Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness?

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2 authors, including:

Jenna Gillen
University of Michigan

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CLINICAL CORNER

Is high-intensity interval training a time-efficient exercise strategy to improve health and fitness?

Jenna B. Gillen and Martin J. Gibala

Abstract: Growing research suggests that high-intensity interval training (HIIT) is a time-efficient exercise strategy to improve cardiorespiratory and metabolic health. "All out" HIIT models such as Wingate-type exercise are particularly effective, but this type of training may not be safe, tolerable or practical for many individuals. Recent studies, however, have revealed the potential for other models of HIIT, which may be more feasible but are still time-efficient, to stimulate adaptations similar to more demanding low-volume HIIT models and high-volume endurance-type training. As little as 3 HIIT sessions per week, involving ≤10 min of intense exercise within a time commitment of ≤30 min per session, including warm-up, recovery between intervals and cool down, has been shown to improve aerobic capacity, skeletal muscle oxidative capacity, exercise tolerance and markers of disease risk after only a few weeks in both healthy individuals and people with cardiometabolic disorders. Additional research is warranted, as studies conducted have been relatively short-term, with a limited number of measurements performed on small groups of subjects. However, given that "lack of time" remains one of the most commonly cited barriers to regular exercise participation, low-volume HIIT is a time-efficient exercise strategy that warrants consideration by health practitioners and fitness professionals.

Key words: interval training, exercise intensity, training adaptations.

Résumé : De plus en plus d'études suggèrent que la méthode d'entraînement par intervalle de haute intensité (« HIIT ») est économique en matière de temps investi pour l'amélioration de la santé cardiorespiratoire et métabolique. Les approches « à fond de train » comme les exercices de type Wingate sont particulièrement efficaces, mais ce mode d'entraînement n'est peut-être pas sécuritaire, facile à tolérer et pratique pour bien des individus. Des études récentes révèlent le potentiel d'autres modèles HIIT — apparemment plus pratiques et aussi efficaces — pour susciter des adaptations similaires aux plus exigeants modèles HIIT à faible volume et d'entraînement en endurance à haut volume. À raison d'aussi peu que trois séances HIIT par semaine comprenant ≤ 10 min d'exercice intense dans une séance de ≤ 30 min incluant l'échauffement, la récupération entre les intervalles et le retour au calme, on améliore la capacité aérobie, la capacité oxydative du muscle squelettique, la tolérance à l'effort et les marqueurs du risque de maladie, et ce, après seulement quelques semaines tant chez des individus en bonne santé que chez des personnes aux prises avec des troubles cardiométaboliques. Il faut réaliser d'autres études, car celles qui ont été effectuées présentaient des résultats à court terme avec un nombre limité de mesures enregistrées auprès de petits groupes de sujets. Cependant, « le manque de temps » étant l'argument généralement évoqué comme obstacle à la pratique régulière de l'activité physique, un programme HIIT à faible volume constitue une approche efficace que devraient prendre en compte les praticiens de la santé et les professionnels de la condition physique. [Traduit par la Rédaction]

Mots-clés : entraînement par intervalle, intensité de l'exercice, adaptations à l'entraînement.

Current physical activity guidelines including those from the Canadian Society for Exercise Physiology (CSEP) recommend that adults should accumulate at least 150 min of moderate- to vigorous-intensity aerobic physical activity per week to achieve health benefits (Tremblay et al. 2011). The CSEP guidelines do not specifically define intensity ranges; however, guidelines from other agencies, including the American College of Sports Medicine, classify moderate intensity as 64%–76% of maximal heart rate (HR_{max}) (46%–63% of maximal oxygen uptake ($\dot{V}O_{2max}$)) and vigorous intensity as 77%–95% of HR_{max} (64%–90% $\dot{V}O_{2max}$) (Garber et al. 2011). While public health guidelines are based on very strong scientific evidence, accelerometer data indicate that as many as 85% of Canadians do not meet the minimum physical activity recommendations (Colley et al. 2011) with "lack of time" being one of the most commonly cited barriers to regular participation (Trost et al. 2002). Recent evidence from relatively small, short-term studies suggests that high-intensity interval training (HIIT) may be as effective as traditional moderate-intensity continuous training to induce physiological remodelling, which in turn may be associated with improved health markers, despite a reduced time commitment.

What is HIIT?

HIIT is characterized by brief, repeated bursts of relatively intense exercise separated by periods of rest or low-intensity exercise. "Low-volume" HIIT refers to exercise training sessions that are relatively brief — consisting of ≤10 min of intense exercise within a training session lasting ≤30 min including warm-up, recovery periods between intervals and cool down — such that the total weekly exercise and training time commitment is reduced compared with current public health guidelines. One of the most common models employed in low-volume HIIT studies is the Wingate Test, which consists of 30 s of "all-out" cycling against a

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J.B. Gillen and M.J. Gibala.* Department of Kinesiology, McMaster University, 1280 Main St. West, Hamilton, ON L8S 4K1, Canada.
Corresponding author: Martin J. Gibala (e-mail: gibalam@mcmaster.ca).

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high resistance on a specialized cycle ergometer. A typical training session consists of 4–6 repetitions interspersed by ~4 min of recovery. As little as 6 sessions of this type of training over 2 weeks robustly increases skeletal muscle oxidative capacity, as reflected by the maximal activity and (or) protein content of various mitochondrial enzymes (Burgomaster et al. 2005, 2006; Gibala et al. 2006), in healthy individuals who were previously sedentary or active on a recreational basis. A 6-week program increased $\dot{V}O_{2max}$ and induced cardiovascular and skeletal muscle remodelling similar to a traditional endurance training program that was modeled on current public health guidelines, despite a ~90% difference in training volume (Burgomaster et al. 2007, 2008), and markedly lowered total time commitment (Table 1). Other studies have shown that short-term Wingate-based HIIT protocols improve insulin sensitivity, measured using oral glucose tolerance tests in young healthy men (Babraj et al. 2009; Metcalfe et al. 2011) and overweight/obese individuals (Whyte et al. 2010), as well as using the gold standard hyperinsulinemic euglycemic clamp method in recreationally active men and women (Richards et al. 2010). Trapp and colleagues (2008) also reported significant fat loss in young women following 15 weeks of low-volume HIIT, which consisted of 8-s all-out sprints followed by 12 s of recovery for 20 min. The same HIIT protocol performed for 12 weeks reduced whole-body fat mass and increased lean mass in the legs and trunk in overweight young men (Heydari et al. 2012*b*).

Modified low-volume HIIT protocols

All-out HIIT protocols are effective; however, considering the need for specialized equipment and the extremely high level of subject motivation, this form of training may not be safe, tolerable or practical for many individuals. Recent studies have also revealed the potential for other models of HIIT, which may be more feasible but are nonetheless time-efficient compared with traditional public health guidelines, to stimulate adaptations similar to more demanding low-volume HIIT models as well as relatively high-volume endurance-type training (Table 1). For example, a model that we have employed consists of 10 × 1-min cycling efforts at an intensity eliciting ~85%–90% of HR_{max} interspersed with 1 min of recovery. The protocol is still relatively time-efficient in that a single training session consists of only 10 min of vigorous exercise within a 25-min training session including warm-up, recovery periods between intervals and cool down. This model has been applied in studies of young healthy individuals (Little et al. 2010), as well as overweight/obese individuals (Gillen et al. 2013), older sedentary adults who may be at higher risk for cardiometabolic disorders (Hood et al. 2011), and patients with coronary artery disease (CAD) (Currie et al. 2013) and type 2 diabetes (T2D) (Little et al. 2011).

Short-term studies employing continuous glucose monitoring have shown that the modified 10 × 1-min model reduced 24-h blood glucose concentration in people with T2D when measured immediately after a single bout (Gillen et al. 2012) as well as 72 h following a 2-week training intervention (Little et al. 2011). Mean ratings of perceived exertion measured in the latter study were ~7 on a 10-point scale, suggesting the stimulus was manageable for subjects. Another recent study found that 10 × 1-min HIIT performed 2 times per week for 12 weeks improved arterial endothelial function (assessed by flow mediated dilation) and $\dot{V}O_{2max}$ in patients with CAD to the same extent as performing ~40 min of continuous cycling at 60% peak power output per session (Currie et al. 2013). In addition, Boutcher (2011) recently reviewed potential mechanisms that may mediate changes in body composition following HIIT, one of which has been speculated to include repeated, transient elevations in postexercise oxygen consumption over the course of training (Hazell et al. 2012). While the findings from these small pilot projects are intriguing, large scale investigations with appropriate participant screening and monitoring are clearly warranted, including randomized clinical trials to directly compare low-volume HIIT versus traditional endurance training in a comprehensive manner, especially in those with, or at risk for, cardiometabolic disorders.

How low can you go?

A modified Wingate-based HIIT protocol that consisted of 4 × 10 s all out sprints induced improvements in aerobic and anaerobic performance that were comparable to a 4 × 30-s protocol (Hazell et al. 2010). Another study by Metcalfe et al. (2011) showed that a protocol consisting of 2 × 20-s all-out sprints, included within a 10-min bout of primarily low-intensity cycling, improved $\dot{V}O_{2max}$ after 6 weeks of training (18 total sessions). Interestingly, while $\dot{V}O_{2max}$ improved in both men and women, insulin sensitivity measured using oral glucose tolerance tests was only improved in men (Metcalfe et al. 2011). These findings suggest that provided exercise is performed using an all-out effort, it may be possible to confer benefits using protocols that are even more time-efficient than employed in previous Wingate-based HIIT studies. There is insufficient evidence at present to make sweeping recommendations, however, and as alluded to earlier, the effort required with this type of training and need for specialized equipment may make it impractical for many individuals. When it comes to low-volume HIIT protocols, there may be a trade-off between relative work intensity and the time required to stimulate adaptations, and this remains a fruitful area of future investigation.

Conclusion and recommendations

While far from definitive, growing evidence suggests that training using brief repeated bursts of relatively intense exercise can be an effective strategy to improve fitness and health. Most of the low-volume HIIT studies have employed a cycling model but other models of traditional whole-body exercise are also likely to be effective, e.g., climbing stairs, brisk uphill walking or running. One recent study found that subjects who trained using 1 set of 8 × 20 s of a single exercise (burpees, jumping jacks, mountain climbers, or squat thrusts) interspersed by 10 s of rest per session, 4 times per week for 4 weeks increased $\dot{V}O_{2max}$ to the same extent as a group who performed 30 min of traditional endurance training per session (McRae et al. 2012). It is possible that the very intense nature of HIIT stimulates rapid changes, whereas adaptations induced by traditional endurance training may occur more slowly. As with the initiation of any new exercise program, it is important to undergo proper screening procedures, which includes completion of an evidence-based screening form such as the Physical Activity Readiness Questionnaire Plus as well as medical clearance especially for those who may be at risk for or afflicted by chronic diseases such as diabetes or cardiovascular disease (Warburton et al. 2011). It may also be prudent to include a preconditioning phase of training consisting of more traditional moderate-intensity aerobic exercise prior to initiating HIIT (e.g., 20–30 min per session, a few times per week for several weeks), as it has been shown that a baseline level of fitness is a cardioprotectant and reduces the risks associated with exercise-induced ischemic events (Thompson et al. 2007). One recent study reported that HIIT was perceived to be more enjoyable compared with moderate-intensity continuous exercise training, at least in young active men (Bartlett et al. 2011), but relatively little is known regarding the feasibility of implementing HIIT into individual exercise prescriptions outside of a laboratory setting. It is also important to note that it may be favourable to include variety in one's exercise program in terms of type, intensity and duration rather than training with only 1 form of exercise. Additional work is clearly warranted to comprehensively evaluate the long-term health benefits associated with low-volume HIIT in comparison

Table 1. Summary of adaptations following 2, 6 and 12–15 weeks of low-volume high-intensity interval training (HIIT).

Protocol	Time/session	2 wk	6 wk	12–15 wk
Wingate HIIT (four to six 30-s sprints; 4-min recovery)	~20 min	↑ $\dot{V}O_{2max}$ (Whyte et al. 2010; Hazell et al. 2010; Astorino et al. 2012) ↑ 250, 750 kJ and 5 km TT performance (Burgomaster et al. 2005; Gibala et al. 2006; Hazell et al. 2010) ↑ Wingate PPO and MPO (Burgomaster et al. 2005; Whyte et al. 2010; Hazell et al. 2010) ↑ Resting muscle glycogen content (Burgomaster et al. 2005) ↑ Maximal activity of CS and COX (Burgomaster et al. 2005, 2006; Gibala et al. 2006) ↑ COXII and COXIV protein content (Gibala et al. 2006) ↑ IS (Cederholm Index and GIR) (Babraj et al. 2009; Richards et al. 2010) ↓ OGTT glucose and insulin AUC (Babraj et al. 2009; Richards et al. 2010) ↑ Resting fat oxidation 24 h post-training (Whyte et al. 2010) ↓ SBP 24-h post-training (Whyte et al. 2010)	↑ $\dot{V}O_{2max}$ (Burgomaster et al. 2007, 2008; Astorino et al. 2012) ↑ 250 kJ TT performance (Burgomaster et al. 2007) ↑ Wingate PPO and MPO (Burgomaster et al. 2008) ↑ Resting muscle glycogen content and ↓ glycogen utilization during exercise (Burgomaster et al. 2008) ↑ Maximal activity of CS and β-HAD (Burgomaster et al. 2008) ↑ GLUT4, PDH and COXIV protein content (Burgomaster et al. 2007, 2008) ↑ Whole-body fat oxidation and ↓ CHO oxidation during exercise (Burgomaster et al. 2008) ↑ Peripheral arterial compliance (Rakobowchuck et al. 2008) ↑ Endothelial function (Rakobowchuck et al. 2008)	
Modified HIIT (10 × 1 min sprints at ~90% HR_{max}; 1 min recovery)	20 min	↑ 50 and 750 kJ TT performance (Little et al. 2010) ↑ W_{max} in T2D patients (Little et al. 2011) ↑ Maximal activity of CS and COX (Little et al. 2010, 2011; Hood et al. 2011) ↑ COXIV and GLUT4 protein content (Little et al. 2010, 2011; Hood et al. 2011) ↓ Fasting [insulin] (Hood et al. 2011) ↑ IS (HOMA) (Hood et al. 2011) ↑ Glycemic control in T2D patients (Little et al. 2011)	↑ $\dot{V}O_{2max}$ (Gillen et al. 2013) ↑ W_{max} (Gillen et al. 2013) ↑ Maximal activity of CS and β-HAD (Gillen et al. 2013) ↑ GLUT4 protein content (Gillen et al. 2013) ↓ Whole-body and abdominal fat mass (Gillen et al. 2013) ↑ Leg and gynoid fat-free mass (Gillen et al. 2013)	↑ $\dot{V}O_{2max}$ in CAD patients (Currie et al. 2013) ↑ Endothelial function in CAD patients (Currie et al. 2013)
10 × 6 s all-out sprints; 60 s recovery (2 wk) 10 min at 60 W with two 20 s all out sprints (6 wk)	10 min	↑ 10 km TT performance (Jakeman et al. 2012)	↑ $\dot{V}O_{2max}$ (Metcalfe et al. 2011) ↑ IS (Cederholm Index) in males only (Metcalfe et al. 2011)	
8 s sprint at 120 rpm; 12 s recovery at 40 rpm. Workload ~90% HR_{max}	20 min			↑ $\dot{V}O_{2max}$ (Trapp et al. 2008; Heydari et al. 2012*b*) ↓ Whole-body abdominal and trunk fat mass (Trapp et al. 2008; Heydari et al. 2012*b*) ↑ Whole-body leg and trunk fat free mass (Trapp et al. 2008) ↑ Resting fat oxidation (Trapp et al. 2008) ↓ Fasting [insulin] and insulin resistance (HOMA-IR) (Trapp et al. 2008) ↓ Arterial stiffness, systolic and diastolic BP (Heydari et al. 2012*a*)

Note: Training adaptations were measured ≥72 h following the last training session unless otherwise specified. Most studies were conducted in recreationally active or sedentary healthy men and women, except for those in overweight men and women (Whyte et al. 2010; Trapp et al. 2008; Heydari et al. 2012*a*, 2012*b*; Gillen et al. 2012), patients with type 2 diabetes (T2D) (Little et al. 2011), patients with coronary artery disease (CAD) (Currie et al. 2013) or triathletes (Jakeman et al. 2012). $\dot{V}O_{2max}$, maximal oxygen uptake; TT, time trial; PPO, peak power output; MPO, mean power output; CS, citrate synthase; COX, cytochrome c oxidase; β-HAD, beta hydroxydehydrogenase; GLUT4, glucose transporter 4; PDH, pyruvate dehydrogenase; IS, insulin sensitivity; GIR, glucose infusion rate; CHO, carbohydrate; OGTT, oral glucose tolerance test; AUC, area under the curve; SBP, systolic blood pressure; HR_{max}, maximal heart rate; W_{max}, maximal workload in watts; HOMA, Homeostasis Model of Assessment; BP, blood pressure.

with traditional exercise training guidelines, and clarify the relative importance of exercise intensity versus duration for improving cardiorespiratory and metabolic fitness.

References

Astorino, T.A., Allen, R.P., Roberson, D.W., and Jurancich, M. 2012. The effect of high-intensity interval training on cardiovascular function, VO_{2max}, and muscular force. J. Strength Cond. Res. **26**: 138–145. PMID:22201691.

Babraj, J.A., Vollard, N.B., Keast, C., Guppy, F.M., Cottrell, G., and Timmons, J.A. 2009. Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC Endocr. Disord. **9**: 3. doi:10.1186/1472-6823-9-3. PMID:19175906.

Bartlett, J.D., Close, G.L., MacLaren, D.P., Gregson, W., Drust, B., and Morton, J.P. 2011. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: implications for exercise adherence. J. Sport Sci. **29**(6): 547–553. doi:10.1080/02640414.2010.545427. PMID:21360405.

Boutcher, S.H. 2011. High-intensity intermittent exercise and fat loss. J. Obes. **2011**: 1–10. doi:10.1155/2011/868305. PMID:21113312.

Burgomaster, K.A., Hughes, S.C., Heigenhauser, G.J.F., Bradwell, S.N., and Gibala, M.J. 2005. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. J. Appl. Physiol. **98**(6): 1985–1990. doi:10.1152/japplphysiol.01095.2004. PMID:15705728.

Burgomaster, K.A., Heigenhauser, G.J.F., and Gibala, M.J. 2006. Effect of short-term sprint interval training on human skeletal muscle carbohydrate metabolism during exercise and time-trial performance. J. Appl. Physiol. **100**(6): 2041–2047. doi:10.1152/japplphysiol.01220.2005. PMID:16469933.

Burgomaster, K.A., Cermak, N.M., Phillips, S.M., Benton, C.R., Bonen, A., and Gibala, M.J. 2007. Divergent response of metabolite transport proteins in human skeletal muscle after sprint interval training and detraining. Am. J. Physiol. Regul. Integr. Comp. Physiol. **292**(5): 1970–1976. doi:10.1152/ajpregu.00503.2006. PMID:17303684.

Burgomaster, K.A., Howarth, K.R., Phillips, S.M., Rakobowchuck, M., MacDonald, M.J., McGee, S.L., et al. 2008. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. J. Physiol. **586**(1): 151–160. doi:10.1113/jphysiol.2007.142109. PMID:17991697.

Colley, R.C., Garriguet, D., Janssen, I., Craig, C.L., Clarke, J., and Tremblay, M.S. 2011. Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. Health Rep. **22**(1): 7–14. PMID:21510585.

Currie, K.D., Dubberley, J.B., McKelvie, R.S., and MacDonald, M.J. 2013. Low-Volume, High-Intensity Interval Training in Patients with CAD. Med. Sci. Sports Exerc. **45**(8): 1436–1442. doi:10.1249/MSS.0b013e31828bbbd4. PMID:23470301.

Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I., et al. 2011. American College of Sports Medicine position stand: Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med. Sci. Sports Exerc. **43**(7): 1334–1359. doi:10.1249/MSS.0b013e318213fefb. PMID:21694556.

Gibala, M.J., Little, J.P., van Essen, M., Wilkin, G.P., Burgomaster, K.A., Safdar, A., et al. 2006. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. J. Physiol. **575**: 901–911. doi:10.1113/jphysiol.2006.112094. PMID:16825308.

Gillen, J.B., Little, J.P., Punthakee, Z., Tarnopolsky, M.A., and Gibala, M.J. 2012. Acute high-intensity interval exercise reduces the postprandial glucose response and prevalence of hyperglycaemia in patients with type 2 diabetes. Diabetes Obes. Metab. **14**: 575–577. doi:10.1111/j.1463-1326.2012.01564.x. PMID:22268455.

Gillen, J.B., Percival, M.E., Ludzki, A., Tarnopolsky, M.A., and Gibala, M.J. 2013. Interval training in the fed or fasted state improves body composition and muscle oxidative capacity in overweight women. Obesity. In press. doi:10.1002/oby.20379. PMID:23723099.

Hazell, T.J., MacPherson, R.E.K., Gravelle, B.M.R., and Lemon, P.W.R. 2010. 10 or 30-s sprint interval training bouts enhance both aerobic and anaerobic performance. Eur. J. Appl. Physiol. **110**(1): 153–160. doi:10.1007/s00421-010-1474-y. PMID:20424855.

Hazell, T.J., Olver, T.D., Hamilton, C.D., and Lemon, P.W.R. 2012. Two minutes of sprint-interval exercise elicits 24-hr oxygen consumption similar to that of 30 min of continuous endurance exercise. Int. J. Sport Nutr. Exerc. Metab. **22**(4): 276–283. PMID:22710610.

Heydari, M., Boutcher, Y.N., and Boutcher, S.H. 2012*a*. High intensity intermittent exercise and cardiovascular and autonomic function. Clin. Auton. Res. **23**(1): 57–65. doi:10.1007/s10286-012-0179-1. PMID:23104677.

Heydari, M., Freund, J., and Boutcher, S.H. 2012*b*. The effect of high-intensity intermittent exercise on body composition of overweight young males. J. Obes. **2012**: 1–8. doi:10.1155/2012/480467. PMID:22720138.

Hood, M.S., Little, J.P., Tarnopolsky, M.A., Myslik, F., and Gibala, M.J. 2011. Low-Volume Interval Training Improves Muscle Oxidative Capacity in Sedentary Adults. Med. Sci. Sports Exerc. **43**(10): 1849–1856. doi:10.1249/MSS.0b013e3182199834. PMID:21448086.

Jakeman, J., Adamson, S., and Babraj, J. 2012. Extremely short duration high-intensity training substantially improves endurance performance in triathletes. Appl. Physiol. Nutr. Metab. **37**: 976–981. PMID:22857018.

Little, J.P., Safdar, A., Wilkin, G.P., Tarnopolsky, M.A., and Gibala, M.J. 2010. A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanisms. J. Physiol. **588**(6): 1011–1022. doi:10.1113/jphysiol.2009.181743. PMID:20100740.

Little, J.P., Gillen, J.B., Percival, M.E., Safdar, A., Tarnopolsky, M.A., Punthakee, Z., et al. 2011. Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. J. Appl. Physiol. **111**: 1554–1560. doi:10.1152/japplphysiol.00921.2011. PMID:21868679.

McRae, G., Payne, A., Zelt, J.G.E., Scribbans, T.D., Jung, M.E., Little, J.P., et al. 2012. Extremely low volume, whole-body aerobic – resistance training improves aerobic fitness and muscular endurance in females. Appl. Physiol. Nutr. Metab. **37**(6): 1124–1131. doi:10.1139/h2012-093. PMID:22994393.

Metcalfe, R.S., Babraj, J.A., Fawkner, S.G., and Vollaard, N.B.J. 2011. Towards the minimal amount of exercise for improving metabolic health: beneficial effects of reduced-exertion high-intensity interval training. Eur. J. Appl. Physiol. **112**(7): 2767–2775. doi:10.1007/s00421-011-2254-z. PMID:22124524.

Rakobowchuck, M., Tanguay, S., Burgomaster, K.A., Howarth, K.R., Gibala, M.J., and MacDonald, M.J. 2008. Sprint interval and traditional endurance training induce similar improvements in peripheral arterial stiffness and flow-mediated dilation in healthy humans. Am. J. Physiol. Regul. Integr. Comp. Physiol. **295**: R236–R242. PMID:18434437.

Richards, J.C., Johnson, T.K., Kuzma, J.N., Lonac, M.C., Schweder, M.M., Voyles, W.F., et al. 2010. Short-term sprint interval training increases insulin sensitivity in healthy adults but does not affect the thermogenic response to beta-adrenergic stimulation. J. Physiol. **588**: 2961–2972. doi:10.1113/jphysiol.2010.189886. PMID:20547683.

Thompson, P.D., Franklin, B.A., Balady, G.J., Blair, S.N., Corrado, D., Estes, N.A.M., III, et al. 2007. Exercise and acute cardiovascular events placing the risks into perspective: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism and the Council on Clinical Cardiology. Circulation, **115**(17): 2358–2368. doi:10.1161/CIRCULATIONAHA.107.181485. PMID:17468391.

Trapp, E.G., Chisholm, D.J., Freund, J., and Boutcher, S.H. 2008. The effects of high-intensity intermittent exercise training on fat loss and fasting insulin levels of young women. Int. J. Obes. **32**(4): 684–691. doi:10.1038/sj.ijo.0803781. PMID:18197184.

Tremblay, M.S., Warburton, D.E.R., Janssen, I., Paterson, D.H., Latimer, A.E., Rhodes, R.E., et al. 2011. New Canadian Physical Activity Guidelines. Appl. Physiol. Nutr. Metab. **36**(1): 36–46. doi:10.1139/H11-009. PMID:21326376.

Trost, S.G., Owen, N., Baurman, A.E., Sallis, J.F., and Brown, W. 2002. Correlates of adults' participation in physical activity: review and update. Med. Sci. Sports Exerc. **34**(12): 1996–2001. doi:10.1097/00005768-200212000-00020. PMID:12471307.

Warburton, D.E.R., Gledhill, N., Jamnik, V.K., Bredin, S.S.D., McKenzie, D.C., Stone, J., et al. 2011. Evidence-based risk assessment and recommendations for physical activity clearance: Consensus Document 2011. Appl. Physiol. Nutr. Metab. **36**(S1): S266–S298. doi:10.1139/h11-062. PMID:21800945.

Whyte, L.J., Gill, J.M.R., and Cathcart, A.J. 2010. Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. Metabolism, **59**(10): 1421–1428. doi:10.1016/j.metabol.2010.01.002. PMID:20153487.