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Communication

Association between Physical Activity and Seasonal Variations in Metabolic and Vascular Function in Adults

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Abstract: This article highlights the association between physical activity (PA) and seasonal variations in metabolic and vascular function in adults. Increasing PA is an important method for preventing cardiovascular disease (CVD) and all-cause mortality by improving blood glucose, blood pressure, blood lipid profiles, body fat, insulin resistance, and vascular function, such as endothelial function. Conversely, various factors, such as seasonal climate conditions, may affect the amount of PA that individuals undertake. Changes in PA often induce seasonal variations in metabolic and vascular function; the deterioration of such functions in winter is the most prominent, and there is clear evidence of an increased risk of CVD in this season. Understanding the influence of PA on seasonal variations observed in metabolic and vascular function is necessary for the management of these physiological functions. In this article summary, few studies have proven that maintaining PA can suppress the variations, and it remains unclear what types, intensities, and durations of regular PA are effective for circumventing seasonal impact. In addition to further studies, there is a need to educate individuals about the strategies to manage PA and other aspects of their lifestyles throughout the year, particularly in winter.

Keywords: physical activity; exercise; metabolic function; vascular function; seasonal variation

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1. Introduction

Deterioration of metabolic function, including blood pressure, blood glucose, and blood lipid profiles, increases the risk of cardiovascular disease (CVD) and mortality [1,2]. Persistent and postprandial hyperglycemia are predictive factors for an increased risk of CVD and all-cause mortality [3,4]. Additionally, vascular endothelial dysfunction is observed before the presence of atherosclerosis [5]; it deteriorates the regulation of vascular tone, growth, thrombogenicity, and inflammation, and thus, it independently increases the risk of CVD [6]. Flow-mediated dilation (FMD) of the brachial artery, which is used to quantify endothelial function, is an assessment of vascular function; previous studies have revealed that decreased FMD can lead to the onset of CVD [7,8].

Therefore, maintaining metabolic and vascular function is necessary to prevent cardiovascular events. Multifactorial intervention, including the management of blood glucose, blood pressure, and blood lipid profiles, is effective in decreasing CVD and mortality in individuals with type 2 diabetes [9,10]. Promoting physical activity (PA) is an effective method for managing metabolic and vascular function, rendering PA an important determinant of CVD and all-cause mortality [11,12].

Conversely, seasonal variations have been often observed in the PA that individuals undertake, and a reduction of engagement in leisure-time activities and sports has been observed during the cold season [13–15]. A previous study from the Michigan Behavioral Risk Factor Survey (n = 2843) has shown that weekly energy expenditure in leisure time was significantly greater during spring (average: 17.5 kcal/kg/week) and summer (17.5 kcal/kg/week) compared with winter (14.8 kcal/kg/week) and fall (15.0 kcal/kg/week) [14]. Moreover, another study, which used a PA questionnaire, has reported that seasonal variations in moderate-to-vigorous PA were observed among rural and urban individuals; the leisure time PA (average: 256 metabolic equivalent (MET)-min/week in spring, 250 MET-min/week in summer, 251 MET-min/week in autumn, and 240 MET-min/week in winter in rural individuals), the household-related PA (437 MET-min/week in spring, 432 MET-min/week in summer, 432 MET-min/week in autumn, and 423 MET-min/week in winter in urban individuals), and the gardening-related PA (7.92 MET-min/week in spring, 22.72 MET-min/week in summer, 5.53 MET-min/week in autumn, and 4.68 MET-min/week in winter in rural individuals) all showed a seasonal variation [13]. These seasonal changes in PA, as well as in the outdoor environments (e.g., temperature, sun exposure that induces vitamin D synthesis) [16,17], can induce variations in metabolic and vascular function [17,18]. As these functions worsen, the risk of CVD may increase in the cold season, especially in older individuals [19]. Other studies have also shown that seasonal variations in the risk of CVD, stroke, and mortality were affected due to the changes in metabolic and vascular function, as these functions are vulnerable to cold temperature [20–22].

Therefore, continuing to perform regular PA during winter may help avoid the deterioration of metabolic and vascular function and onset of CVD and mortality. However, few studies have examined whether seasonal variations in metabolic and vascular function could be decreased by maintaining the PA levels, including exercise, throughout the year.

The purpose of this article is to review the knowledge about the association between managing PA and seasonal variations in metabolic and vascular function in adults.

2. Seasonal Variations in Metabolic and Vascular Function

2.1. Metabolic Function

Seasonal variations in metabolic function are often observed with changes in outdoor environmental factors, such as temperature, which affect blood circulation [23]. Exposure to low temperatures causes various endocrinological responses and changes in sympathetic nervous system activity [24,25].

Blood pressure can rise in response to low outdoor temperatures in winter [26]. A previous study showed that a 1 °C decrease in outdoor temperatures raised systolic and diastolic blood pressure by 0.43 mmHg and 0.29 mmHg, respectively [27]. It is likely that low temperatures may induce the secretion of catecholamines, increase the sympathetic nervous system activity, and raise peripheral vascular resistance, heart rate, and arteriolar vasoconstriction, causing an increase in blood pressure [26,28,29]. Moreover, temperature changes (from medium to high or low) may increase blood urea nitrogen/creatinine [30]. Additionally, a decrease in vitamin D synthesis during winter also increases blood pressure levels through low sun exposure and inhibition of the renin–angiotensin system [28]. Furthermore, a cold-activated renin–angiotensin system and cold-mediated dehydration can also be the mechanisms underlying the onset of CVD [21].

Low temperatures have been shown to increase blood glucose concentration, which may be due to the changes in blood pressure, blood flow, and heart rate variability [31–34]. Hyperglycemia induces endothelial dysfunction and hypercoagulability, and thus, it injures vascular function [21]. Glycated hemoglobin (HbA1c) levels, which are affected by blood glucose, increase in winter and decrease in summer in individuals with type 2 diabetes [35,36]. In type 1 diabetes, higher HbA1c levels are observed in autumn and winter compared with other seasons [37]. Seasonal variations in HbA1c may be caused by the change in insulin resistance along with the change in body fat, which can be increased by plasma cortisol and tissue sensitivity to glucocorticoids that are higher in winter [38].

A large population study, which analyzed over 230,000 adults in 15 countries, revealed that the mean seasonal variations in body mass index (BMI) and waist circumference were 0.3 kg/m^2 and 0.6 cm, respectively [17]. Seasonal variations in body fat may be readily observable in individuals with metabolic dysfunction, such as type 2 diabetes [36], but not in healthy young adults [39]. Blood lipid profiles change seasonally and are highest in winter [40,41]. A previous study investigating male workers (aged 20–69 years) reported that high-density lipoprotein cholesterol as well as blood pressure were significantly higher in winter than in summer, although changes in waist circumference and triglycerides were low [42]. Other studies have found higher total cholesterol and low-density lipoprotein cholesterol levels in winter [43,44] and higher triglyceride levels in summer [45]. Generally, exposure to cold temperatures increases the activity of brown adipose tissue and decreases body fat mass [46]. Winter is the best season for lipid metabolism and weight loss due to an increase in available metabolites [47]. Conversely, long exposure to comfortable temperatures can lead to a loss of brown adipose tissue and an increase in body fat [48]. A previous study showed that the BMI increased more in individuals who lived in regions with higher outdoor temperatures [49].

Seasonal variations in metabolic function can be a result of a difference in food intake. A previous study, which investigated 184 Japanese adults (aged 31–76 years) in three urban and rural areas using a self-administered questionnaire, reported that the consumption of high-energy food in winter was elevated by 254 kcal/day and 156 kcal/day in spring and summer, respectively [50]. Moreover, seasonal variations in blood lipid profiles may differ by region [51], and the variations are often observed after special holidays (e.g., Christmas) and long-term vacations [43,44,51], during which greater amounts of high-fat foods tend to be consumed. Thus, metabolic function may vary profoundly across seasons due to habitual culture-related diets.

2.2. Vascular Function

Vascular function changes seasonally. Outdoor temperatures can affect endothelial function, which is related to the risk of CVD [7,8] through changes in blood pressure [52]. An increase in blood pressure caused by low temperatures impairs endothelial function and induces a decrease in FMD; as a result, FMD is lower in cool seasons compared with warm seasons [23]. Additionally, in low temperature, blood pressure increases along with decreased peripheral circulation and increased urinary voiding, which leads to dehydration [53]. Previous studies reported that prolonged cold exposure impaired endothelium-dependent relaxation and decreased the adiponectin mRNA expression that induces cold-induced atherosclerosis plaque development and dysfunctional endothelial nitric oxide synthase signaling [21,54,55]. Seasonal changes in such vascular functions increase the risk of acute myocardial infarction [56,57], sudden cardiac death [58,59], and hemorrhagic stroke [22,60].

Several investigations have demonstrated seasonal variations in FMD. A cross-sectional study, which was part of the Framingham Heart Study, revealed that the FMD value was lowest in winter (from December 21 to March 20) and highest in summer (from June 21 to September 20) [23]. This study investigated FMD in a large population (n = 2587) but in different individuals across seasons; thus, it remains unclear whether there is a similar change in the FMD value in the same individuals. However, a prospective longitudinal study that investigated FMD in the same individuals across seasons reported similar observations: in individuals (n = 27) with type 2 diabetes, hypertension, and/or dyslipidemia, FMD was higher in the warm season (from July to September) compared with the cool season (from November to March) [61]. Therefore, it is considered that there is a difference in vascular function between seasons.

Other parameters, such as the cardio-ankle vascular index (CAVI), which is used to assess systemic arterial stiffness independent of blood pressure [62], may not change as much as FMD. The CAVI does not correlate with FMD [63], and an improvement in the latter may occur without a change in the former [64]. Hence, seasonal variations in vascular function can be observed at the level of endothelial function assessed by early arteriosclerosis markers such as FMD [63].

3. Seasonal Variations in PA

Variability in habitual PA may be linked to residence [65,66], income [67], and climate conditions, such as precipitation, humidity, air pollution, and outdoor temperature [68,69]. The general amount of PA is lower in winter than in summer in both sexes [70,71], which is likely due to the observation that individuals are often less active and more sedentary during winter than during spring and summer [14,15]. These changes can be induced by climate conditions or based on the decrease in opportunities for regular participation in exercise, sports, and leisure-time activities [14,15,72]. A previous study showed that in older Japanese individuals, PA decreased by approximately 2600 steps/day as a consequence of increased precipitation [69]. This study also found that PA was affected by outdoor temperatures when precipitation was <1 mm/day, and the number of daily steps was found to be highest at an outdoor temperature of approximately 17 °C [69]. Seasonal variations in PA can also be observed in individuals with diseases, such as heart failure and chronic obstructive pulmonary disease [73,74].

Seasonal variations in PA lead to changes in energy consumption and physical fitness. A previous study revealed that although total energy expenditure was not significantly different across seasons, the PA level and activity-related energy expenditure were significantly different in young adults [75]. A decrease in PA in winter may induce reductions in maximal oxygen intake and muscle strength [71]. Moreover, although some fitness parameters, such as walking speed and stride length, are lower in summer, grip strength and steps per day are lower in winter in healthy community-dwelling adults [76].

4. Managing PA for Circumventing Seasonal Variations in Metabolic and Vascular Function

4.1. Effect of PA on Metabolic and Vascular Function

As we have discussed, avoiding seasonal deterioration in metabolic and vascular function is beneficial to managing individuals' health, especially to reduce the risk of CVD and all-cause mortality. Promoting PA is a useful method for improving metabolic and vascular function. Regular PA, including exercise, improves body weight, BG, BP, BL profiles, and insulin resistance in individuals with type 2 diabetes, hypertension, and dyslipidemia [77–79]. Generally, it is recommended to perform ≥150 min/week of moderate-intensity (or ≥75 min/week of vigorous-intensity) aerobic PA and ≥2 days/week of moderate-to-vigorous intensity resistance exercise [1,2,80,81]. A recent study showed that physically active males were able to reduce the odds ratio of elevated triglycerides compared with inactive males who lived in the same climate conditions [68].

Performing regular PA can improve vascular endothelial function by increasing endothelium-derived nitric oxide production and bioavailability [82]. A meta-analysis revealed that regular aerobic exercise (20–60 min, 3–5 times per week) or combined aerobic and resistance exercises (60 min, 3 times per week) improved FMD in individuals with type 2 diabetes [83]. Remarkably, a systematic review of cross-sectional studies showed that even short (<10 min) moderate-to-vigorous PA correlated with improved resting blood pressure and CVD risk, as assessed by the Framingham Risk Score [84].

4.2. Influence of PA on Seasonal Variations in Metabolic and Vascular Function

Changes in PA during seasons are one of the reasons for the occurrence of seasonal variations in metabolic and vascular function [16,17,23,85], including an increase in blood pressure, and metabolic and homeostatic coronary risk factors [86,87]. The total PA changes seasonally in individuals with type 2 diabetes, leading to poor blood glucose control in winter [88]. Furthermore, previous studies have shown that there are seasonal variations in body weight and blood lipid profiles in overweight and obese individuals on account of lower PA levels in winter compared with other seasons [43,89]. Decreased PA causes a reduction in skeletal muscle contractions, which in turn lowers local blood flow and cardiac output, resulting in a decrease in shear stress on the vascular endothelium and nitric oxide production that affect endothelial function [90].

However, it is unclear whether maintaining PA throughout the year, especially during winter, can suppress seasonal variations in metabolic and vascular function. A few studies have attempted to minimize the deterioration in metabolic function in winter (during Christmas holidays) by performing exercise training as an intervention. One study (38 males; aged 57 ± 8 years) showed that exercise could protect against unfavorable changes in body weight, systolic and diastolic blood pressure, mean arterial pressure, blood insulin, and homeostasis model assessment of insulin resistance, and improve total and low-density lipoprotein cholesterols [91]. In contrast, another study (48 males and 100 females; aged 33.5 ± 1.1 years) reported that exercise did not protect against holiday-related body weight and fat gain [92] (Table 1).

Furthermore, few studies have investigated whether exercise or the promotion of PA could suppress the deterioration of vascular function in the cold season. Previous studies that evaluated seasonal variation in FMD were performed without taking into account the individuals' PA (e.g., exercise habits) [23,61] (Figure 1). Seasonal variations in vascular function may be observed even if individuals perform exercises throughout the year, although the influence of total daily PA is unclear [93].

Thus, further studies, such as prospective studies that investigate the effect of total PA levels throughout the year, are needed to confirm the effect of PA on reducing seasonal variations in metabolic and vascular function.

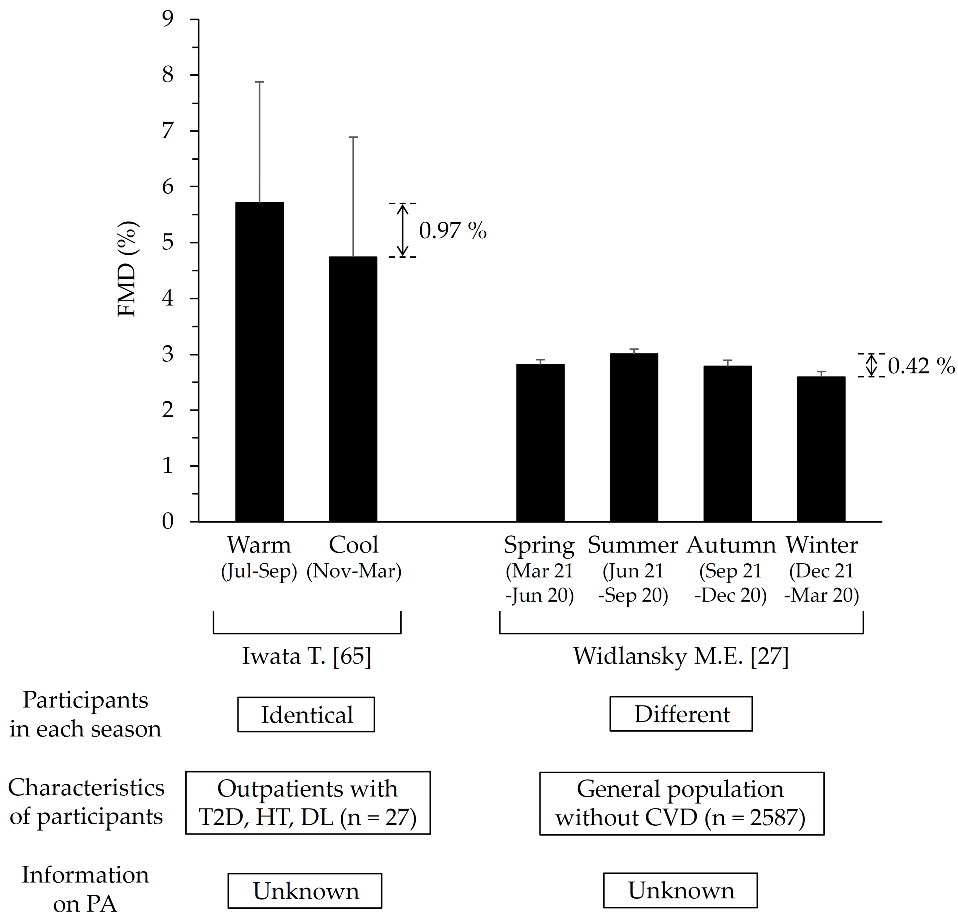

Figure 1. Comparisons of annual ranges (based on the subtraction of the minimum value from the maximum value during the year) of flow-mediated vasodilation (FMD) in studies that investigated seasonal variations in FMD. Values are presented as mean ± standard deviation. T2D: type 2 diabetes; HT: hypertension; DL: dyslipidemia; CVD: cardiovascular disease; PA: physical activity.

Table 1. Comparison of the influence of exercise (Ex) or promoting physical activity (PA) on seasonal variations in metabolic function.

Study	Participants (Male/Female)	Study Design	Ex/Promoting PA (Proportion of Participants Fully Adherent)	Observation Period	Positive Effects in Ex/Promoting PA Group
Ramirez-Jimenez M. (2020) [91]	38 overweight adults with metabolic syndrome (38/0)	Randomized control trial	HIIT: 43 min (4 × 4-min intervals at 90% HRmax with 3-min active recovery at 70% HRmax) (100%)	3 weeks (during Christmas holidays)	BW, BP, mean arterial pressure, blood insulin, HOMA-IR, TC, LDL-C
Stevenson J.L. (2013) [92]	148 healthy adults (48/100)	Prospective observational study	MIPA: ≥150 min/week (52%)	≈2 months (from mid-November to early January)	None

HIIT: high-intensity interval training; HRmax: maximal heart rate; BW: body weight; BP: blood pressure; HOMA-IR: homeostasis model assessment of insulin resistance; TC: total cholesterol; LDL-C: low-density lipoprotein cholesterol; MI: moderate intensity.

5. Conclusions

The aim of this article was to provide an overview of the association between managing PA and seasonal variations in metabolic and vascular function in adults. Various factors, such as climate conditions and individuals' lifestyles, affect these parameters. Although there is some evidence, it largely remains unclear whether maintaining PA throughout the year can suppress seasonal variations in metabolic and vascular function, and what types, intensities, and durations of regular PA are effective for avoiding seasonal variations in these functions. Thus, further understanding the influence of PA on seasonal variations in metabolic and vascular function is required to maintain health. Additionally, individuals should be informed about the variation in these functions during the cold season and be educated about a strategy to manage PA and other lifestyle aspects throughout the year, particularly in winter. Further studies that attempt to circumvent seasonal variations in PA as well as metabolic and vascular function are needed.

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