



High-Intensity Interval Training for Cardiometabolic Disease Prevention

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ABSTRACT

CAMPBELL, W. W., W. E. KRAUS, K. E. POWELL, W. L. HASKELL, K. F. JANZ, J. M. JAKICIC, R. P. TROIANO, K. SPROW, A. TORRES, K. L. PIERCY, and D. B. BARTLETT, FOR THE 2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE. High-Intensity Interval Training for Cardiometabolic Disease Prevention. *Med. Sci. Sports Exerc.*, Vol. 51, No. 6, pp. 1220–1226, 2019. **Purpose:** The 2018 Physical Activity Guidelines Advisory Committee systematically searched existing literature reviews to assess the relationship between high-intensity interval training (HIIT) and reduction in cardiometabolic disease risk. **Methods:** Duplicate independent screenings of 260 articles identified from PubMed®, Cochrane Library, and CINAHL databases yielded suitable data from one systematic review and two meta-analyses. Search terms included a combination of “high intensity” “physical activity/exercise” and “interval training” and outcome-specific terms. The quality of the included reviews was assessed using a tailored version of the AMSTARExBP report on quality. Exposure Subcommittee members graded scientific evidence strength based on a five-criteria rubric and assigned one of four grades: strong, moderate, limited, or not assignable. **Results:** Moderate evidence indicates that HIIT can improve insulin sensitivity, blood pressure, and body composition in adults with group mean ages ranging from ~20 to ~77 yr. These HIIT-induced improvements in cardiometabolic disease risk factors are comparable with those resulting from moderate-intensity continuous training, and they are more likely to occur in adults at higher risk of cardiovascular disease and diabetes than in healthy adults. Moderate evidence also indicates that adults with overweight or obesity classification are more responsive than adults with normal weight to HIIT-related improvements in insulin sensitivity, blood pressure, and body composition. Insufficient evidence was available to determine whether a dose–response relationship exists between the quantity of HIIT performed and several risk factors for cardiovascular disease and diabetes, or whether the effects of HIIT on cardiometabolic disease risk factors are influenced by age, sex, race/ethnicity, or socioeconomic status. **Conclusions:** HIIT by adults, especially those with overweight and obesity classification, can improve insulin sensitivity, blood pressure, and body composition, comparable with those resulting from moderate-intensity continuous training. **Key Words:** INSULIN SENSITIVITY, BLOOD PRESSURE, BODY COMPOSITION, OVERWEIGHT, OBESITY, PHYSICAL ACTIVITY

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Traditionally, physical activity guidelines have focused on moderate-intensity continuous training (MICT) and, more recently, have included resistance training. However, since the 2008 Physical Activity Guidelines Advisory Committee (PAGAC) Scientific Report (1), there has arisen a resurgence in interest and use of interval training. High-intensity interval training (HIIT) is one type of interval training that has progressively increased in popularity among physically active individuals and has garnered scientific research. The media also presents HIIT as an alternative means by which individuals can achieve health benefits similar to those of MICT. Some have suggested that it might be an

attractive long-term strategy by which to achieve the health benefits of regular physical activity because HIIT consumes less overall time per week. The 2018 PAGAC considered it prudent to examine scientific evidence regarding the use of HIIT for cardiometabolic health benefits relative to MICT (2).

To this end, the 2018 PAGAC addressed the following: 1) the nature of the relationship between HIIT and reduction in cardiometabolic disease risk, 2) whether a dose–response relationship exists, and 3) what is the shape of any dose–response relationship. Further, the committee was interested in any evidence pointing to whether such relationships might vary by age, sex, race/ethnicity, socioeconomic status, or weight status. Finally, the committee explored the relative rates of adverse events of HIIT programs compared with MICT programs.

Importantly, the term “HIIT” is not precisely defined, and multiple descriptions, exercise protocols, and exertion-related criteria are used among the original studies included in each of the systematic reviews and meta-analyses of literature vetted by the 2018 PAGAC. We retained the descriptions of HIIT stated in each of the manuscripts included in this umbrella systematic review, in part, to avoid misrepresenting or redefining the published research. For this review, we use the following description of HIIT: “episodic short bouts of high intensity exercise separated by short periods of recovery at a lower intensity.” On the basis of the literature vetted for this review, the “high intensity” in these bouts may be as low as about 65% of $\dot{V}O_2$ maximum or 60% of $\dot{V}O_2$ reserve (which may be inferior to moderate continuous exercise) and as high as maximal effort, such as during sprinting. The results and conclusions presented in this review encompass a relatively wide range of HIIT exercise intensities, which should be taken into consideration when evaluating these results and using them when developing exercise programs.

METHODS

An umbrella systematic review was conducted to identify existing reviews assessing the association of HIIT to reduction in cardiometabolic disease risk. This review was one of the systematic reviews conducted for the 2018 PAGAC, and the full methods are described elsewhere (3). Briefly, systematic searches were conducted in three electronic databases, including PubMed®, CINAHL, and Cochrane from database inception until May 7, 2017. Subsequently, the search was updated through March 30, 2018, for this manuscript. Search terms included a combination of “high intensity” “physical activity/exercise” and “interval training” and outcome-specific terms.

Final studies were selected using the following inclusion criteria: systematic reviews, meta-analyses, and pooled analyses published in English, including adult populations, assessing PA performed as HIIT, and examining cardiometabolic risk outcomes—all-cause and cardiovascular disease (CVD) mortality, CVD incidence, type 2 diabetes, and CVD risk factors, including blood pressure, blood lipids, and body composition. Reviews exclusively examining patients with existing CVD or athletes were excluded. All articles were independently screened

by two reviewers. Data abstraction was conducted by two independent abstractors who also assessed the quality of the included reviews using a tailored version of the AMSTARExBP (3,4). The protocol for this review was registered with the PROSPERO database, registration ID CRD42018093024.

The full literature search strategy is available at https://health.gov/paguidelines/second-edition/report/supplementary_material/pdf/Exposure_Q6_HIIT_Evidence_Portfolio.pdf. Information available here includes the following: 1) evidence summaries of the three articles reviewed (website Table 2); 2) AMSTARExBP-based article review quality assessment chart (website Table 3); 3) systematic review analytical framework (website appendix A); 4) *a priori* strategies for the PubMed®, CINAHL, and Cochrane searches (website appendix B); 5) literature tree detailing the identification, screening, eligibility, and inclusion of vetted articles (website appendix C); 6) search inclusion/exclusion criteria (website appendix D); and 7) the rationale for excluding articles at abstract or full-text triage (website appendix E).

RESULTS

Description of the Evidence

An initial search for systematic reviews, meta-analyses, pooled analyses, and reports identified sufficient literature to adequately address the research questions. The initial search conducted for the 2018 PAGAC resulted in 274 articles identified among the three electronic databases. After removing duplicates, 260 articles were title screened, of which 48 were abstract screened, 11 articles were full-text screened, and three articles used for data extraction. Two additional meta-analyses provide pertinent data from 77 new articles identified in the updated search. Figure 1 outlines the search results from both the original and updated search.

Overview

A total of three existing reviews were included: one systematic review (5) and two meta-analyses (6,7). The reviews were published from 2012 to 2017. The systematic review by Kessler et al. (5) included 24 studies and covered a time frame from database inception to 2011. The meta-analyses included larger numbers of studies. Batacan et al. (6) included 65 studies, and Jelleyman et al. (7) included 50 studies. They covered time frames from 1970 to 2015 and from 1946 to 2015, respectively.

Exposures

The three existing reviews examined physical activity performed as HIIT. There are no universally accepted lengths for the high-intensity period, the recovery period, or the ratio of the two; no universally accepted number of cycles for any HIIT session or the entire duration of the training bout; and no universally accepted relative intensity at which the high-intensity component should be performed. Batacan et al. (6) defined HIIT as “activities with intermittent bouts of activity that were performed at maximal effort, $\geq 85\%$ $\dot{V}O_2$ max,

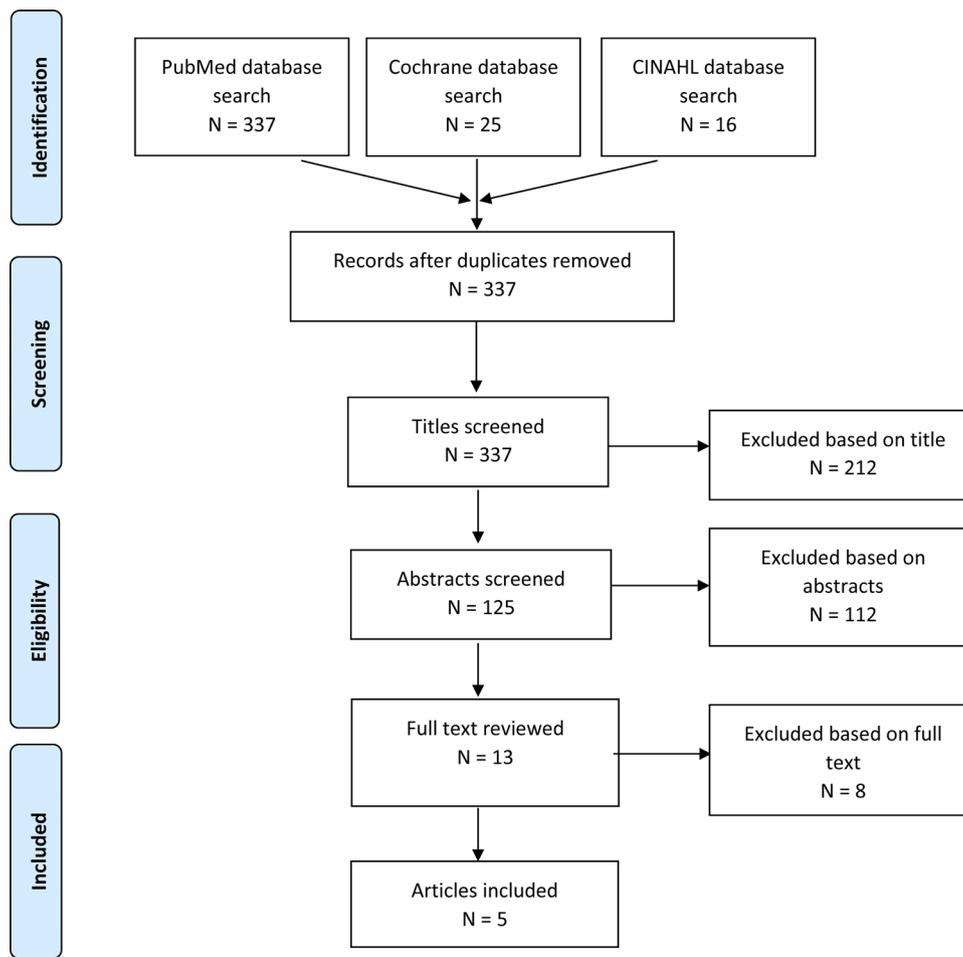


FIGURE 1—Literature Tree Study Selection HIIT Umbrella Review. Includes both original 2018 PAGAC search and updated search results.

≥85% heart rate (HR) reserve or the relative intensity of at least 90% HR max.” Jolleyman et al. (7) applied the following description of HIIT to their literature search: “at least two bouts of vigorous or higher intensity exercise interspersed with periods of lower intensity exercise or complete rest.” Kessler et al. (5) defined HIIT as “vigorous exercise performed at a high intensity for a brief period interposed with recovery intervals at low-to-moderate intensity or complete rest.”

Outcomes

The outcomes initially identified for systematic review included all-cause and CVD mortality, CVD and type 2 diabetes incidences, cardiorespiratory fitness, and cardiometabolic disease risk factors. After extensive discussion, the 2018 PAGAC Exposure Subcommittee members made a conscious decision to exclude cardiovascular fitness as a primary outcome of interest, choosing to focus effort and resources on reviews of literature that included multiple risk factors of CVD and diabetes. The decision to not focus on cardiorespiratory fitness as an outcome of interest was PAGAC-wide for the entire report; this decision was multifactorial and is addressed in the report. While the Exposure Subcommittee did not vet systematic reviews and meta-analyses of literature exclusively focused on fitness-related parameters,

pertinent cardiovascular fitness outcomes contained in the articles reviewed are described in the Review of the Evidence (see below). The 2018 PAGAC Exposure Subcommittee’s assessment and evaluation specifically focused on outcomes related to cardiometabolic disease risk factors (blood pressure, fasting blood lipids and lipoproteins, fasting blood glucose and insulin, and body mass index [BMI]) due to a lack of information regarding mortality and cardiometabolic morbidities.

Review of the Evidence

The 2018 Advisory Committee based its conclusions on evidence published before May 2017, specifically from the three existing systematic reviews and/or meta-analyses (5–7). Participants were men and women predominantly with group mean ages ranging from ~20 to ~77 yr. The exposure was predominantly supervised physical activity performed as HIIT using a variety of exercise modalities (mainly stationary cycling or treadmill running/walking, and much less often swimming, track running, or stair climbing).

Evidence on the Overall Relationship

Results from these systematic reviews and/or meta-analyses of clinical intervention studies consistently support

that HIIT can improve cardiorespiratory fitness (increase $\dot{V}O_{2\max}$) in adults with varied body weight and health status (5–7). HIIT-induced improvements in insulin sensitivity (5,7), blood pressure (5,6), and body composition (5–7) more consistently occur in adults with overweight or obesity classification, with or without high risk of CVD and diabetes—especially if these individuals train for 12 or more weeks. These HIIT-induced improvements in cardiometabolic disease risk are comparable with those achievable with MICT (7).

Healthy adults who have normal weight and lower risk of cardiometabolic disease do not typically show improvements in insulin sensitivity, blood pressure, and body composition with HIIT. Blood lipids and lipoproteins apparently are not influenced by HIIT (6). Batacan et al. (6) reported findings based on 65 individual studies involving 2164 participants (including 936 individuals who performed HIIT). Participants were predominantly 18- to 35-yr-old men and women (sex distribution not reported), and group mean ages ranged from ~20 to ~77 yr. This meta-analysis included randomized controlled trials (RCT) and non-RCT and comparative studies in groups of individuals without (46 of 65 studies) or with (19 of 65 studies) a diagnosed, current medical condition.

Batacan et al. (6) defined HIIT “as activities with intermittent bouts of activity that were performed at maximal effort, greater than or equal to 85% $\dot{V}O_{2\max}$, greater than or equal to 85% heart rate reserve or the relative intensity of at least 90% maximum heart rate.” The modes of exercise included treadmill running, cycling, and swimming. The 65 studies were categorized with respect to exercise training intervention duration and participant BMI classification. Among groups of participants with normal weight (BMI = 18.5–24.9 kg·m⁻²), short-term (<12 wk) and long-term (≥12 wk) HIIT interventions increased $\dot{V}O_{2\max}$ but did not significantly or consistently influence clinical indexes of cardiometabolic disease risk (systolic and diastolic blood pressures; total cholesterol, HDL cholesterol, LDL cholesterol, or triglycerides, fasting glucose, or insulin). Among groups of participants classified with overweight (BMI = 25–29.9 kg·m⁻²) or obesity (BMI ≥ 30 kg·m⁻²) status, short-term and long-term HIIT significantly and consistently increased $\dot{V}O_{2\max}$ and decreased diastolic blood pressure and waist circumference. Long-term HIIT also decreased resting heart rate, systolic blood pressure, and body fat percentage among groups with overweight or obesity. Batacan et al. (6) presented these results as effect sizes (ES) of the standardized mean differences, not as changes over time in typical units of measure.

Jelleyman et al. (7) conducted a meta-analysis of 50 studies involving 2033 participants (sex distribution not reported)—including 1383 individuals who performed HIIT—to assess the effect of HIIT interventions compared with continuous training or control conditions on indexes of blood glucose control and insulin resistance. Both studies with a control group ($n = 36$, 72%) and studies without a control group ($n = 14$, 28%) were included, but the results from studies without a control group were only used for within-group analyses. HIIT

was defined as “at least two bouts of vigorous or higher intensity exercise interspersed with periods of lower intensity exercise or complete rest” (7). Participant ages ranged from 18 to 68 yr, and the HIIT interventions ranged from 2 to 16 wk. Among 20 studies (40%) providing data, mean exercise session attendance was 90% ± 10%. Subgroup analyses were performed after stratifying participants by disease status based on a wide range of health characteristics: the categories were labeled healthy (well trained, recreationally active, or sedentary but otherwise healthy), weight status (overweight or obese), metabolic syndrome (metabolic syndrome or type 2 diabetes), or with another chronic disease.

Compared with baseline, $\dot{V}O_{2\max}$ increased after HIIT by 0.30 L·min⁻¹ (95% confidence interval [CI] = 0.25–0.35, $P < 0.001$). The increase in $\dot{V}O_{2\max}$ was greater for HIIT than for nonexercising control conditions (weighted mean difference [WMD] = 0.28 L·min⁻¹, 95% CI = 0.12–0.44, $P = 0.001$) and attenuated but still significant compared with continuous training (WMD = 0.16 L·min⁻¹, 95% CI = 0.07–0.25, $P = 0.001$). HIIT reduced body weight, compared with baseline, by 0.7 kg (95% CI = -1.19 to -0.25, $P = 0.002$). Compared with nonexercise control, the HIIT-induced weight loss was 1.3 kg (95% CI = -1.90 to -0.68, $P < 0.001$). HIIT-induced weight loss was not different than weight loss from continuous training. HIIT decreased fasting glucose, compared with baseline, by 0.13 mmol·L⁻¹ (95% CI = -0.19 to -0.07, $P < 0.001$). This response over time was not statistically different compared with nonexercise control or continuous training. In subgroup analysis, for the groups of individuals with metabolic syndrome or type 2 diabetes, fasting glucose was reduced by HIIT compared with nonexercise control by 0.92 mmol·L⁻¹ (95% CI = -1.22 to -0.63, $P < 0.001$). HIIT decreased fasting insulin from baseline by 0.93 μU·L⁻¹ (95% CI = -1.39 to -0.48, $P < 0.001$); however, this response was not statistically different from the nonexercise control. HIIT decreased insulin resistance compared with baseline (change in Homeostasis Model Assessment of Insulin Resistance score = -0.33; 95% CI = -0.47 to -0.18, $P < 0.001$). Reduction in insulin resistance (results from multiple insulin resistance models combined) was greater for HIIT versus nonexercise control (-0.49; 95% CI = -0.87 to -0.12) and HIIT versus continuous training (-0.35; 95% CI = -0.68 to -0.02). Among all 13 studies reporting data within metabolic syndrome or type 2 diabetes groups, HIIT did not change HbA1c. In subgroup analyses, HIIT reduced HbA1c by 0.25% (95% CI = -0.27 to -0.23, $P < 0.001$). Among all studies, the HbA1c response over time (no change) was not statistically different among HIIT, continuous training, and control groups. Subgroup analyses based on health (physical activity) status or other chronic diseases were either not significant or inconclusive; this was due, in part, to limited data being available.

Kessler et al. (5) conducted a quasisystematic, qualitative review of 24 RCT with 661 participants (sex distribution not reported) assessing the effects of HIIT interventions on changes in cardiometabolic disease risk factors. Of the

24 trials, 14 included MICT comparison group, which included a wide range of exercise programs, typically performed at 50% to 75% of $\dot{V}O_{2\max}$ for 45 to 60 min per session. The other 14 studies included a nonexercise control group. Participants had various weight statuses (normal weight, overweight, or obese) and health groups (17 studies), CVD (5 studies), metabolic syndrome (1 study), and type 2 diabetes (1 study). Intervention durations ranged from 2 wk to 6 months. HIIT was categorized into two subtypes: aerobic interval training (19 studies) and sprint interval training (SIT; 5 studies). For the subcommittee's assessment, because of the low number of SIT studies included in the Kessler et al. (5) review ($n = 3$ for glucose metabolism, $n = 1$ for lipids and lipoproteins, and $n = 1$ for blood pressures), results from only aerobic interval training studies were considered for strength of evidence grading purposes. Aerobic interval training increased $\dot{V}O_{2\max}$ (14 of 14 studies), increased insulin sensitivity (4 of 4 studies), and decreased blood pressure in participants not ingesting antihypertensive medication (5 of 5 studies with intervention periods ≥ 12 wk). Other indexes of cardiometabolic disease risk were not influenced by aerobic interval training, including fasting glucose, total cholesterol, HDL cholesterol, LDL cholesterol, and triglycerides. Results for body weight, BMI, body fat percent, and waist circumference were mixed; improvements more consistently were observed for aerobic interval training interventions of 12 wk or longer in participants with overweight or obesity classification. Collectively, these aerobic interval training responses were comparable with continuous moderate-intensity exercise, except $\dot{V}O_{2\max}$, which was greater for aerobic interval training versus continuous moderate-intensity exercise.

The updated search identified two additional pertinent HIIT-related reviews. Keating et al. (8) conducted a systematic review with a meta-analysis of 31 studies directly comparing MICT to HIIT ($n = 17$) or SIT ($n = 14$) on body adiposity. For their analyses, HIIT and SIT studies were combined. Of the 28 studies assessed by Keating et al. (8), 19 were not included in the three reviews vetted by the 2018 PAGAC members. A combined 837 individuals (402 women, 402 men, and 33 not reported) were assessed, with ages ranging from 10 to 65 yr, including two studies with a combined 59 adolescent boys and girls. Keating et al. (8) included results from these two studies with adolescents in their overall analyses. Most studies recruited participants classified as untrained ($n = 12$) or overweight/obese ($n = 13$), with three recruiting children/adolescents. HIIT was defined as studies using 85%–95% peak heart rate (PHR) or 80%–100% peak work rate for the high intensities, with a minimum duration of 4 wk. Of the 31 studies, 17 (55%) included a HIIT intervention, whereas 14 (45%) included a SIT intervention. Interventions ranged from 4 to 16 wk, with 12 wk the most common (42% of studies). Compared with baseline, both HIIT/SIT and MICT reduced body fat (%) and fat mass (kg). HIIT/SIT reduced body fat (%), on average, by -1.26% (95% CI = -1.80 to -0.72) and fat mass by -1.38 kg (95% CI = -1.99 to -0.77), whereas MICT reduced by -1.48% (95% CI = -1.89 to -1.06) and -0.91 kg (95% CI = -1.45 to -0.37). When all

studies were pooled, no differences between HIIT/SIT and MICT were observed for body fat percent (WMD = 0.15% , 95% CI = -0.57 to 0.88 , $P = 0.370$) or fat mass (WMD = -0.73 kg, 95% CI = -1.81 to 0.35 , $P = 0.619$) changes. Among a subset of studies with protocols having the workload or energy expenditure of each HIIT/SIT session less than the workload or energy expenditure of each MICT session, there was a trend for MICT to have greater reductions in total body fat percentage ($P = 0.09$). Among a subset of studies with the workload and/or energy expenditure per exercise session matched between exercise types, no differences in body fat percentage were observed between HIIT/SIT and MICT ($P = 0.40$). Further, no differences were observed for fat mass when workload or energy expenditure was lower for HIIT/SIT versus MICT ($P = 0.56$) or matched between exercise types ($P = 0.38$). Collectively, HIIT/SIT was comparable, but not superior, when directly compared with MICT for body fat reductions.

Maillard et al. (9) conducted a meta-analysis of 39 studies, which included 617 individuals (321 women and 296 men) who had completed a HIIT intervention assessing total ($n = 35$), abdominal ($n = 20$), and visceral fat mass ($n = 14$). Of the 39 studies assessed by Maillard et al. (9), 30 were not included in the three reviews vetted by the 2018 PAGAC members. Assessed individuals were adults with a mean age ranging from 20 ± 0.8 to 69 ± 2.8 yr. Except for four studies, which totaled 44 participants, all participants were classified as overweight or obese (mean BMI range, 25.4 ± 2.4 to 38.2 ± 7.9 kg·m⁻²). Participants were generally healthy, although some studies included patients with type 2 diabetes ($n = 6$), polycystic ovary syndrome ($n = 2$), menopausal ($n = 2$), nonalcoholic fatty liver disease ($n = 1$), metabolic syndrome ($n = 5$), and rheumatic disease ($n = 1$). HIIT was defined as studies using 85%–95% PHR or 80%–100% peak work rate for the high intensities, with a minimum duration of 4 wk. Studies using a SIT protocol were excluded. Interventions ranged from 4 wk to 6 months, with the majority being 12 wk and used either cycling ($n = 26$) or running ($n = 13$). Whole-body adiposity was assessed primarily by dual-energy x-ray absorptiometry, with bioelectrical impedance, plethysmography, and skinfolds also used. For the assessment of visceral and abdominal adiposity, computed tomography, magnetic resonance imaging, and dual-energy x-ray absorptiometry were used. HIIT reduced total fat (ES = -0.2 , 95% CI = -0.31 to -0.07 , $I^2 = 0.0\%$, $P = 0.003$), abdominal fat mass (ES = -0.19 , 95% CI = -0.32 to -0.05 , $I^2 = 0.0\%$, $P = 0.007$), and visceral fat mass (ES = -0.24 , 95% CI = -0.44 to -0.04 , $I^2 = 0.0\%$, $P = 0.018$). Stratified analyses suggested that running ($P = 0.003$) was better than cycling ($P = 0.137$) for reductions in total fat mass, cycling ($P = 0.004$) was better than running ($P = 0.773$) at reducing abdominal fat mass, and only running ($P = 0.042$) reduced visceral fat mass. The greatest effect on total fat mass was observed with higher-intensity ($>90\%$ PHR) protocols ($P = 0.017$), whereas lower-intensity ($<90\%$ PHR) protocols elicited the best effects on abdominal ($P = 0.029$) and visceral fat mass ($P = 0.021$). Although HIIT

was only successful at reducing total ($P = 0.001$), abdominal ($P = 0.008$), and visceral ($P = 0.016$) fat mass in adults classified as overweight or obese, there were only two studies assessing normal weight in each subgroup.

Dose-Response

Among the three review articles systematically reviewed for the 2018 PAGAC report (5–7), results were not presented from RCT designed to assess dose-response relationships of duration of HIIT to responses in cardiometabolic disease risk factors. Using meta-regression techniques, in the Batacan et al. (6) report, change in $\dot{V}O_{2\max}$ was predicted by longer HIIT intervention duration (β coefficient = 0.77, 95% CI = 0.35–1.18) and BMI (β coefficient = 0.84, 95% CI = 0.29–1.38), but not by total time performing HIIT (min) (β coefficient = 0.0002, 95% CI = –0.0017 to 0.0021) among groups of participants with overweight or obesity classification. Intervention duration, total time performing HIIT, and BMI did not predict the improvements observed in systolic blood pressure and diastolic blood pressure among groups with overweight or obesity. Other cardiometabolic risk factors were not assessed due to heterogeneity of responses. Regarding indexes of glucose control, Jelleyman et al. (7) (also using meta-regression techniques) reported that HIIT characteristics, interval intensity, and weekly high-intensity exercise did not predict the improvements over time in insulin resistance, fasting glucose, fasting insulin, or HbA1c.

Evidence on Specific Factors

Age, sex, race/ethnicity, and socioeconomic status. Information on the age, race/ethnicity, and socioeconomic status of participants was limited, inconsistently presented, and not statistically assessed. As a result, no conclusions about these relationships were possible. Only one of the new articles, Maillard et al. (9), assessed differences between sexes for HIIT and found no differences in changes for total, abdominal, or visceral fat mass.

Weight status. Weight status influenced the effect of HIIT on several risk factors of cardiometabolic disease, with groups of adults classified as overweight or obese, but not normal weight, reducing blood pressure and body fat (6) and improving insulin sensitivity (5,7).

Evidence on Participant Safety

Participant safety is central to using HIIT as a tool to reduce the risk of cardiometabolic disease among adults, especially those who have overweight or obesity, with cardiometabolic disease risk factors, diagnosed CVD or type 2 diabetes, or other chronic diseases. Although the committee did not address participant safety among adults performing HIIT, the issue is highly relevant with respect to using HIIT for health promotion. Jelleyman et al. (7) documented adverse events reported in the 50 studies included in their meta-analysis. Among the 19 total adverse events reported from the 17 studies (34% of the total studies), including this type of

information, 18 adverse events were attributable to musculoskeletal injuries incurred with exercise; 14 of 18 occurred with HIIT. None of the reported injuries was a serious adverse event or necessitated the participant to discontinue the intervention or drop out of the study. Perhaps consistent with the very low incidence of adverse events, mean participant dropout rate was $10\% \pm 10\%$ among the 36 (72%) studies documenting attrition. The health and disease characteristics of the participants experiencing an adverse event were not presented or discussed.

For additional details on this body of evidence, visit <https://health.gov/paguidelines/second-edition/report/supplementary-material.aspx> for the Evidence Portfolio.

CONCLUSIONS

HIIT can improve insulin sensitivity, blood pressure, and body composition in adults. These HIIT-induced improvements in cardiometabolic disease risk factors are comparable with those resulting from continuous, moderate-intensity aerobic exercise, and they are more likely to occur in adults at greater risk of CVD and diabetes, compared with healthy adults. The committee considered the strength of evidence to be moderate for this issue. Insufficient evidence was available to determine whether a dose-response relationship exists between HIIT quantity and several risk factors for CVD and diabetes. Insufficient evidence was available to determine whether the effects of HIIT on cardiometabolic risk factors are influenced by age, sex, race/ethnicity, or socioeconomic status. There was moderate evidence indicating that adult weight status influences the effectiveness of HIIT to reduce cardiometabolic disease risk. Adults with overweight or obesity classification are more responsive than adults with normal weight to HIIT's effects on improving insulin sensitivity, blood pressure, and body composition. The committee considered the strength of evidence to be moderate for this conclusion.

Summary, public health impact, and needs for future research. HIIT can improve insulin sensitivity, blood pressure, and body composition in adults. Such improvements in cardiometabolic disease risk factors are comparable with those resulting from continuous, moderate-intensity aerobic exercise and are more likely to occur in adults with overweight and obesity classification.

Research is required in several areas to improve the scientific foundations for long-term effectiveness and safety of HIIT. Specifically, the committee recommends the following:

RCT of at least 6 months should be undertaken to assess the adherence to and the effects of HIIT when compared with other types of physical activity programs on physiological, morphological, and cardiometabolic health outcomes. Such studies should address issues of dose-response and be of at least 6 months in duration. These RCT should include diverse groups of adults, including those with overweight or obesity classification and at high risk of CVD or type 2 diabetes. They should systematically assess adverse events, including musculoskeletal injuries, attributable to HIIT, compared with other

types of exercise training, among adults with a wide variety of health and disease characteristics.

Rationale: Most HIIT intervention periods are less than 12 wk, which are likely insufficient time to assess the magnitude and sustainability of clinically important changes in some physiological, morphological, and cardiometabolic health outcomes. The willingness and the ability of individuals to adhere to HIIT currently are not well known. Further research, complementary to the scoping review of the psychological responses to interval exercise that supports “the viability of interval exercise as an alternative to continuous exercise” (10), is warranted. Prescriptively designing these studies to include participants who have overweight or obesity classification and are at high risk of CVD or type 2 diabetes will inform health promotion practitioners and policy leaders on the utility of recommending HIIT for health among a large proportion of the U.S. adult population. At present, the evaluation of the safety of HIIT among adults with varied health and disease characteristics is compromised by the limited availability of relevant data; this is due, in part, to the low proportion of studies reporting adverse events.

Continued research is warranted to assess, compare, and systematically review the effects of specific types of HIIT-related programs on cardiometabolic disease risk factors.

Rationale: There is no universally accepted definition for HIIT. The relatively broad range of HIIT-related exercise protocols and intensities used among studies currently limit physical performance, fitness, and allied health professionals’ abilities to optimally plan HIIT programs for health. Yet HIIT protocols generally fall into three categories based on exercise intensities: SIT (intensities greater than $\dot{V}O_2$ maximum), near-

maximum interval training (90%–100% of maximum heart rate, oxygen uptake, or other pertinent parameter), and vigorous aerobic intensity (60%–89% $\dot{V}O_2$ reserve or 64%–90% $\dot{V}O_2$ maximum).

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REFERENCES

1. Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Report, 2008*. Washington (DC): U.S. Department of Health and Human Services. p. 2008.
2. 2018 Physical Activity Guidelines Advisory Committee. *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington (DC): U.S. Department of Health and Human Services; 2018.
3. Torres A, Tennant B, Ribeiro-Lucas I, Vaux-Bjerke A, Piercy K, Bloodgood B. Umbrella and systematic review methodology to support the 2018 Physical Activity Guidelines Advisory Committee. *J Phys Act Health*. 2018;15(11):805–10.
4. Johnson BT, MacDonald HV, Bruneau ML Jr, et al. Methodological quality of meta-analyses on the blood pressure response to exercise: a review. *J Hypertens*. 2014;32(4):706–23.
5. Kessler HS, Sisson SB, Short KR. The potential for high-intensity interval training to reduce cardiometabolic disease risk. *Sports Med*. 2012;42(6):489–509.
6. Batacan RB Jr, Duncan MJ, Dalbo VJ, Tucker PS, Fenning AS. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *Br J Sports Med* 2017;51:494–503.
7. Jelleyman C, Yates T, O’Donovan G, et al. The effects of high-intensity interval training on glucose regulation and insulin resistance: a meta-analysis. *Obes Rev*. 2015;16(11):942–61.
8. Keating SE, Johnson NA, Mielke GI, Coombes JS. A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. *Obes Rev*. 2017;18(8):943–64.
9. Maillard F, Pereira B, Boisseau N. Effect of high-intensity interval training on total, abdominal and visceral fat mass: a meta-analysis. *Sports Med*. 2018;48(2):269–88.
10. Stork MJ, Banfield LE, Gibala MJ, Martin Ginis KA. A scoping review of the psychological responses to interval exercise: is interval exercise a viable alternative to traditional exercise? *Health Psychol Rev*. 2017;11(4):324–44.