High-intensity interval training (HIT): A time-efficient exercise prescription for pre-diabetes?

Matthew Haines, Warren Gillibrand, Gerard Garbutt

Pre-diabetes invariably precedes type 2 diabetes, for which the personal and economic burdens are well known. Exercise is usually recommended as part of lifestyle interventions that aim to prevent progression from pre-diabetes to diabetes. However, adherence to such interventions is often poor, with lack of time usually cited as the main barrier to exercise. High-intensity interval training, or HIT, has been put forward as a more time-efficient approach to exercise compared to traditional exercise guidelines. This article considers the nature of HIT in comparison to traditional exercise guidelines and the basis of how insulin sensitivity and glucose transport might be improved. Finally, implications for practice with individuals with pre-diabetes are considered.

Pre-diabetes (impaired glucose tolerance and impaired fasting glucose, as defined in *Table 1*) represents a transitory state between normoglycaemia and type 2 diabetes. Without intervention it is estimated that the majority of those people with pre-diabetes will progress to type 2 diabetes within 5–10 years (Nathan et al, 2002). Therefore, interventions for people who are diagnostically considered to have pre-diabetes should be a priority.

Lifestyle intervention, including exercise, is considered a cornerstone of diabetes prevention and management. Nevertheless, despite strong evidence that exercise can delay or prevent type 2 diabetes (Knowler et al, 2002) the challenge of encouraging individuals and populations to lead a more active lifestyle remains. Here we contrast traditional exercise guidelines with the development of high-intensity interval training (HIT), which has been put forward as a more time-efficient approach to exercise.

Early Japanese research dates back more than 15 years (Tabata et al, 1996), but more recently HIT has been pioneered by Gibala and colleagues in Canada from 2004 to the present day (e.g. Burgomaster et al, 2004; Gibala et al, 2012). Research interest is developing significantly, although participants involved in HIT research are typically young, healthy individuals familiar with exercise rather than individuals with long-term health conditions. The aim of this article is to consider the evidence for using HIT, in addition to looking at issues of implementation in practice.

Traditional exercise guidelines for health

Early studies focused on patterns of exercise and time spent sitting in the occupational setting, although since then exercise guidelines have evolved (Haskell et al, 2007; Brown et al, 2009). A focus on vigorous aerobic exercise during the mid-1970s was replaced by 30 minutes of moderate-intensity activity on most days of the week by the 1990s. The American College of Sports Medicine later clarified this as 30 minutes "on at least five days per week" establishing the 150 minutes per week that persists to the current day (Haskell et al, 2007). Recent perspective has shifted focus onto drivers of inactivity in what has been termed an obesogenic environment; that is, profiles of activity and inactivity in transport, occupation, domestic and leisure pursuits of everyday life (Brown et al, 2009).

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Article points

1. Exercise is usually recommended as part of lifestyle interventions to prevent progression from pre-diabetes to diabetes, but lack of time is a frequently cited reason for poor adherence.
2. High-intensity interval training (HIT) has been proposed as a time-efficient alternative.
3. HIT may be considered as part of lifestyle interventions for treating diabesity in suitable individuals.
4. Appropriate health screening must be carried out by healthcare professionals before prescribing HIT.

Key words

- Exercise
- Pre-diabetes
- Prevention

Authors

Authors' details can be found at the end of the article.

Page points

1. A commonly cited barrier for engaging in exercise is lack of time.
2. There is a growing interest in shorter-duration but higher-intensity exercise, such as HIT.
3. HIT is typically performed on a cycle ergometer for a period of approximately 15–30 minutes inclusive of a warm-up and cool-down period.

Table 1. Diagnostic criteria for pre-diabetes.

	World Health Organization (2006)	American Diabetes Association (2010)
IGT	*2-h glucose: ≥7.8 and <11.1 mmol/L *and* Fasting glucose: <7.0 mmol/L	*2-h glucose: ≥7.8 and <11.1 mmol/L
IFG	Fasting glucose: 6.1–6.9 mmol/L *and* *2-h glucose: <7.8 mmol/L (if measured)	Fasting glucose: 5.6–6.9 mmol/L

IFT=impaired fasting glucose; IGT=impaired glucose tolerance.
*Venous plasma glucose 2 hours after ingesting 75 g glucose load. It should be noted that IGT and IFG can occur as mutually exclusive conditions or they can occur in combination.

Current guidelines for exercise in the UK (e.g O'Donovan et al, 2010; Department of Health, 2011) focus on high-volume, time-consuming exercise. In particular, adults at high risk of type 2 diabetes are recommended to engage in 300 minutes or more of moderate-intensity aerobic activity each week, or 150 minutes or more of vigorous-intensity aerobic activity each week. This can be problematic, since the most commonly cited barrier for engaging in exercise is lack of time (Korkiakangas et al, 2009). As a result there is a growing interest in shorter-duration but higher-intensity exercise, such as HIT, which might be time-efficient and appealing to individuals who otherwise would not adhere to the volumes of exercise outlined in traditional guidelines. This is important because the efficacy of any exercise intervention should be considered not only in terms of the physiological effectiveness of the activity but also the likelihood that individuals will engage with it. The acceptability and accessibility of the activity to those for whom the intervention is intended, and the practicalities of building the activity into everyday life, also need to be considered.

Although the independent relationship between physical inactivity and a range of diseases, including diabetes, has been established (Booth et al, 2002), the optimal dose of exercise remains unclear. Church and Blair (2009) highlight that the commonly prescribed dose of 150 minutes per week of moderate-intensity physical activity is the result of a self-fulfilling prophecy whereby, based primarily on epidemiological data, 150 minutes per week was identified as a good recommendation. Subsequent research has used this threshold to define intervention goals resulting in research examining 150 minutes per week rather than research examining different doses, intensities, types or frequencies of exercise.

What is high-intensity interval training (HIT)?

HIT is typically performed on a cycle ergometer (specialised stationary bicycle; *Figure 1*) for a period of approximately 15–30 minutes inclusive of a warm-up and cool-down period. Most of this time is spent at low intensity, with the caveat that a series (4–12) of maximal or "all out" cycling sprints are included throughout this time period, with each sprint lasting 30–60 seconds. This approach to exercise is performed three times per week resulting in a total weekly time commitment of 45–90 minutes.

Most studies on HIT have used 30-second cycling sprints against a braking force equal to 7.5% of body weight, commonly known as the Wingate Test (Bar-Or, 1987). This is a very intense protocol resulting in considerable fatigue. Nevertheless, this short but intense protocol has demonstrated a remarkable ability to induce beneficial changes in a range of physiological parameters important for metabolic health. For example, Gibala et al (2006) used this protocol to compare active men assigned to HIT or traditional cardiovascular training (90–120 minutes of moderate-intensity continuous cycling) over 2 weeks. The training volume for the HIT group was approximately 90% lower than the traditional exercise group (approximately 150 kcal versus 1550 kcal energy expenditure per week). Despite this, muscle biopsy samples obtained before and after training revealed similar increases in muscle oxidative capacity and glycogen content.

Similar studies have demonstrated improvements in insulin sensitivity. Babraj et al (2009) showed that after just 2 weeks of HIT (equal to approximately 250 kcal of work each week) the area under the plasma glucose, insulin and non-esterified fatty acid concentration–time curves were all reduced (12%, 37% and 26%, respectively) demonstrating an improvement in risk factors for metabolic disease. In addition, peripheral insulin sensitivity and muscular glucose uptake was improved by 23%. Similarly, Little et al (2010) used a HIT protocol, equal to approximately 150 kcal per week, to demonstrate increases in resting muscle glycogen and total glucose transporter (GLUT)-4 protein content after 2 weeks. Considering the potency of HIT to induce physiologically meaningful changes for a range of factors important to health and diabetes risk, it is clear to see why exercise physiologists are interested in this alternative form of exercise. Nevertheless, it is apparent that such time-efficient approaches to exercise might suffer from similarly poor adherence because the high-intensity nature of the activity is likely to present another barrier for most people. Additionally, it is unknown if the general population could safely or practically adopt this type of exercise.

Figure 1. A demonstration of HIT using a cycle ergometer. (Image author's own.)

Gibala (2007) has suggested that the focus needs to shift to identify modified (less intense) approaches to HIT to establish the optimal combination of intensity and volume of exercise necessary to induce adaptations in a practical, time-efficient manner across various populations, including those with pre-diabetes. Recent research has postulated that the traditional approach to HIT (as outlined above) might be unnecessarily strenuous. Metcalfe et al (2012) used a reduced-exertion HIT exercise intervention three times per week over 6 weeks. The reduced-exertion HIT consisted 10 minutes of low-intensity cycling interspersed with 1–2 "all out sprints" of 10–20 seconds against a braking force of 7.5% body weight. The 10 minutes of cycling included a 3-minute warm-up and 3-minute cool-down period, meaning the total exercise time per week was just 30 minutes. Despite this, aerobic capacity improved by 12–15% and insulin sensitivity, assessed in response to ingesting a 75 g glucose load, increased by 28%. These early findings are encouraging because they show that a more practical approach to HIT might be beneficial for metabolic health.

Why might HIT work for pre-diabetes? The physiological rationale

The exact mechanistic basis underlying how exercise increases insulin sensitivity and stimulates muscle glucose transport is

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Page points

1. Intracellular changes are mediated in response to the metabolic status of the muscle caused specifically by muscle contraction.
2. As the insulin-independent increase in glucose transport diminishes, depletion of muscle glycogen in response to exercise increases muscle insulin sensitivity.
3. More intense exercise might be of greater benefit to people with pre-diabetes because higher-intensity exercise will place greater reliance on intramuscular glycogen as fuel, thus mediating enhanced insulin-stimulated glucose transport.

not completely understood. Holloszy (2005) suggested that these are extremely complex processes and it will be some time before mechanisms responsible for mediating this phenomenon are understood. However, how exercise can improve glucose homeostasis has been described (for reviews see Wojtaszewski et al, 2003; Hawley and Lessard, 2008). It is useful for the reader to consider exercise-induced improved regulation of muscle glucose transport operating via two separate pathways.

Firstly, molecular signalling mechanisms increase glucose uptake. These intracellular changes are mediated in response to the metabolic status of the muscle caused specifically by muscle contraction. For example, release of calcium from the sarcoplasmic reticulum changes ion balance activating the Ca^{2+}/calmodulin-dependent protein kinase pathway, which stimulates glucose transport (Wright et al, 2005). Similarly, another feedback pathway involves changes to substrate levels. During muscle contractions, decreases in cellular chemical energy (ATP and creatine phosphate) increase adenosine monophosphate (AMP) levels, evoking the AMP-activated protein kinase (AMPK) mechanism which also improves insulin sensitivity (Jessen and Goodyear, 2005). Furthermore, feed-forward control mechanisms such as the stimulation frequency of motor nerves might further regulate glucose transport (Richter et al, 2003). It is important to note that these mechanisms are "insulin independent" and therefore bypass the typical insulin signalling defects associated with insulin resistance conditions (Hawley and Lessard, 2008). It is possible that these mechanisms are responsible for the acute increase in glucose transport 2–4 hours after exercise (Holloszy, 2005) and that high-intensity exercise could activate them to a greater extent than moderate-intensity exercise.

Secondly, as the insulin-independent increase in glucose transport diminishes, depletion of muscle glycogen in response to exercise increases muscle insulin sensitivity. This is caused by up-regulation of the enzyme glycogen synthase and GLUT-4 protein. GLUT-4 allows facilitated diffusion of glucose into the muscle cells where it can be polymerised and stored as glycogen. Since exercise depletes this stored glycogen, muscle cells must recover during the post-exercise period and often overcompensate in a process known as muscle glycogen super-compensation (Wojtaszewski et al, 2003). This is achieved by an increase in glucose transport mediated by translocation of more GLUT-4 to the muscle sarcolemma (cell surface) from intracellular storage sites followed by an increase in the intrinsic activity of the transporters (Furtado et al, 2003). In this way, exercise is able to enhance insulin-stimulated glucose transport post-exercise because of an enhanced recruitment and activity of GLUT-4 in response to glycogen depletion. This may last for 16–48 hours (Perseghin et al, 1996).

Wright and Swan (2001) suggested that more intense exercise such as HIT might be of greater benefit to people with pre-diabetes because the higher-intensity exercise will place greater reliance on intramuscular glycogen as fuel, thus mediating enhanced insulin-stimulated glucose transport. It has been demonstrated experimentally using exercise protocols similar to those of HIT that significant glycogenolysis–the use of glycogen as fuel–does indeed occur in cycle sprints of less than 30 seconds (Parolin et al, 1999). It should be acknowledged that much of the physiological research surrounding the improvements in insulin sensitivity and muscle glucose transport have been carried out using animal studies. Also, little evidence specifically supports HIT because research has generally considered more traditional higher volume approaches to exercise.

Implications for practice

It is unlikely that HIT would result in sufficient calorific expenditure to create the negative energy balance required for significant weight loss. However, Yates (2012) stated that the historic preoccupation of judging lifestyle interventions solely by their effects on body weight might be damaging and that emphasising healthy lifestyles for their own sake will allow exercise to be used to its full potential. In fact, the question of whether exercise without weight loss can improve insulin sensitivity has been considered and, although the evidence is equivocal, there is little doubt that the acute effects of each exercise session are beneficial (Ross, 2003; Yates et al, 2007). When exercise is performed regularly these benefits are "topped up", irrespective of weight loss. Nevertheless, there is little doubt that excessive body fat is harmful to health and it is very likely that the beneficial impact of exercise on insulin resistance would be magnified if associated with diminished body fat. Therefore the suggestion is not that HIT should replace other exercise advice but that it should complement it, and in particular be considered as a time-efficient approach to health improvement. This approach would allow for use of HIT to elicit clinically meaningful benefits in people with pre-diabetes.

A common criticism of exercise as a treatment is poor adherence. As previously stated "lack of time" is cited as the most prevalent barrier to exercise. The potential for HIT to reduce the time burden and appeal to individuals who otherwise would not engage with exercise should not be overlooked. In addition, high-intensity interval exercise has been perceived to be more enjoyable than moderate-intensity continuous exercise (Bartlett et al, 2011) and reduced-exertion HIT has been shown to result in only modest ratings of perceived exertion (Metcalfe et al, 2012). Taken together, this information is encouraging in that HIT might be relevant for improving exercise adherence. Furthermore, it is possible that HIT could be administered by the patient at home, by fitness industry personnel and by a range of healthcare professionals, such as specialist diabesity nurses, who are likely to be in contact with people with pre-diabetes. The protocol is straightforward to communicate, requires minimal equipment and could clearly be incorporated into a multidisciplinary diabesity clinic. Nurses could have an important role to play in treating diabesity through exercise interventions but would need appropriate training and organisational support to do so.

Potential limitations to the approach

Although the relative risk of an acute cardiac event increases during exercise, the absolute risk is low and has been reported in prospective research as one death per 1.51 million episodes of exercise in healthy people (Albert et al, 2000), although data were collected using subjective interpretation of vigorous exercise defined as "How often do you exercise vigorously enough to work up a sweat?" Whilst higher-intensity exercise increases risk, people who experience an exercise-related cardiac event generally have underlying structural cardiac disease (Thompson et al. 2007). Therefore, appropriate screening for high-risk individuals should be carried out before commencing HIT because risk could be substantial in this population.

This has resource implications. An appropriate Physical Activity Readiness Questionnaire (PAR-Q) must be administered by healthcare professionals and fitness industry personnel including those involved in exercise referral schemes who prescribe exercise. Medical conditions that complicate the exercise prescription include knowledge of risk factors or conditions associated with cardiovascular and chronic obstructive pulmonary disease, diabetes, arthritis and osteoporosis. Individual risk stratification should be completed using an established pre-participation algorithm to classify individuals as low, moderate or high risk (e.g. ACSM, 2006). At this stage individuals considered to be at moderate risk might need to undergo health-related physical testing or clinical exercise testing with the breadth and depth of testing dependent on risk. High-risk individuals should be excluded from HIT because the benefit-to-risk ratio for this

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1. Nurses could have an important role to play in treating diabesity through exercise interventions but would need appropriate training and organisational support to do so.
2. Appropriate screening for high-risk individuals should be carried out before commencing HIT because risk could be substantial in this population.
3. Individual risk stratification should be completed using an established pre-participation algorithm to classify individuals as low, moderate or high risk.

"Caution should be exercised in people with diabetes using insulin because of the risk of hypoglycaemia caused by exercise-induced increase in the rate of glucose clearance into skeletal muscles."

population might be more favourable with moderate-intensity exercise.

Furthermore, caution should be exercised in people with diabetes using insulin because of the risk of hypoglycaemia caused by exercise-induced increase in the rate of glucose clearance into skeletal muscles. However, no adverse events were reported in recent research using HIT with individuals with type 2 diabetes (Little et al, 2011). People with pre-diabetes may not have many of the disease complications associated with type 2 diabetes because of the relatively early state of disease progression (Wright and Swan, 2001). Consequently the prescription of HIT to this population group should be acceptable as long as other co-morbidities have been appropriately screened for.

Cost

Regarding cost considerations, the cycle ergometer pictured in *Figure 1* costs in the region of £1200. However, cheaper ergometers and potentially cheaper standard exercise bikes could feasibly be used as an alternative to perform HIT exercise.

Conclusion

HIT represents an intriguing alternative to traditional exercise guidelines and might improve exercise adherence whilst benefitting a range of parameters that are clinically meaningful for health. HIT could be considered part of lifestyle interventions for treating diabesity and might be ideally suited to people with pre-diabetes as long as their overall risk profile is minimal. However to ensure an optimal benefit-to-risk ratio, healthcare professionals must use appropriate health screening measures before prescribing HIT and this has inevitable resource implications. Currently, there is insufficient evidence to suggest that HIT be adopted by everyone with diabesity and the approach is likely to be hazardous for high-risk and sedentary individuals. However, further research on HIT as a means of preventing future burden of type 2 diabetes is warranted. ■

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Authors

Matthew Haines is Senior Lecturer Health and Wellbeing, School of Human and Health Sciences, University of Huddersfield; Warren Gillibrand is Senior Lecturer Podiatry and Clinical Sciences, School of Human and Health Sciences, University of Huddersfield; Gerard Garbutt, Visiting Professor of Clinical Exercise Science, University of Huddersfield.

Online CPD activity

Visit www.diabetesonthenet.com/cpd to record your answers and gain a certificate of participation

Participants should read the preceding article before answering the multiple choice questions below. There is ONE correct answer to each question. After submitting your answers online, you will be immediately notified of your score. A pass mark of 70% is required to obtain a certificate of successful participation; however, it is possible to take the test a maximum of three times. A short explanation of the correct answer is provided. Before accessing your certificate, you will be given the opportunity to evaluate the activity and reflect on the module, stating how you will use what you have learnt in practice. The CPD centre keeps a record of your CPD activities and provides the option to add items to an action plan, which will help you to collate evidence for your annual appraisal.

1. Which ONE of the following is the MAIN barrier for patients wanting to exercise as part of lifestyle intervention to prevent progression of pre-diabetes?

A. Cardiac co-morbidity
B. Embarrassment
C. Fatigue
D. Knee-joint pain in obese people
E. Lack of time

2. Which ONE of the following molecular mechanisms BEST explains how high-intensity interval training (HIT) could increase insulin sensitivity?

A. Decreased muscle adenosine monophosphate levels
B. Decreased glucogenolysis
C. Decreased glucose uptake
D. Increased glucose transporter (GLUT)-4 activity
E. Increased muscle glycogen storage

3. Pre-diabetes without intervention is estimated to progress to type 2 diabetes in the majority of individuals within HOW MANY years?
Select ONE option only.

A. 0–1
B. 2–4
C. 5–10
D. 11–15
E. 16–25

4. According to current evidence, what is the OPTIMAL amount of physical activity per week (in minutes) that should be recommended as part of a healthy lifestyle?
Select ONE option only.

A. 100
B. 150
C. 200
D. 300
E. None of the above

5. HIT typically consists of which type of exercise?
Select ONE option only.

A. Aerobics classes
B. Cycling (stationary)
C. Jogging
D. Sprinting
E. Swimming

6. For WHAT LENGTH of TIME have studies that demonstrated improved insulin sensitivity been carried out for?
Select ONE option only.

A. 1 day
B. 2 weeks
C. 3 months
D. 6 months
E. 1 year

7. Which of the following is the MOST appropriate statement about HIT?
Select ONE option only.

A. A less intense approach to HIT shows significant benefit compared to standard HIT
B. HIT has been shown to improve concordance with exercise advice
C. HIT is recommended for people with pre-diabetes
D. HIT is safer for people with type 2 diabetes than for people with type 1 diabetes
E. Screening for high-risk individuals should be carried out before commencing HIT

8. HIT has been shown to REDUCE which ONE, if any, of the following?

A. BMI
B. Cholesterol
C. HbA_{1c}
D. Weight
E. None of the above

9. HIT has been shown to IMPROVE outcomes in which ONE, if any, of the following?

A. Gestational diabetes
B. Pre-diabetes
C. Type 1 diabetes
D. Type 2 diabetes
E. None of the above

10. If 3 million healthy people undertake an episode of exercise, how many acute cardiac events resulting in death are likely to occur?
Select ONE option only.

A. <1
B. 2
C. 3
D. 5
E. 10