroke volume and heart rate. The increased cardiac output is not uniformly distributed throughout the mother's body. Hepatic and cerebral blood flow remains unchanged, while blood flow to the uterus is increased. Renal blood flow is increased throughout pregnancy and especially during early pregnancy (23). The increase in red cell volume is relatively less and so hemodilution occurs. The arteriovenous oxygen difference decreases in early pregnancy, but near term it approaches the non-pregnant value. Systolic blood pressure is relatively stable throughout pregnancy (23). Diastolic blood pressure falls; being lowest at mid-pregnancy, and then tends to reach non-pregnant value by term. Both hormonal changes and the added uteroplacental circulation may elevate stroke volume and cardiac output in pregnant women (24).

1.2.2 Respiratory system

The size and shape of the thoracic cage change due to the elevated diaphragm as well as the widened transverse diameter of the thorax that develops with advancing pregnancy (24,25). Expiratory reserve volume and functional residual capacity progressively decrease during the second half of pregnancy. However, vital capacity remains essentially normal, since inspiratory capacity increases slightly. Minute ventilation increases by approximately 50%, i.e. to an extent far in excess of the need for gas exchange (24). Thus, the volume of gas for each liter of oxygen consumed (ventilatory equivalent) is higher throughout pregnancy. This is caused by increased tidal volume since respiratory frequency remains unchanged. This hyperventilation leads to a fall in arterial pCO2 to about 30mm Hg in late pregnancy. However, blood pH remains normal or is only slightly alkaline due to the increased renal excretion of bicarbonate.

Minute ventilation in pregnant women is higher than in non-pregnant control women during cycle and treadmill exercise (26). In addition, alveolar ventilation during exercise was higher in pregnant than in postpartum subjects only during the second half of pregnancy. The ventilatory equivalent, which is already increased at rest, did not change during exercise. The increase in respiratory frequency in response to a given exercise task during pregnancy has been repeatedly shown to be no different from that observed postpartum. Thus the rise in minute ventilation in exercising pregnant women is due to a rise in tidal volume. The rate of change in minute ventilation at the onset of exercise is greater than normal during pregnancy. The more rapid approach to the steady-state ventilatory response is already evident in the first 10 seconds of exercise and remains for the next 60-80 seconds. Edward et al (8) suggests that an enhanced venous return to the central circulation, via the action of the active muscles, could account for the more rapid increase in oxygen consumption.

1.2.3 Blood, pH, pO2, and pCO2

In general, blood plasma carbon dioxide may be expected to be lower than normal in pregnant women during moderate exercise, since hyperventilation is already evident during rest. However, the blood plasma carbon dioxide is unchanged, even though the blood pH is decreased during short-term cycle exercise at 80W (24). The response during a more intense exercise effort in humans is not known. It may be that the elevated blood pH, lower plasma carbon dioxide or unchanged or elevated blood plasma oxygen found in late pregnant ewes during treadmill exercise, could also occur in mammals (27).

1.2.4 Endocrine systems

The endocrine systems undergo profound changes in pregnancy (22,24,28). There is a moderate and progressive increase in Adrenocorticotropic hormone (ACTH) secretion during pregnancy (22). It is followed by a rise in both total and free plasma cortisol concentrations. Plasma growth hormone levels are low, and its secretion in response to stimuli, such as arginine or hypoglycemia, is blunted. Thyroid-stimulating hormone (TSH) secretion may be reduced during the first trimester of pregnancy, and thereafter secretion does not differ from that in healthy non-pregnant women. Nonetheless thyroid function is normal during pregnancy, probably due to the presence of human chorionic thyrotropin (24). The concentrations of total plasma thyroxin and triiodothyronine increase during pregnancy. However, there is a related increase in the principle binding protein, thyroxin-binding globulin, in plasma. Therefore, the levels of free thyroxin and triiodothyronine remain essentially normal during pregnancy. Resting circulating catecholamine concentrations in humans also remain normal. Plasma insulin and glucagon levels increase during pregnancy. However, on a molar basis, the insulin level increases more than the glucagon level; therefore, the molar insulin: glucagon ratio increases during pregnancy (24). Normally, this should result in a more dominant insulin influence in the body. However, in reality this does not happen and there is actually insulin resistance during pregnancy (28). During pregnancy the placenta plays an important role as a multifunctional endocrine gland. One hormone secreted is human placental lactogen. This hormone antagonizes the peripheral action of insulin and has a lipolytic effect in adipose tissue (29). These data suggest that the endocrine response to exercise may differ during pregnancy from that found in non-pregnant subjects.

1.2.5 Metabolism

Resting oxygen consumption of the mother increases in a somewhat biphasic manner, to approximately 15-29% above normal, during pregnancy. The initial increase is primarily due to increased cardiac and renal energy costs; these remain essentially constant throughout pregnancy. The major increase in resting oxygen consumption, which occurs during the second half of pregnancy, is due to the rapidly growing fetus, the enlarging placenta, and the uterus (24). However, in situations of marginal nourishment there is some evidence that mothers adjust their metabolism thereby sparing nutrients for the development of the fetus (23). Additionally, when there is chronic undernutrition, the limits of adaptation might be exceeded leading to fetal growth retardation.

Fat accumulation in the mother is one of the most obvious metabolic adaptations during pregnancy. On average, approximately 3.5kg of fat accumulates, primarily during the first half of pregnancy. The circulating free fatty acid concentration increases in the third trimester of pregnancy to nearly 2-4 times normal (500-1250μM). Similarly plasma triglyceride concentration increases during pregnancy, and near term it is approximately three times the normal value. Plasma ketone levels are also markedly increased in late pregnancy (24). During a glucose tolerance test, the peak concentrations of glucose and insulin in the plasma become progressively higher throughout the duration of pregnancy. It has been estimated that during late pregnancy the sensitivity to insulin is reduced by as much as 80% (28).

1.3 Effect of exercise during pregnancy on the mother and the fetus

Exercise in the normal adult is also associated with an increase in cardiac output, metabolic rate, body temperature, substrate mobilization and utilization and biomechanical stress. However, in contrast to pregnancy it redistributes the blood flow away from the splanchnic organs to the muscles and skin. The vascular tone increases, blood pressure rises, and the circulating volume falls by approximately 20%. The blood levels of catecholamines and glucagon increases as a result of exercise whereas insulin release and that of other tropic hormones is suppressed. The hepatic clearance rate also decreases due to a decrease in blood flow through the celiac axis (22,23).

The mother and fetus could be at an increased risk when the combined physiological consequences of exercise and pregnancy are considered. The relevant literature in this regard is presented below.

1.3.1 Fetal Risks

In response to exercise, potential risks to the fetus include hypoxemia, harmful heart rate changes, hyperthermia and problems associated with high altitude sports and underwater sports.

1.3.1.1 Hypoxemia

The decrease in blood flow to the uterus due to exercise may cause an inadequate oxygen supply to the fetus (30,31). Exercise induced increase in maternal catecolamines and a decrease in cardiac output could lead to hypoxia as catecholamine levels have a vasoconstrictory effect on the uterine and umbilical blood flow (32). Eventually this could lead to fetal bradycardia (abnormal slowness of the heart) and fetal distress. Laboratory studies in sheep have demonstrated that a decrease in oxygen tension and an increase in carbon dioxide tension occur as a result (33). Evidently, decreased fetal oxygen uptake with or without fetal acidosis, fetal bradycardia or both does not occur until the reduction in uteroplacental flow exceeds 50% (27,34,35).

Animal studies have shown that maternal exercise in late pregnancy produces transient fetal hypoxemia (19,22). However, there is no evidence at delivery to suggest that regular sustained exercise in late pregnancy produce recurrent fetal hypoxemia in the human (19,21). Transient fetal bradycardia has been observed in untrained pregnant women performing short-term high intensity exercise in late pregnancy (36,37). On the other hand, in fit pregnant women regularly engaging in sustained aerobic exercise at intensities between 40-88% VO2 max, the fetal heart rate has been found to increase consistently during exercise (38). This implies that the fetal heart rate response could be an adaptation to a minor fall in placental oxygen occurring as a result of a small progressive decrease in placental perfusion. The liver readily synthesizes erythropoietin whenever there is an intermittent or long-term reduction in fetal oxygen delivery (39,40). Clapp et al investigated this response in a study on erythropoietin production in the amniotic fluid at the time of membrane rupture in exercising women, as it is a biological marker of tissue oxygen availability (20). They found that the rise in circulating erythropoietin occurring in regular, sustained, strenuous exercise throughout late pregnancy was not associated with elevated erythropoietin levels at labor and delivery in the human (20).

1.3.1.2 Fetal heart rate changes

Fetal heart rate changes are another measure of uteroplacental insufficiency. Fetal heart rate recordings are used as summary indicators of well-being during and after exercise. In the third trimester of pregnancy, it is approximately 120-160 beats per minute, with an average of 140 beats per minute (24).

Depending on the extent of circulatory changes various fetal heart rate responses can be expected after exercise in pregnancy. Acceleration of fetal heart rate with fetal movement i.e. a reactive non stress test has been used to evaluate the antepartum fetal well being of the fetus with potent uteroplacental insufficiency (34). A reactive pattern required the presence of two accelerations of > 15 beats per minute and 15 seconds duration associated with fetal movement during a 20 minute period (32). Acceleration of fetal heart rate following maternal exercise could be related to factors such as fetal arousal, placental transfer of maternal catecholamines, an increase in maternal and fetal temperatures, or a reduction in uterine blood flow (41).

In response to exercise, studies have shown that the baseline fetal heart rate can initially decrease and then return to baseline levels before increasing (40). Several studies have found no change or an increase of not more than 30 beats per minute after exercise (32,38,40,42,45,).

A study by Hauth et al on women who jogged during pregnancy reported no fetal bradycardia (abnormal slowness of the heart) at anytime either before or after jogging (46). The fetal heart rate increased after jogging and the nonstress test was reactive on all testing occasions. However, the authors concluded that moderate maternal exercise does not result in acute fetal distress. Artal and colleagues investigated fetal heart rate patterns during strenuous exercise and reported fetal bradycardia in only three of the nineteen cases studied (36). Fetal bradycardia after exercise is of concern as it may reflect marked fetal hypoxia, fetal acidosis or severe hyperthermia (17,45). However, the bradycardia was of a transitory nature and appeared to be compensated by an increase in fetal heart rate after cessation of exercise. This could reflect a compensatory response in the fetus to overcome the brief periods of hypoxia.

Aerobic activity during pregnancy failed to produce cases of marked tachycardia or bradycardia either before or after exercise except in 10% of the cases (41). Tachycardia is rapid heartbeat and is a term usually applied to a pulse rate above 100 beats per minute. Moreover, aerobic activity during pregnancy did not interfere with normal fetal growth and development (41). No correlation was found between the individual fetal heart rate responses, gestational age, exercise intensity, and maternal circulating catecholamines in pregnant women involved in mild, moderate or strenuous exercise (32). Mild maternal exercise was not found to change the uteroplacental peripheral vascular bed resistance (47). Thus in healthy pregnant women, with no clinical complications in childbearing, fetal heart rate does not appear to be significantly affected in any predictable manner.

1.3.1.3 Hyperthermia

The increased heat production associated with exercise has detrimental effects on the fetus. Laboratory experiments in animals have shown that elevation of maternal temperature is associated with an increase in the risk of fetal malformations (48,49). The fetus is totally dependent on the mother for the dissipation of body heat. Under resting conditions the fetal temperature is about 0.5°C above that of the mother. Animal studies have shown that elevation of maternal temperature is associated with elevation of fetal temperature (50). The decline in temperature after exercise is more prolonged in the fetus than the mother, suggesting that heat exchange in the placenta is compromised during exercise. However, the increased heat production associated with endurance exercise and pregnancy brings about a variety of adaptive mechanisms to regulate body heat.

Exercise duration and intensity are important in determining the temperature increase. In a study by Clapp et al on women jogging prior to and during pregnancy, the exercise intensity and duration decreased in pregnancy (51). Likewise, the magnitude of the rise in rectal temperature also decreased. The authors suggest that this decrease in heat production could be due to the training effect and also heat acclimatization. Moreover, they speculate that the physiological changes associated with pregnancy increase the efficiency of heat dissipation due to increased blood volume and cutaneous circulation. Jones et al observed no change in the thermoregulatory response to sustained exercise during pregnancy (18). Another study by Clapp et al, reported a decrease in mean rectal temperatures by 0.3°C at 8 weeks and then a fall at a rate of 0.1°C per lunar month through the thirty-seventh week, which again suggests physiological adaptations to pregnancy (52).

1.3.1.4 Decreased barometric pressure

In activities like mountain sports performed at high altitudes hormonal and other factors intrinsic to pregnancy may be responsible for a two-fold increase in the maternal hypoxic ventilatory response. Maternal low exercise levels have not been found to be associated with significant fetal heart rate changes at altitudes 2500m or less. Moore et al found that pregnancy-induced hypertension was more frequent at an altitude of 3100m than at 1600m (53). They concluded that maternal hypoxia could play a role. High altitude living has been associated with fetal growth retardation. In addition, altitude induced hypoxia may aggravate maternal cardiac disease thereby compromising fetal well-being (54).

1.3.1.5 Increased Barometric pressure

Activities like scuba and snorkel diving performed at increased barometric pressures can result in mixing of the inhaled nitrogen in blood and other tissues (30). Thus accumulation of nitrogen in maternal tissue results. Accumulation in fetal tissue may occur as well. The fetus is at risk of malformation and gas embolism after decompression disease (54).

1.3.2 Maternal risks

The concerns regarding risks to the mothers exercising in pregnancy range from hypoglycemia during exercise sessions, chronic fatigue, the risk of injury, the effect that exercise could have on the heart rate of the mother, and the risk the increase in temperature could pose to the mother (22,23,55,56,57). Potential benefits for the mother are many and include increased fitness, reduced stress, prevention of excess weight gain, decreased risk of gestational diabetes, facilitation of labor, faster recovery from childbirth, and improved mood and body image (58,59).

1.3.2.1 Effect of injury

There is concern that certain physical activities involve chances of maternal trauma during pregnancy and are best avoided. During pregnancy, as a result of greater ligamentous laxity, heavier body weight, and change in the center of gravity, pregnant women are probably at increased risk of sprains, stress fractures, and falls (55,56). Direct trauma to the abdomen could result in maternal and fetal injury. The consequences will depend on the stage of pregnancy, the type and severity of the trauma and the extent of injury to the fetoplacental unit.

In a study of trauma cases, out of 84 women with abdominal trauma, after 25 weeks gestation 39% of the injuries were due to falls (56). Seventeen women from the 84 trauma cases i.e. about 20% had uterine contractions after the event. The authors suggest that a high number of falls in late pregnancy could probably be due to problems with balance because of a protruding abdomen. Trauma in late pregnancy can also cause abruptio placentae (premature separation of a normally situated placenta) and its incidence is estimated to be between 1 and 5 percent (57). This could be followed by fetal distress, fetal death, or long-term placental insufficiency. A review by Bell et al, reported that the risk of fetal injury is also high in late pregnancy due to a decrease in the amniotic fluid: fetal ratio (17).

Injury to the placenta can cause fetomaternal hemorrhage and the risk could be as high as 28%. Potential complications include Rhesus sensitization of the mother, fetal anemia, and in severe cases fetal death.

1.3.2.2 Effects of temperature

Heat production in pregnancy increases due to increased activity of maternal tissues and the fetoplacental unit. A rise in rectal temperature of up to 1.5 °C was found in late pregnant ewes after fairly intense treadmill exercise or prolonged walking to exhaustion (22). Exercise during pregnancy leads to even greater heat production due to the increased activity of the skeletal muscles. Dissipation of this excess heat poses a challenge to the maternal thermoregulatory processes especially when temperature regulation is complicated by environmental conditions (22,23).

1.3.2.3 Effect on heart rate

Studies on the effect of exercise on cardiac output have reported conflicting findings. Bader et al found cardiac output during exercise to be similar to a reference control response and to be stable throughout pregnancy (23). Knuttgen et al also found the cardiac output to be similar in pre and postpartum subjects (24). On the other hand Ueland et al found that the cardiac output to be higher during exercise compared to postpartum values (58). Moreover, the cardiac output was found to be elevated throughout pregnancy. The greater cardiac output was due to a greater stroke volume. The increase in cardiac output during exercise at 200 $kpm.min^{-1}$ decreased gradually as pregnancy progressed, and near term the increase appeared less than that found postpartum. These gradual changes during pregnancy were due to changes in both heart rate and stroke volume. In a study by Guzman et al, the cardiac output was found to be higher throughout pregnancy than in the non-pregnant controls at all levels of cycle ergometry (26). This was due to heart rates and stroke volume in the pregnant subjects. It thus seems probable that exercise induced increase in cardiac output during pregnancy is essentially normal and adequate for the work demands.

1.4. Exercise with coexistent conditions unique to pregnancy

The potential risks and benefits of exercise during pregnancy with coexistent gestational diabetes and preeclampsia are reviewed below.

1.4.1 The effect of work in pregnancy on the risk of severe preeclampsia

Preeclampsia is a disease unique to pregnancy characterized by progressive hypertension, pathologic edema and proteinuria (61). It contributes substantially to maternal and fetal morbidity and mortality as it could lead to eclampsia, which is fatal (62). Eclampsia is defined as the onset of convulsions or coma during pregnancy or postpartum in a patient who has signs and symptoms of preeclampsia (63). Maternal deaths could occur due to intracerebral hemorrhage, pulmonary edema or renal hepatic or respiratory failure (63). Perinatal mortality and morbidity can occur; the main causes being preterm delivery, fetal growth retardation and abruptio-placentae (63).

The belief that preeclampsia is characterized by vasoconstriction has recently been challenged. In a study of nulliparous women with uncomplicated pregnancies, it was demonstrated that, preeclampsia is characterized by high cardiac output rather than vasoconstriction (61). Thus working conditions could play a role in the development of preeclampsia. Several studies have shown that the risk of preeclampsia is two times greater in women who worked during pregnancy as compared to those who were unemployed (63,65). In addition, moderate/high physical activity at work was associated with a 2-fold increase in the risk of severe preeclampsia compared to mild activity (63). Marcoux et al found that increased leisure time activity was associated with a reduction in the risk of preeclampsia probably because women spending longer hours at work have less time for leisure type activity (64). In another study conducted to identify the risk factors for severe preeclampsia in nulliparous and multiparous cases, it was found that severe obesity was a risk factor in all cases (66). Obese patients have an elevated baseline cardiac output, which increases even further secondary to pregnancy-associated physiological changes. Thus these patients cannot compensate further for the increase in cardiac output especially with increased physical activity. They may then develop hypertension while sustaining the increased blood flow leading to vascular lesions and the clinical picture of preeclampsia.

Thus the risk of preeclampsia is greater in obese subjects especially in those indulging in high amounts of physical activity during pregnancy (66).

1.4.2 Gestational Diabetes Mellitus

Gestational Diabetes Mellitus is a complication of pregnancy and occurs in 2-13% of all pregnant women (68). It is associated with increased risk for perinatal morbidity. Improved glucose control in pregnancy may minimize the risk of complications.

In a study, every one out of eight women with class A1 gestational diabetes delivered a large-for-gestational age infant attributable to glucose intolerance (69). Macrosomic infants born of mothers with gestational diabetes mellitus were found to have unique patterns of adiposity that are present at birth and persist at 1-year (70). Long-term studies of growth in infants of mothers with gestational diabetes have revealed increasing adiposity at ages 5-9 years in both normosomic and macrosomic infants, suggesting that the more important risk factor with increasing age is maternal diabetes (71,72). In a study of pregnancy outcome in insulin dependent diabetic mothers, 5.5% of the infants born had congenital malformations ranging from, congenital heart defects, to skeletal malformations and malformations of the visceral organs (73). Intensive treatment begun on another group of diabetic women before conception in the same study, revealed a significant reduction in malformations to 0.8%, indicating the importance of good metabolic control of diabetes in pregnant women (73).

It is well established that gestational diabetes mellitus is a disease of glucose clearance and is characterized by high glucose levels even in the presence of high insulin levels (74). Its treatment aims at maintenance of euglycemia i.e. a normal level of glucose in the blood. Diet therapy is traditionally used as a method of treatment. If this fails, insulin is used. Ideally, treatment should aim at methods that overcome insulin resistance. Increased insulin receptors have been found after exercise in patients with insulin-dependent diabetes mellitus. Cardiovascular conditioning exercise facilitates glucose utilization by increasing insulin binding to and affinity for its receptor (74). Jovanovic-Peterson et al studied the impact of a training program on glucose tolerance in gestational diabetes mellitus (75). Arm ergometer training was used and resulted in lower glycosylated hemoglobin, fasting and 1-hour plasma glucose concentrations, than diet alone. In another study on the efficacy of an exercise program in normalizing glucose tolerance in gestational diabetic patients requiring insulin it was found that 17 of the 21 patients completing the exercise program maintained normoglycemia without insulin therapy (76). Furthermore, in this entire study there was no occurrence of fetal late deceleration or bradycardia. A fetal late deceleration may be defined as a transient decrease in fetal heart rate occurring at or after the peak of a uterine contraction and resulting from fetal hypoxia. Bradycardia is slowness of the heartbeat as evidenced by slowing of the pulse rate to < 60 beats per minute. However, a partially home-based exercise program failed to reduce blood glucose levels, but did result in a modest increase in cardiorespiratory fitness (77).

Recently, a study was carried out to assess whether exercise results in a lower prevalence of gestational diabetes mellitus and to investigate whether there is an association between Body Mass Index, exercise, and the prevalence of gestational diabetes mellitus. The authors found no difference in the rates of gestational diabetes mellitus between women with a Body Mass Index of 30 or less, who exercised and those that didn't exercise during pregnancy (78). However, women with a Body Mass Index over 30 had lower rates of gestational diabetes mellitus if they exercised than those that didn't. In the Nurses' Health Study II, no association was found between the MET scores and subsequent gestational diabetes mellitus risk (79). Although the risk for gestational diabetes mellitus was found to be slightly lower with frequent participation in vigorous physical activity, the association was not significant enough in the cohort as a whole or among those women considered to be at high risk for gestational diabetes mellitus such as the obese women, or those with a family history of diabetes mellitus, or over 35 years of age. Despite studies showing the benefits of exercise in maintaining euglycemia, exercise as a form of therapy is not widely recommended in pregnancy because of the effect it may have on the uteroplacental and fetal circulation.

1.5. Occupational activity hazards and pregnancy outcome

More women who have been working before pregnancy continue their employment during gestation. More than half of all women now work (80). The increase in the number of women who work during pregnancy may be attributed to greater dependence on a second salary to support the family. Health care providers and working women are concerned whether work during pregnancy has any adverse pregnancy outcomes.

Women are now employed in the workforce in almost all areas of work. The impacts of occupational activity on pregnancy outcome are varied (36,47,81). Four physical stresses are associated with occupational activity, which include quiet standing, long hours of standing, protracted ambulation, and heavy lifting. It is believed that these stresses could cause intermittent but protracted reductions in uterine blood flow and increase intra-abdominal pressure (46). Premature rupture of the uteroplacental membrane could occur leading to a shortened duration of gestation. A short duration of gestation is associated with serious neonatal and infant morbidity (82).

In studies carried out to assess the impact of physical activity on the gestational age at delivery in women performing physical tasks in their job during pregnancy, it was found that the daily duration of tasks with a high physical workload was significantly correlated with a shorter gestational age at delivery (11,15). Prolonged standing and walking especially were found to increase the risk of preterm delivery in a prospective cohort of 8,711 women (83). A significant association was also found between standing and preterm birth, but not with low birth weight (84). With stand-up work activity right up to late gestation, not only was growth retardation in the infants observed, but also the frequency of large placental infarcts were found to increase (14).

The prematurity rate in a French study was found to be 8.3% in women involved in occupations requiring long hours of standing whereas in the other occupational categories, the rate was found to be 3.5%(85). The longer the standing hours the higher was the risk of premature births. A Montreal study on a large sample of about 22,761 pregnant women employed for more than 30hrs per week, revealed 7.4% of preterm births and 6.6% low birth weights (86). There was a large overlap i.e. 4.1% were both preterm and of low birth weight. Classified by occupation, the managerial sector had a low rate of preterm and low birth weight children. Those occupations involving a lot of standing such as the services sector had a slightly increased ratio of preterm births. Low birth weight was also found to be higher in occupations involving both standing and lifting (80). This was confirmed by another study, where intra uterine growth retardation (IUGR) was studied with the use of ultrasonography. Manual workers were found to be at a slightly higher risk for IUGR (14). Employment during pregnancy was found to be a risk factor for spontaneous as well as indicated preterm birth, in a study by Meis et al (87).

A prospective study of the effect of work-related physical exertion on the risk of spontaneous abortion found no association in 5,144 pregnant women (88). Physical exertion was measured as time spent working, standing and bending at work, hours between breaks, and hours spent doing housework or yardwork; shiftwork, number of times lifted heavy weight > 15 pounds at work or home; number of children under age 5 years cared for at home. Moreover, physical activity at home and work combined together was not related to increased risk either (88). A study of 5,552 pregnant women also revealed no evidence that work per se had any detrimental or beneficial effects on the risk of having a small for gestational age infant or preterm delivery (89). A study in Western Australia on energy expenditure and its effect on pregnancy outcome reported that women in the medium expenditure group delivered babies with higher birth weight and had fewer incidences of premature rupture of membranes as compared to women in the lower energy expenditure group who had increased risks of antepartum admission to the hospital. However, these results were not due to the physical activity levels as such but due to other confounding variables present (90).

1.6. Leisure time activity and pregnancy outcome

More and more pregnant women are continuing their leisure time activities during pregnancy. These include a wide range of sports such as swimming, diving, dancing, skiing etc. Many investigations have shown that women who participated in sports or physical fitness exercises during pregnancy had a significantly lower rate of preterm delivery as compared with those who were not active (91,92,93). Lack of leisure-physical activity during pregnancy was one of a number of factors contributing significantly to an increased risk for pre-term delivery (94,95,96).

Exercise in the water offers physiological advantages to the pregnant women (97). The hydrostatic force of water pushes extravascular fluid into the vascular spaces, producing an increase in central blood volume that may lead to increased uterine blood flow. This force is proportional to the depth of immersion. The increase in blood volume is proportional to the women's edema. A marked diuresis and natruresis accompanies the fluid shifts. The buoyancy of water supports the pregnant women. Water is thermoregulating. Studies of pregnant women exercising in the water have shown less fetal heart rate changes in the water than on land in response to exertion. Pregnant women's heart rates and blood pressures during water exercise are lower than on land exercise, reflecting the immersion-induced increase in circulating volume (97). However, pregnant females should refrain from diving, because the fetus is not protected from decompression problems and is at a risk of malformation and gas embolism (98).

Pregnant women exercising at high altitudes must do so with caution. In the first few days, exercise should be performed at lower altitude. The effects of exercise and altitude may be synergistic, and so an altitude of 2,500m (8,250 ft) should not be exceeded in the first 4 to 5 days of short-term exposure. Compounding risks, e.g., maternal smoking, anemia or fetal growth retardation must be carefully excluded (54).

1.7. Physical activity and the course of pregnancy, labor and delivery

Studies on the effect of exercise on pregnancy outcome present conflicting findings (99,100,101,102). Exercise during pregnancy poses potential hazards to the fetus as mentioned earlier in this review, such as early miscarriage, induction of premature labor, altered fetal development, shortened gestation, and reduced birthweight. Potential benefits include the possibility of fewer complications during labor and delivery when the mother is in good physical condition.

1.7.1 Length of labor

There is the general belief in the medical community that fitness for delivery is an asset to the mother. However, some obstetricians feel that intensive sport activities stiffen the pelvic floor and perineum, thereby making labor more difficult than for the normal population. In contrast, others consider that the strengthened abdominal muscles in the athletes are beneficial during the second stage of labor.

Research on the effects of exercise on length of labor has shown conflicting findings (103, 104,105, 106, 107, 108, 109). Erdelyli reported that 87.2% of 107 German female athletes delivered faster than the established average (103). Similarly, that group had fewer cesarean sections, fewer perineal tears, and shorter total duration of labor, with the third stage lasting only half as long as in non-athletes. Horns et al (104), have reported the findings of a study wherein the length of labor in 65 primiparae who did and did not attend exercise classes was studied. Women who participated in an exercise program had significantly shorter labors than those who did not. Kupla et al reported a shorter active labor phase in primigravidas who had participated in aerobic exercise during pregnancy (105). Clapp (106) found exercise throughout pregnancy to be associated with shorter active labor (223 vs. 302 minutes, $p<0.01$).

Pomerance et al, found a negative correlation between exercise and the combined length of first and second stages of labor in primiparae (107). No significant difference was found in length of labor of primiparae who did and did not exercise. Physically fit multiparae, however, were found to have shorter labors than multiparae who did not exercise. Hall et al, found no significant difference in mean length of labor in either primigravidae or multigravidae who had exercised during pregnancy (108). A retrospective study by Kardel et al, performed a detailed documentation of the physical activity of 42 women before conception, during pregnancy and delivery on the onset of labor (109). They found that the gender of the child affected the onset and duration of labor. A later onset of labor was found in the medium intensity activity group than in the high intensity activity group but only for mothers giving birth to girls, and a tendency for shorter duration of labor for both genders in the medium intensity group compared with the high intensity group. However, to objectively summarize the current research regarding the effect of exercise on the length of labor, a meta-analysis by Lokey et al, has reported that women who exercised during pregnancy did not differ form sedentary women in the length of labor (110).

1.7.2 Apgar Score

Wong and McKenzie found that newborns of primigravidae who engaged in regular exercise during pregnancy had higher 1-minute Apgar scores (111). No differences were found in the 5-minute Apgar scores. Additionally newborns of women who exercised at a high level had slightly higher Apgar scores than newborns of mothers in the control, low exercise level, and medium exercise level groups. Hall et al (108) reported that newborns of mothers who exercised at a high level had slightly higher 1-minute Apgar scores than newborns of mothers in the control, low exercise level, and medium exercise level groups. The mean 5-minute Apgar scores for newborns of mothers in the high exercise level group were slightly higher than those for newborns of mothers in the control and medium exercise level groups.

A review by Wallace and Engstrom on the effects of aerobic exercise on the pregnant woman, her fetus and pregnancy outcome, concluded that moderate exercise is safe for pregnant women who have no medical or obstetric complications (112). A recent study by Zeanah et al reported that women who exercised in excess of the American College of Gynecologists guidelines did not experience adverse affects from the activity (113). A meta-analytic review of research by Lokey et al (110), on the effects of exercise on pregnancy outcomes, found no significant difference in active and sedentary women for maternal weight gain, neonatal birth weight, length of gestation, length of labor, or Apgar scores. Still other reviews on the effects of exercise on pregnancy outcomes found no difference in the Apgar scores between newborns of women who exercised during pregnancy and newborns of sedentary women. A recent study found no significant difference in the Apgar scores between active and sedentary groups for caesarean delivered newborns or between the 1-minute Apgar scores for vaginally delivered newborns (104).

1.7.3 Birth intervention

Neonatal outcome varies greatly because of several possible influences including genetics, socioeconomic differences, maternal physical and health characteristics before and during pregnancy, nutrition, exposure to drugs and toxic agents, stress, obstetric care and exercise (22). Mostly cross-sectional studies have reported the long-term effect of physical activity on pregnancy outcome (103,105,107,114). These studies have been mainly on athletes and controls. Also some recent studies have been retrospective (93,108,116,117), there are others which are prospective (118,119,120,121).

Most studies suggest a normal or improved parturition and neonatal outcome for women who exercise during pregnancy. Compared to untrained women it has been shown that athletes and more fit women tend to have shorter labors (107,111), lower rates of complications during pregnancy and similar childbearing capabilities (103,122). Other prospective studies suggest no difference in pregnancy outcome in women exercising during pregnancy compared to those who did not. A few studies suggest that exercise during pregnancy may be related to the type of delivery, but the direction of this relationship is not clear. Hall and Kaufman (108), found an inverse relationship between the amount of exercise during pregnancy and the proportion of caesarean deliveries, ranging from 6.75% in the high exercise group to 28.1% in the sedentary group ($p< 0.01$). This study is in agreement with the findings in a study of Hungarian athletes (123), in whom a low frequency of C-sections and forcep deliveries was found, but is in contrast with another study of runners, which reported greater likelihood of C-sections with greater exercise (183). Caesarean deliveries occur due to several reasons. These include fetal indications as well as maternal indications (82). Fetal indications include fetal distress, prematurity, fetal growth restriction, malpresentation, alloimmunization, fetal malformations, and multiple gestation. Maternal indications include preeclampsia, diabetes, invasive cervical cancer, dystocia (abnormal labor or childbirth due to some condition inherent in the mother), and previous caesarean. Maternal obesity and increased pregnancy weight gain have also been found to be associated with increased mean birth weight and caesarean rates (82).

1.7.4 Length of gestation

Gestational age is the most important factor that determines perinatal morbidity. Mixed results have been obtained from studies on exercise, birth weight and gestational age. No difference in birth weight or gestational age has been found in some studies. In a study by Clapp and Dickensen, continued, sustained endurance exercise during pregnancy significantly reduced gestational length (119). Another well-controlled trial by Clapp et al (124), found that women who continued to exercise during pregnancy at least 3 times a week for at least 30 minutes at an intensity greater than 50% of age-predicted maximum heart rate had shorter gestation, a higher incidence of small-for-gestational age babies and less gestational weight gain. These associations between exercise and shortened gestation have not been confirmed by other studies (108,125). A meta-analysis by Lokey et al (110), of 18 observational and interventional studies found no difference in the gestational age of infants born to exercising and non-exercising women.

1.7.5. Physical activity and birth weight

Birth weight is the single most important predictor of infant survival, since both neonatal and postneonatal mortality increase exponentially with decreasing birth weight (126). Apart from gestational age, birth weight is also known to be positively, influenced by maternal characteristics such as height, weight, age, and parity. Smoking, hypertension, lower social class and physical activity, influence birth weight negatively (127,128).

Starting a program of regular cycle ergometry, swimming, stretching, or multimodality exercise in the second trimester of pregnancy has been associated with either no change or a small increase in birth weight

(124,125,129). Several retrospective and epidemiological studies have also reported similar findings when regular walking and running is continued throughout pregnancy (38,130). However, when exercise volume is prospectively monitored, birth weight is significantly reduced in infants of women maintaining regular, vigorous, and sustained exercise throughout pregnancy and is increased in those who stop in late pregnancy (124). Moreover, it has been observed that in those who continue, the reduction in birth weight is directly related to the overall level in late pregnancy and is primarily due to a decrease in fat mass (about 220 gm). The remainder (about 100gm) is explained by the 5-day difference in gestational age at delivery (124). Head and axial growth has been found to be unchanged. An increase in low-birth-weight infants has been observed in women who work in adverse conditions or in jobs with known hazardous exposures. Thus it seems that the relationship between exercise during pregnancy and birth weight may be U-shaped. Clapp et al speculate that at low levels of physical activity, the effects on maternal blood volume, insulin sensitivity, placental growth, and rest-activity cycles may actually improve fetal substrate availability and growth (38). At higher levels of performance the effects are balanced, whereas at very high levels the adaptive mechanisms may not entirely compensate and caloric storage as fat is reduced.

1.7.6 Cord entanglement and clinical evidence of fetal distress

There are no reports of an increase in fetal cord entanglement, meconium staining, fetal heart rate abnormalities during labor, low Apgar scores, or neonatal complications in exercising women. In one study the incidence of these findings was found to be significantly decreased or similar to a closely matched population (124). Likewise, erythropoietin levels were not found to be elevated in newborns of exercising mothers (131). Moreover, in fit women, fetal heart rate responses to sustained exercise were not found to suggest fetal hypoxia (130). However, 10% to 20% of fetuses of healthy, relatively unfit women have been found to experience transient decreases in heart rate during and immediately after both moderate- intensity, sustained cycle ergometry and rapidly progressive submaximal cycle ergometry, suggesting that exercise in this population may significantly reduce uterine blood flow and fetal oxygen tension (132).

1.8. A review of methods used for assessing physical activity

Methods for assessing physical activity include, direct and indirect calorimetry, doubly labeled water technique, questionnaires, heart rate monitoring and accelerometry or pedometry (133,134,135,136). The advantages and disadvantages of the different methods of data collection are discussed in the following paragraphs.

Energy expenditure in humans is typically measured by either direct or indirect calorimetry (133). Direct calorimetry involves measurement of heat production directly. This approach is technically demanding, especially in human studies, and is therefore infrequently used, especially in population studies (133). Indirect calorimetry measures energy production by respiratory gas analysis (133). This method is based on measurement of oxygen consumption and carbon dioxide production that occurs during the combustion (or oxidation) of protein, carbohydrate, fat and alcohol. One of the limitations of using indirect calorimetry to measure resting metabolic rate is that measurements can be performed over only a very short time (usually 30 minutes). Measurements over 24 hours can be achieved by having subjects live in a metabolic chamber. Thus the disadvantage in using this technique for the present study is that free-living expenditure cannot be measured other than by confining the subject in a metabolic chamber for the entire activity period. Moreover, even for short measurement periods, the subject has to wear a facemask or a mouthpiece, or canopy system for gas collection (133). This method is therefore unsuitable for such large-scale studies. Thus although direct and indirect accurately measure energy expenditure, they are so intrusive that they alter activity patterns (134).

Free-living energy expenditure can be accurately measured by using the doubly labeled water technique (135). It is a noninvasive technique, which can be used to estimate energy expenditure from activity when combined with measurement of resting metabolic rate. However, it is an expensive technique requiring an isotope ratio mass spectrometer for sample analysis. It is thus unsuitable for large-scale epidemiological studies. This method provides a direct measure of carbon dioxide production but not of energy expenditure, as the food quotient of the diet is required for generating estimates of energy expenditure.

Heart-rate monitoring is an alternative method, which has been found to provide close estimation of total energy expenditure of population groups in validation against whole body calorimetry and the doubly labeled water method (135,136). However, the appropriate use of this technique requires a proper and undisturbed minute-by-minute heart rate recording during a period of at least three days. It also requires a calibration procedure in each subject in order to determine the individual relationship between oxygen uptake and heart rate exceeding a predetermined heart rate level at light, moderate and heavy work loads. Requirement of the resting heart rate and basal metabolic rate for each individual restricts the use of this method.

Questionnaires may be useful for large-scale epidemiological studies (137). They are more practical to use in a population setting, as they are an inexpensive method. However, the major difficulty with the questionnaire approach is that it relies on the ability of the subject to recall behavioral information accurately. Another difficulty with these questionnaires is translation of qualitative information on physical activity to quantitative data (138). It is also difficult to establish the validity of questionnaires used. There is a lack of standards against which the physical activity recall and other physical activity assessment techniques can be judged. Use of an activity diary to record daily activity from time to time helps to reduce the subjective error (135).

Activity diaries have been used for several decades in the assessment of physical activity (135,138). These methods do not rely on complicated methodology, are inexpensive and therefore suitable for population studies.

Data from the physical activity diaries is classified using different classification systems. The Compendium of Physical Activity used in this study (138), is an internationally used system of classification, which provides a comprehensive system for coding physical data on physical activity by purpose and energy cost. The energy cost of specific activities listed in this Compendium were obtained primarily from the previously published physical activity energy expenditure lists: Tecumseh Occupational Questionnaire, Minnesota Leisure Time Physical Activity, McArdle, Katch, and Katch's physical activity list, the 7-day Recall Physical Activity Questionnaire, and the American Health Foundation's physical activity list.

In this compendium all activities are assigned an intensity unit based on their rate of energy expenditure expressed as METS. The intensity of activities in the Compendium is classified as multiples of one met or the ratio of the associated metabolic rate for the specific activity divided by the resting metabolic rate. One MET is defined, as the energy expenditure for sitting quietly.

Thus,

$$1MET = 3.5ml\ O_2 / kg\ body\ weight/min$$

or

$$1\ MET = 1\ kcal/kg\ body\ weight/hour.$$

Moreover, this Compendium is organized by activity types or purpose and includes activities of daily living or self-care, leisure and recreation, occupation, and rest. The major headings in the Compendium explain the reason a person is engaging in a specific activity and is useful in categorizing activity types.

1.9. Study Objective

The objectives of this study were:

- To provide baseline data on activity levels during pregnancy in a sample of New Zealand European, Maori and Pacific women.
- To examine the association between activity levels during pregnancy on maternal medical issues during pregnancy and birth e.g. use of birth interventions, length of labor.
- To examine the association between activity levels during pregnancy on the gestational age, health and birth weight of the baby.
- To examine the effect of physical activity on weight gain during pregnancy and weight retention post partum.