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Physical Activity to Prevent and Treat Hypertension: A Systematic Review

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ABSTRACT

PESCATELLO, L. S., D. M. BUCHNER, J. M. JAKICIC, K. E. POWELL, W. E. KRAUS, B. BLOODGOOD, W. W. CAMPBELL, S. DIETZ, L. DIPIETRO, S. M. GEORGE, R. F. MACKO, A. MCTIERNAN, R. R. PATE, and K. L. PIERCY, FOR THE 2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE. Physical Activity to Prevent and Treat Hypertension: A Systematic Review. *Med. Sci. Sports Exerc.*, Vol. 51, No. 6, pp. 1314–1323, 2019. **Purpose:** This systematic umbrella review examines and updates the evidence on the relationship between physical activity (PA) and blood pressure (BP) presented in the 2008 Physical Activity Guidelines Advisory Committee Scientific Report. **Methods:** We performed a systematic review to identify systematic reviews and meta-analyses involving adults with normal BP, prehypertension, and hypertension published from 2006 to February 2018. **Results:** In total, 17 meta-analyses and one systematic review with 594,129 adults ≥18 yr qualified. Strong evidence demonstrates: 1) an inverse dose–response relationship between PA and incident hypertension among adults with normal BP; 2) PA reduces the risk of cardiovascular disease (CVD) progression among adults with hypertension; 3) PA reduces BP among adults with normal BP, prehypertension, and hypertension; and 4) the magnitude of the BP response to PA varies by resting BP, with greater benefits among adults with prehypertension than normal BP. Moderate evidence indicates the relationship between resting BP and the magnitude of benefit does not vary by PA type among adults with normal BP, prehypertension, and hypertension. Limited evidence suggests the magnitude of the BP response to PA varies by resting BP among adults with hypertension. Insufficient evidence is available to determine if factors such as sex, age, race/ethnicity, socioeconomic status, and weight status or the frequency, intensity, time, and

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duration of PA influence the associations between PA and BP. **Conclusions:** Future research is needed that adheres to standard BP measurement protocols and classification schemes to better understand the influence of PA on the risk of comorbid conditions, health-related quality of life, and CVD progression and mortality; the interactive effects between PA and antihypertensive medication use; and the immediate BP-lowering benefits of PA. **Key Words:** BLOOD PRESSURE, CARDIOVASCULAR DISEASE, EXERCISE, HIGH BLOOD PRESSURE, PREHYPERTENSION

Cardiovascular disease (CVD) is the leading cause of death in the United States and the world, accounting for approximately one in three deaths (807,775 or 30.8%) in the United States and 17.3 million (31%) globally (1). Hypertension is the most common, costly, and preventable CVD risk factor (1). Nearly 70% of Americans have high blood pressure (BP) (i.e., preestablished to established hypertension) (1), according to the Joint National Committee Seven (JNC 7) BP criteria (2). Using JNC 7 BP thresholds, the lifetime risk for developing hypertension is 90%, and one in five people with prehypertension will develop hypertension within 4 yr (2–4). From 2010 to 2030, the total direct costs attributed to hypertension are projected to triple (US $130.7 to US $389.9 billion), whereas the indirect costs due to lost productivity will double (US $25.4 to US $42.8 billion) (1).

The American College of Cardiology (ACC)/American Heart Association (AHA) Task Force on Clinical Practice Guidelines recently redefined hypertension to a lower BP threshold of 130 mm Hg for systolic BP (SBP) or 80 mm Hg for diastolic BP (DBP) (5) versus the JNC 7 threshold of 140 mm Hg for SBP or 90 mm Hg for DBP (2). This change now classifies nearly half of US adults with hypertension as compared to 32% by the JNC 7 definition, underscoring the importance of hypertension as a public health problem. The authors of the recent ACC/AHA guidelines state that nearly all of those newly diagnosed with hypertension, due to the lower BP threshold, can treat their hypertension with lifestyle modification rather than medications (5). They also emphasize that decreasing the prevalence and improving the control of hypertension by increasing the use of lifestyle antihypertensive therapy, such as participation in habitual physical activity, would provide major societal public health and economic benefit (5).

In addition to the ACC/AHA, professional organizations throughout the world recommend physical activity to lower BP (6). Nonetheless, a systematic review of 33 meta-analyses on the BP response to exercise (7), and another on the existing professional exercise recommendations for hypertension (6), revealed significant shortcomings in this literature. Since the publication of the first Physical Activity Guidelines Advisory Committee (PAGAC) Report, 2008 (8), there has been a considerable expansion of knowledge about the relationships between physical activity and BP. The charge given to 2018 PAGAC was to make evidence-based conclusion statements based upon the newest, best informed science. To do this we conducted a systematic umbrella review of systematic reviews and meta-analyses on the relationship between physical activity and BP published since the 2008 PAGAC Report among adults with normal BP, prehypertension, and hypertension using methodology adhering to the best practices of systematic reviews (9). This manuscript presents the seminal portions of the sections on the role of physical activity in the prevention and treatment of hypertension in the 2018 PAGAC Report (9).

METHODS

This systematic review is reported consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (10,11). The purpose of this umbrella review was to identify systematic reviews and meta-analyses published since the 2008 PAGAC Report (8) that examined the relationship between physical activity and BP among adults with normal BP, prehypertension, and hypertension by the JNC 7 BP criteria because the literature reviewed was based upon this BP classification scheme (2). The specific questions addressed in this review are shown in Table 1. The methods are described in detail in the 2018 PAGAC Report (9), and the protocol is registered at PROSPERO 95748.

Search strategy and selection criteria. The searches were conducted in electronic databases (PubMed®, Cumulative Index to Nursing and Allied Health Literature, and Cochrane) and were supplemented by the authors who were experts in the area to provide additional articles identified through their knowledge of this literature. The studies were considered potentially eligible if they were systematic reviews, meta-analyses of randomized controlled trials (RCT), or pooled analyses published in English from 2006 until February 2018 and investigated the relationship between all types and intensities of physical activity and BP among healthy adults ≥18 yr with normal BP, prehypertension, and

TABLE 1. Questions related to the relationship between physical activity and blood pressure among adults with normal blood pressure, prehypertension, or hypertension* addressed by the 2018 Physical Activity Guidelines Advisory Committee.

Major questions
1. In people with normal blood pressure, prehypertension, or hypertension, what is the relationship between physical activity and blood pressure?
2. In people with hypertension, what is the relationship between physical activity and:
   (a) risk of comorbid conditions,
   (b) physical function,
   (c) health-related quality of life, and
   (d) cardiovascular disease progression and mortality?

Subquestions
a. Is there a dose–response relationship? If yes, what is the shape of the relationship?
b. Does the relationship vary by age, sex, race/ethnicity, socio-economic status, weight status, or resting blood pressure level?
c. Does the relationship vary based on frequency, duration, intensity, type (mode), or how physical activity is measured?

*Of note, we used the JNC 7 BP classification scheme (2) for data extraction purposes. The JNC 7 defines these BP classifications as follows: Hypertension is defined as having a resting SBP of ≥140 mm Hg and/or a resting DBP of ≥90 mm Hg, or taking antihypertensive medication, regardless of the resting BP level. Prehypertension is defined as a SBP from 120 to 139 mm Hg and /or DBP from 80 to 89 mm Hg. Normal BP is defined as having a SBP <120 mm Hg and DBP <80 mm Hg.

hypertension. Studies of non-ambulatory adults, hospitalized patients, or animals were excluded. Search terms included physical activity terms combined with BP terms. See Figure 1 for the systematic search and selection process, and the 2018 PAGAC Report for the detailed full search strategy (9).

Data extraction and methodological study quality assessment. The titles, abstracts, and full-text articles of the identified articles were independently screened by two reviewers. Disagreement between reviewers was resolved by discussion or a third person when necessary. We used the JNC 7 BP classification scheme for data extraction purposes because this literature was based upon this BP classification scheme (2). The JNC 7 BP definitions are as follows: Hypertension, resting SBP of ≥140 mm Hg and/or a resting DBP of ≥90 mm Hg, or taking antihypertensive medication, regardless of the resting BP level; Prehypertension, resting SBP from 120 to 139 mm Hg and/or DBP from 80 to 89 mm Hg; and Normal BP, a resting SBP <120 mm Hg and DBP <80 mm Hg. Two abstractors independently extracted data and conducted a methodological study quality assessment using a modified version of the Assessment of Multiple Systematic Reviews (AMSTAR) (12), specifically adapted for physical activity related health outcomes such as BP (AMSTARExBP) (7).

Grading of evidence. The 2018 PAGAC carefully deliberated the qualifying reviews, and then graded the evidence for the conclusion statements as strong, moderate, limited, or “not assignable” based on grading criteria that included applicability, generalizability, risk of bias/study limitations, quantity and consistency of results across studies, and magnitude and precision of effect. More detailed information about the grading of evidence rubric can be found in the 2018 PAGAC report (9).

RESULTS

Study and Sample Characteristics

Qualifying reviews included one systematic review of longitudinal studies with a minimum of 1 yr of follow up (13) and 17 meta-analyses of RCT (14–30) (see Supplemental Digital Content 1, Table of the qualifying meta-analyses and systematic review by physical activity type, http://links.lww.com/MSS/B522). The total sample size of this umbrella review was 594,129 adults ≥18 yr, ranging from 216 to 330,222 participants. The systematic review (13) included two large longitudinal prospective cohort studies that examined the influence of general and leisure-time habitual physical activity on CVD mortality among adults with hypertension (31,32); 15 of the meta-analyses included RCT that examined the BP response to an exercise training intervention among adults with normal BP (k = 7) (14,15,17–19,21), prehypertension (k = 5) (17–20,24), or hypertension (k = 15) (14–21,24–30) compared with a control condition among similar adults who were physically inactive at baseline; and two of the meta-analyses examined prospective cohort studies of adults initially free of hypertension for the influence of general and leisure-time habitual physical activity on the risk of the development of hypertension (22,23). When this information was disclosed, the samples in the qualifying reports were generally an

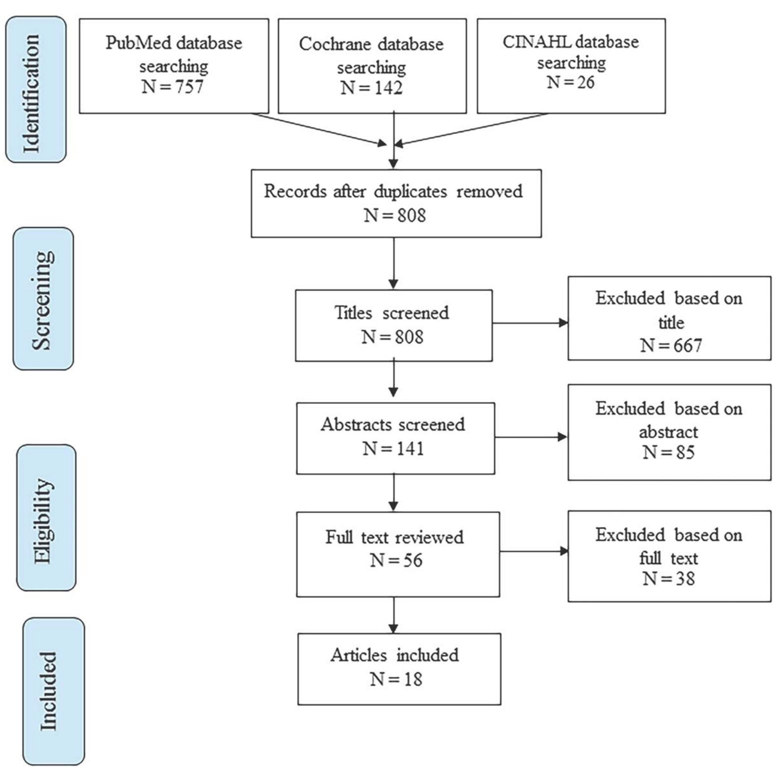

FIGURE 1—Flow diagram of search strategy and study selection. CINAHL, Cumulative Index to Nursing and Allied Health Literature.

equal mix of men and women, and mostly Caucasian followed by Asian and some African American, African, or Indian samples with a body mass index (BMI) that ranged from normal weight to obese. The overall methodological study quality of the qualifying reports was moderate as assessed by AMSTARExBP (7), with 83.3% of the included trials scoring poor to moderate and 16.7% high methodological study quality.

Evidence on the Overall Relationship between Physical Activity and BP

The risk of developing of hypertension or incident hypertension among adults with normal BP and prehypertension was defined in two ways. We regarded the BP response to an exercise training intervention ranging from low to vigorous intensity, and the association between habitual leisure-time physical activity and the risk of developing hypertension as the indicators of the risk of incident hypertension.

The prevention of incident hypertension. *The BP response to an exercise training intervention.* There were eight meta-analyses of RCT that examined the BP response to an exercise training intervention ranging from low to vigorous intensity among adults who were physically inactive at baseline and with prehypertension (17–19,24,25) and/or normal BP (14,15,17–19,21,24) (see Table, Supplemental Digital Content 1, Summary of the Included Systematic Reviews, http://links.lww.com/MSS/B522). Of the five meta-analyses involving adults with prehypertension, all reported a statistically significant reduction in SBP and four reported a statistically significant reduction in DBP. Of the seven meta-analyses involving adults with normal BP, three reported a statistically significant reduction and one reported a statistically significant rise in SBP, and six reported a statistically significant reduction in DBP. The magnitude of the BP reductions ranged from about 2 to 5 mm Hg for SBP and 1 to 4 mm Hg for DBP.

Habitual leisure-time physical activity and incident hypertension. We also regarded the association between habitual leisure-time physical activity and incident hypertension as an indicator of the BP response to physical activity. Huai et al. (22) examined this association among 136,846 adults with normal BP at baseline. After an average of 10 yr (2 to 45 yr) of follow up, 15,607 adults developed hypertension (11.4% of the sample). In this meta-analysis, high amounts (i.e., volume and/or intensity) of leisure-time physical activity were associated with a 19% decreased risk of incident hypertension compared to the referent group engaging in low amounts of leisure-time physical activity (relative risk [RR] = 0.81; 95% CI [Confidence Interval]: 0.76–0.85). Moderate amounts of leisure-time physical activity were associated with an 11% decreased risk of hypertension compared to the referent group engaging in low amounts of leisure-time physical activity (RR, 0.89; 95% CI, 0.85–0.94). *Strong evidence demonstrates that physical activity reduces BP among adults with prehypertension and normal BP. PAGAC Grade: Strong.*

The dose–response relationship between physical activity and incident hypertension. Two meta-analyses investigated the relationship of physical activity and incident hypertension among adults with normal BP (22,23). Of these two, Liu et al. (23) quantified the dose–response relationship between physical activity and incident hypertension among adults with normal BP (see Figure 2). Among 330,222 adults with normal BP, 67,698 incident cases of hypertension occurred (20.5% of the sample) after 2 to 20 yr of follow-up. The risk of hypertension was reduced by 6% (RR, 0.94; 95% CI, 0.92–0.96) at 10 $MET \cdot h \cdot wk^{-1}$ of leisure-time light, moderate, and vigorous physical activity among adults with normal BP. The protective effect increased by about 6% for each further increase of 10 $MET \cdot h \cdot wk^{-1}$. For adults with 20 $MET \cdot h \cdot wk^{-1}$ of leisure-time light, moderate, and/or vigorous physical activity, the risk of hypertension was reduced by 12% (RR, 0.88; 95% CI, 0.83–0.92); and for those for 60 $MET \cdot h \cdot wk^{-1}$ of leisure-time light, moderate, and/or vigorous physical activity, the risk of hypertension was reduced by 33% (RR, 0.67; 95% CI, 0.58–0.78). The relationship between leisure-time physical activity and incident hypertension was linear, with no cutoff of benefit, and slightly weaker with

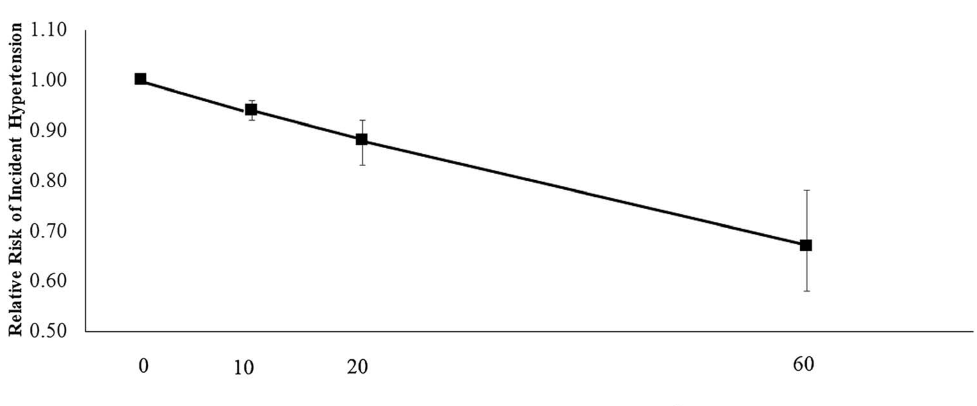

FIGURE 2—A meta-analysis of the inverse relationship between incident hypertension and leisure-time physical activity ($MET \cdot h \cdot wk^{-1}$) among adults with normal blood pressure. Adapted from Liu et al. (23).

(RR, 0.94; 95% CI, 0.92–0.96) than without (RR, 0.91; 95% CI, 0.89–0.93) BMI adjustment as a covariate. *Strong evidence demonstrates an inverse dose–response relationship between physical activity and incident hypertension among adults with normal BP. PAGAC Grade: Strong. However, the available evidence is insufficient to determine whether a dose–response relationship exists between physical activity and incident hypertension among adults with prehypertension. PAGAC Grade: Not Assignable.*

The treatment of hypertension. CVD progression was defined in two ways. Because BP is considered a proxy measure of CVD risk (20,33), we regarded the BP response to physical activity among adults with hypertension as an indicator of CVD progression, and the outcome of CVD mortality as an indicator of long-standing hypertension. The evidence on the BP response to physical activity is discussed first, and the evidence on CVD mortality outcomes follows.

The BP response to physical activity. There were 15 meta-analyses of RCT that examined the BP response to physical activity ranging from low- to vigorous-intensity among adults with hypertension compared with a control condition of adults who were physically inactive at baseline (14–21,24–30). Of these, 13 reported a statistically significant reduction in SBP and 14 reported a statistically significant reduction in DBP (see Table, Supplemental Digital Content 1, Summary of the Included Systematic Reviews, http://links.lww.com/MSS/B522). The magnitude of the BP reductions ranged from 5 to 17 mm Hg for SBP and 2 to 10 mm Hg for DBP. *Strong evidence demonstrates that physical activity reduces BP among adults with hypertension. PAGAC Grade: Strong.*

The relationship between physical activity and CVD mortality. There was one systematic review (13) that included two large longitudinal prospective cohort studies that addressed the impact of self-reported general and leisure-time habitual physical activity on CVD mortality among adults with hypertension followed from 5 to 24 yr (31,32). Hu et al. (31) investigated the associations among occupational, daily commuting, and leisure-time physical activity and CVD mortality among 26,643 Finnish men and women 25 to 64 yr who were overweight and had hypertension that were followed for 20 yr. The multivariate-adjusted hazard ratios of CVD mortality associated with low (almost completely inactive), moderate (some physical activity >4 $h \cdot wk^{-1} \approx 12$ $MET \cdot h \cdot wk^{-1}$ or more), and high (vigorous physical activity >3 $h \cdot wk^{-1}$ ≈ 18 $MET \cdot h \cdot wk^{-1}$ or more) leisure-time physical activity were 1.00, 0.84 (95% CI, 0.77–0.92), and 0.73 (95% CI, 0.62–0.86) among men, respectively; and 1.00, 0.78 (95% CI, 0.70–0.87) and 0.76 (95% CI, 0.60–0.97) among women, respectively (see Figure 3).

Furthermore, Vatten et al. (32) found that among men with a resting SBP between 140 and 159 mm Hg, whose status of medication use was not disclosed, compared with the referent group of men with a SBP between 120 and 129 mm Hg, men with a resting SBP between 140 and 159 mm Hg who were highly physically active (RR, 1.21; 95% CI, 0.97–1.52) reduced their risk of CVD mortality by 30% versus those who were physically inactive (RR, 1.73; 95% CI, 1.37–2.19). Among men with a resting SBP >160 mm Hg compared to the referent group of men with a SBP between 120 and 129 mm Hg, those who were highly physically active (RR, 1.82; 95% CI, 1.46–2.28) reduced their risk of CVD mortality by 19% versus those who were physically inactive (RR, 2.24; 95% CI, 1.78–2.83). In addition, among women with a resting SBP between 140 and 159 mm Hg compared to the referent group of women with a SBP between 120 and 129 mm Hg, those who were highly physically active (RR, 1.47; 95% CI, 1.04–2.09) reduced their risk of CVD mortality by 24% versus those who were physically inactive (RR, 1.93; 95% CI, 1.39–2.69). Among women with a resting SBP >160 mm Hg compared with the referent group of women with a SBP between 120 and 129 mm Hg, those who were highly physically active (RR, 1.77; 95% CI, 1.26–2.54) reduced their risk of CVD mortality by 27% versus those who were physically inactive (RR, 2.41; 95% CI, 1.76–3.30). Therefore, as SBP increases within hypertensive ranges, the risk of CVD mortality increases. However, the increased risk is attenuated with higher levels of physical activity. *Moderate evidence indicates an inverse, dose–response relationship between physical activity and CVD mortality among adults with hypertension. PAGAC Grade: Moderate.*

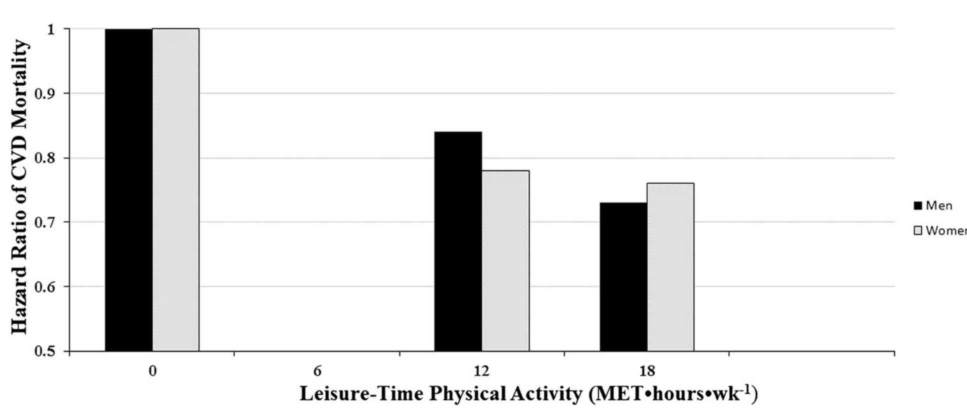

FIGURE 3—The inverse relationship between CVD mortality and leisure-time physical activity ($MET \cdot h \cdot wk^{-1}$) among adults with hypertension adapted from (31) in the systematic review of Rossi et al. (13).

Comorbid Conditions, Physical Function, and Health-related Quality of Life

Hypertension comorbidities include CVD, obesity, diabetes mellitus, chronic kidney disease, congestive heart failure, and the metabolic syndrome, among others. However, because of a lack of evidence, no conclusions could be drawn about whether a relationship exists between physical activity and risk of comorbid conditions, physical function, or health-related quality of life among adults with hypertension.

Evidence on Specific Factors

Age, sex, race/ethnicity, socioeconomic status, or weight status. Three meta-analyses found age not to be a significant moderator of the BP response to physical activity (17,18,23), but two of these contained samples with mixed BP levels, and the other did not stratify analyses by age. One meta-analysis reported that men exhibited BP reductions twice as large as did women following aerobic exercise training among samples with mixed BP levels (18), and another found no difference by sex (23). Race/ethnicity was poorly reported, and when reported in nine of the meta-analyses (20,22–24,26–30), the samples were largely white or Asian. One meta-analysis reported that nonwhite samples with hypertension experienced greater BP reductions than did white samples with hypertension (24).

Six meta-analyses reported the weight status of their samples which ranged from normal weight to obese (17,19,20,23,24,28). Cornelissen et al. (18) found the SBP reductions resulting from aerobic training tended to be larger with greater ($\beta1 = 0.49$, $P = 0.08$) compared to less ($\beta1 = 0.45$, $P = 0.06$) weight loss among 5,223 adults with mixed BP levels. Among a large sample of 330,222 adults with normal BP who were followed for 2 to 20 yr, Liu et al. (23) found that the inverse dose–response relationship between leisure-time physical activity and incident hypertension was slightly weaker with (RR, 0.94; 95% CI, 0.92–0.96) than without BMI adjustment as a covariate (RR, 0.91; 95% CI, 0.89–0.93), but these analyses were not stratified by BMI. No meta-analysis disclosed the socio-economic status of their sample. *The available evidence is insufficient to determine whether the relationship between physical activity and BP varies by age, sex, race/ethnicity, socioeconomic status, or weight status among adults with normal BP, prehypertension, and hypertension. PAGAC Grade: Grade not assignable. Also, the available evidence is insufficient to determine whether the relationship between physical activity and the CVD disease progression indicators of BP and CVD mortality vary by age, sex, race/ethnicity, socioeconomic status, or weight status among adults with hypertension. PAGAC Grade: Grade not assignable.*

Resting BP level. Of the six meta-analyses examining BP classification as a moderator of the BP response to physical activity (14,17–19,21,24), four (18,19,21,24) found that the greatest BP reductions occurred among samples with hypertension (5 to 8 mm Hg, 4 to 6% of resting BP level) followed by samples with prehypertension (2 to 4 mm Hg, 2 to 4% of resting BP level), and normal BP (1 to 2 mm Hg, 1 to 2% of resting BP level) (see Figure 4; see Table, Supplemental Digital Content 1, Summary of the Included Systematic Reviews, http://links.lww.com/MSS/B522). *Strong evidence demonstrates the magnitude of the BP response to physical activity varies by resting BP level, with the greatest benefits occurring among adults with hypertension followed by prehypertension and then normal BP. PAGAC Grade: Strong. However, limited evidence suggests the disease progression indicator of the BP response to physical activity varies by resting BP level among adults with hypertension. PAGAC Grade: Limited.*

Frequency, intensity, time, duration or how physical activity was measured. The frequency of the physical activity interventions was reported by 12 meta-analyses (15,17–21,23–26,29,30), and it ranged from 1 to 7 $d \cdot wk^{-1}$, with 3 $d \cdot wk^{-1}$ most common. The intensity of physical activity was reported in 13 meta-analyses (14–26), and ranged from low to vigorous intensity, with low to moderate most common. The time of the exercise session was reported in 11 of the meta-analyses (14,16,18–21,23,25,26,29,30), and ranged from 12 to 100 min, with 30 to 60 min per session most common. The duration of the physical activity intervention was reported in 14 meta-analyses with 1 to 4 to 5 months most common and duration of follow up ranging from 1 to 24 yr, (14,16–21,24–30). All 15 meta-analyses that examined the BP response to physical activity

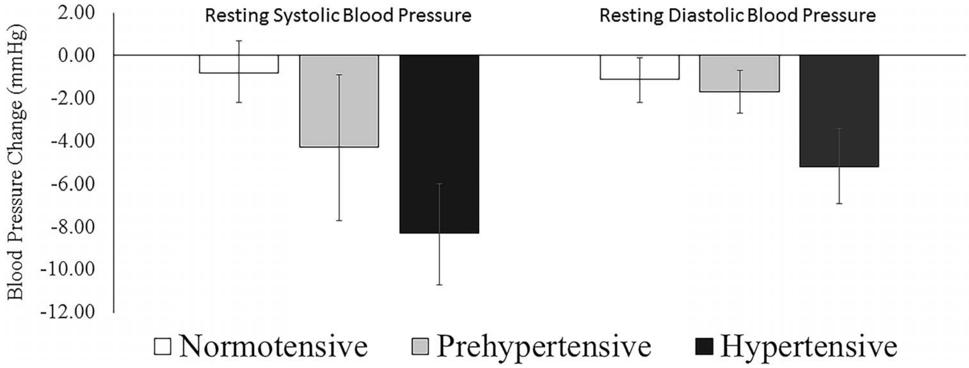

FIGURE 4—A meta-analysis of the BP response to 4 months of aerobic exercise training among adults with normal BP, prehypertension, and hypertension adapted from (18).

included interventions that were structured by the frequency, intensity, time, duration, and type of physical activity, but the details of these features were not well specified (14–21,24–30). None of these meta-analyses reported any physical activity measure outside of the structured physical activity intervention. Furthermore, the meta-analyses of general and leisure-time physical activity on either the influence of physical activity on incident hypertension (22,23) or the systematic review on CVD progression among those with hypertension (13) did not specify how physical activity was measured, although in most cases it appeared to be self-report. *Insufficient evidence is available to determine whether the relationship between BP and physical activity varies by the frequency, intensity, time, duration, or how physical activity is measured among adults with normal BP, prehypertension, and hypertension. PAGAC Grade: Not Assignable. In addition, insufficient evidence is available to determine whether the relationship between physical activity and the disease progression indicators of BP and CVD mortality varies by the frequency, intensity, time, duration, or how physical activity is measured among adults with hypertension. PAGAC Grade: Grade not assignable.*

The type of physical activity. There were five meta-analyses that examined the BP response to aerobic exercise training (16,18,21,25,28), three meta-analyses that examined the BP response to resistance exercise training [one acute (15) and two chronic (17,24)], one meta-analysis examined the BP response to combined aerobic and resistance exercise training (also referred to as concurrent exercise training) (19), and one meta-analysis examined the BP response to isometric resistance training (14) (see Table, Supplemental Digital Content 1, Summary of the Included Systematic Reviews, http://links.lww.com/MSS/B522). Cornelissen and Smart (18) examined aerobic exercise training performed, on average, at moderate to vigorous intensity for 40 min per session 3 $d \cdot wk^{-1}$ for 16 wk and reported SBP/DBP reductions of −8.3 (95% CI, −10.7 to −6.0)/−5.2 (95% CI, −6.9 to −3.4), −4.3 (95% CI, −7.7 to −0.9)/−1.7 (95% CI, −2.7 to −0.7), and −0.8 (95% CI, −2.2 to +0.7)/−1.1 (95% CI, −2.2 to −0.1) mm Hg among adults with hypertension, prehypertension, and normal BP, respectively (Fig. 4). MacDonald et al. (24) examined dynamic resistance training performed, on average, at moderate intensity for 32 min per session 3 $d \cdot wk^{-1}$ for 14 wk and reported SBP/DBP changes of −5.7 mm Hg (95% CI, −9.0 to −2.7 mm Hg)/−5.2 mm Hg (95% CI, −8.4 to −1.9 mm Hg), −3.0 mm Hg (95% CI, −5.1 to −1.0 mm Hg)/−3.3 mm Hg (95% CI, −5.3 to −1.4 mm Hg), and 0.0 mm Hg (95% CI, −2.5 to 2.5 mm Hg)/−0.9 mm Hg (95% CI, −2.1 to 2.2 mm Hg) among adults with hypertension, prehypertension, and normal BP, respectively. Corso et al. (19) examined combined aerobic and dynamic resistance exercise training performed, on average, at moderate intensity for 58 min per session 3 $d \cdot wk^{-1}$ for 20 wk and reported SBP/DBP changes of −5.3 mm Hg (95% CI, −6.4 to −4.2 mm Hg)/−5.6 mm Hg (95% CI, −6.9 to −3.8 mm Hg), −2.9 mm Hg (95% CI, −3.9 to −1.9 mm Hg)/−3.6 mm Hg (95% CI, −5.0 to −0.2 mm Hg), and +0.9 mm Hg (95% CI, 0.2 to 1.6 mm Hg)/−1.5 mm Hg (95% CI, −2.5 to −0.4 mm Hg) among adults with hypertension, prehypertension, and normal BP, respectively. *Moderate evidence indicates the relationship between resting BP level and the BP response to physical activity does not vary by traditional type (i.e., aerobic, dynamic resistance, combined) of physical activity among adults with normal BP, prehypertension, and hypertension. PAGAC Grade: Moderate.*

Carlson et al. (14) investigated the BP response among adults with hypertension (n = 61) and normal BP (n = 162) to four or more weeks of handgrip isometric resistance training at 30% to 50% maximal voluntary contraction, with four contractions held for 2 min with 1 to 3 min of rest between contractions. SBP, DBP, and mean arterial BP were reduced among the adults with hypertension, all of whom were on medication, by −4.3 mm Hg (95% CI, −6.6 to −2.2 mm Hg)/−5.5 mm Hg (95% CI, −7.9 to −3.3 mm Hg)/−6.1 mm Hg (95% CI, −8.0 to −4.0 mm Hg), and by −7.8 mm Hg (95% CI, −9.2 to −6.4 mm Hg)/−3.1 mm Hg (95% CI, −3.9 to −2.3 mm Hg)/−3.6 mm Hg (95% CI, −4.4 to −2.7 mm Hg) among adults with normal BP, respectively. These investigators were unable to explain reasons for the larger reductions in SBP among the adults with normal BP compared with adults with hypertension, and the reverse pattern of BP response for DBP and mean arterial BP. Therefore, no conclusions can be made about the antihypertensive benefits of isometric resistance training.

There were four meta-analyses that examined complementary and alternative types of physical activity (26,27,29,30) (see Table, Supplemental Digital Content 1, Summary of the Included Systematic Reviews, http://links.lww.com/MSS/B522). Xiong et al. (29) investigated the BP response to Baduanjin, an ancient Chinese mind-body exercise characterized by simple, slow, and relaxing movements, among 572 Asian adults with hypertension, and reported SBP/DBP reductions of −13.0 mm Hg (95% CI, −21.2 to −4.8 mm Hg)/−6.1 mm Hg (95% CI, −11.2 to −1.1 mm Hg) following 3 to 12 months of Baduanjin, respectively. Xiong et al. (30) investigated the BP response to Qigong, an ancient Chinese healing art that consists of breathing patterns, rhythmic movements, and meditation, among 2349 Asian adults with hypertension, and reported SBP/DBP reductions of −17.4 mm Hg (95% CI, −21.1 to −13.7 mm Hg)/−10.6 mm Hg (95% CI, −14.0 to −6.3 mm Hg), respectively, following 2 months to 1 yr of Qigong. Wang et al. (27) investigated the BP response to Tai Chi, an ancient Chinese exercise that combines deep diaphragmatic breathing with continuous body movements to achieve a harmonious balance between body and mind, among 1371 mostly Asian adults with hypertension. They reported SBP/DBP reductions of −12.4 mm Hg (95% CI, −12.6 to −12.2 mm Hg)/−6.0 mm Hg (95% CI, −6.2 to −5.9 mm Hg), respectively, following 2 to 60 months of all forms and types of Tai Chi. Park et al. (26) investigated the BP response to yoga, which incorporates meditation with physical movement, among 394 adults with hypertension. They reported SBP/DBP reductions of −11.4 mm Hg (95% CI, −14.6 to −8.2 mm Hg)/−2.4 mm Hg (95% CI, −4.3 to −0.4 mm Hg), respectively, among older adults 60 yr and older following 6 to 12 wk of yoga. These favorable findings of the antihypertensive effects of complementary and alternative physical activity types must be interpreted with caution due to the low study methodological quality of this literature, lack of disclosure of important study design considerations, considerable heterogeneity in this literature, inability to generalize findings to other racial/ethnic groups, and lack of long-term follow-up. *Moderate evidence indicates the relationship between physical activity and the disease progression indicator of BP does not vary by type of physical activity, with the evidence more robust for traditional types (modes, i.e., aerobic, dynamic resistance, combined) of physical activity than complementary and alternative types (modes, i.e., Baduanjin, Qigong, Tai Chi, Yoga) among adults with hypertension. PAGAC Grade: Moderate.*

DISCUSSION

A summary of the grading of the evidence-based conclusion statements on the relationship between physical activity and BP among adults with normal BP, prehypertension, or hypertension from this systematic umbrella review appears in Table 2. In total, four conclusion statements were strong, three moderate, one limited, and five were not assignable. The evidence was strong demonstrating that physical activity reduced BP among adults with normal BP, prehypertension, and hypertension. Indeed, of the four meta-analyses that included samples with normal BP, prehypertension, and hypertension (18,19,21,24), the investigative teams found that the greatest BP reductions occurred among samples with hypertension (5 mm Hg to 8 mm Hg, 4% to 6% of resting BP level) followed by samples with prehypertension (2 to 4 mm Hg, 2% to 4% of resting BP level), and normal BP (1 to 2 mm Hg, 1% to 2% of resting BP level). Consistent with the law of initial values (34), adults with hypertension experience BP reductions from exercise training that are approximately two times greater than the BP reductions among adults with prehypertension and approximately four to five times greater than the BP reductions among adults with normal BP. The BP reductions of this magnitude may be sufficient to reduce the resting BP of some of the samples with hypertension into prehypertensive and normotensive ranges; and the risk of coronary heart disease by 4% to 22% and stroke by 6% to 41% among adults with hypertension (2,35,36).

Surprisingly, the evidence regarding nearly all the effect modifiers we examined was insufficient so that a grade was not assignable. These effect modifiers included age, sex, race/ethnicity, socioeconomic status, or weight status; and the frequency, intensity, time, duration, or how physical activity was measured among adults with normal BP, prehypertension, and hypertension. In the few instances where these effect modifiers were examined as moderators of the BP response to physical activity, the findings were too disparate to synthesize because they were often not reported separately by BP classification but were reported for the overall sample that included adults with hypertension, prehypertension, and normal BP. We found strong evidence demonstrating the magnitude of the BP response to physical activity varies by resting BP level, with greater benefits occurring among those with higher resting BP. Therefore, inclusion of samples of mixed BP status (i.e., adults with normal BP, prehypertension, and hypertension)

TABLE 2. The grading of the evidence for the conclusion statements on the relationship between physical activity and BP and the effect modifiers organized by the questions being asked.

Conclusion Statement	PAGAC Grade
1. Strong evidence demonstrates that physical activity reduces BP among adults with prehypertension and normal BP.	Strong (14,15,17–19,21,22,24,25)
2. Strong evidence demonstrates an inverse dose–response relationship between physical activity and incident hypertension among adults with normal BP.	Strong (23)
3. The available evidence is insufficient to determine whether a dose–response relationship exists between physical activity and incident hypertension among adults with prehypertension, as the magnitude and precision of the effect cannot be ascertained from findings that are too scarce to synthesize.	Not assignable
4. Strong evidence demonstrates that physical activity reduces BP among adults with hypertension.	Strong (14–21,24–30)
5. Moderate evidence indicates an inverse, dose–response relationship between physical activity and CVD mortality among adults with hypertension.	Moderate (13,31,32)
6a. The available evidence is insufficient to determine whether the relationship between physical activity and BP varies by age, sex, race/ethnicity, socioeconomic status, or weight status among adults with normal BP, prehypertension, and hypertension.	Not assignable
6b. The available evidence is insufficient to determine whether the relationship between physical activity and the disease progression indicators of BP and CVD mortality varies by age, sex, race/ethnicity, socio-economic status, or weight status among adults with hypertension.	Not assignable
7a. Strong evidence demonstrates the magnitude of the BP response to physical activity varies by resting BP level, with the greatest benefits occurring among adults with hypertension followed by prehypertension and then normal BP.	Strong (18,19,21,24)
7b. Limited evidence suggests the disease progression indicator of the BP response to physical activity varies by resting BP level among adults with hypertension.	Limited
8a. Insufficient evidence is available to determine whether the relationship between BP and physical activity varies by the frequency, intensity, time, duration, or how physical activity is measured among adults with normal BP, prehypertension, and hypertension.	Not assignable
8b. Insufficient evidence is available to determine whether the relationship between physical activity and the disease progression indicators of BP and CVD mortality varies by the frequency, intensity, time, duration, or how physical activity is measured among adults with hypertension.	Not assignable
9a. Moderate evidence indicates the relationship between resting BP level and the BP response to physical activity does not vary by traditional type (i.e., aerobic, dynamic resistance, combined) of physical activity among adults with normal BP, prehypertension, and hypertension.	Moderate (18,19,24)
9b. Moderate evidence indicates the relationship between physical activity and the disease progression indicator of BP does not vary by type of physical activity, with the evidence more robust for traditional types (modes, i.e., aerobic, dynamic resistance, combined) of physical activity than complementary and alternative types (modes, i.e., Baduanjin, Qigong, Tai Chi, Yoga) among adults with hypertension.	Moderate (18,19,24,26,27,29,30)

underestimates the effectiveness of physical activity as antihypertensive lifestyle therapy.

The 2008 Scientific Report concluded that both aerobic and dynamic resistance exercise training of moderate-to-vigorous intensity produced small but clinically important reductions in SBP and DBP, with the evidence more convincing for aerobic than dynamic resistance training (8). Reflecting on the accumulating evidence over the past decade, we found moderate evidence indicating that the relationship between the BP response to physical activity is similar for aerobic, dynamic resistance, and combined aerobic and dynamic resistance exercise among adults with normal BP, prehypertension, and hypertension. Furthermore, there is promising, but limited, evidence that complementary and alternative types of physical activity are effective in lowering BP among adults with hypertension. Yet, very little research of high quality has been conducted in this area, and RCT are lacking that directly compare the BP-lowering effects of complementary and alternative to traditional types (aerobic, dynamic resistance, combined) of physical activity among adults with hypertension. Gaining this information will inform the public health recommendations on the types of physical activity that will optimize BP benefit and possibly provide adults with hypertension other effective exercise options to lower their high BP.

In conclusion, this systematic umbrella review provides strong, convincing evidence of the importance of physical activity in the prevention of the development of hypertension among adults with normal BP and prehypertension, and of its protective effects in the treatment of hypertension by attenuating the progression of CVD among adults with hypertension. These findings occurred in dose–response fashion with no cutoff to the amount of physical activity that confers benefit. Furthermore, we found moderate evidence that aerobic and dynamic resistance exercise training alone or combined were equally effective in lowering BP among adults with normal BP, prehypertension, and hypertension. Yet, important knowledge gaps remain regarding nearly all effect modifiers of the relationship between physical activity and BP that we examined, notably race/ethnicity. Due to the disproportionate burden of hypertension among African Americans (1,37,38), large RCT are needed that are sufficiently powered to perform stratified analyses between African Americans and other racial/ethnic groups to inform this important research gap. Future research is also needed that adheres to standard BP measurement protocols and classification schemes to better understand the influence of physical activity on the risk of comorbid conditions, health-related quality of life, and CVD progression and mortality; the interactive effects between physical activity and antihypertensive medication use; and the immediate BP-lowering benefits of physical activity.

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HHS staff provided general administrative support to the Committee and assured that the Committee adhered to the requirements for Federal Advisory Committees. HHS also contracted with ICF, a global consulting services company, to provide technical support for the literature searches conducted by the Committee. HHS and ICF staff collaborated with the Committee in the design and conduct of the searches by assisting with the development of the analytical frameworks, inclusion/exclusion criteria, and search terms for each primary question; using those parameters, ICF performed the literature searches.

This article is being published as an official pronouncement of the American College of Sports Medicine. This pronouncement was reviewed for the American College of Sports Medicine by members-at-large and the Pronouncements Committee. This article serves as an update to the topics covered in the 2004 ACSM position stand, "Exercise and Hypertension" [*Med. Sci. Sports Exerc*. 2004;36(3);533–53].

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