ORIGINAL ARTICLE

CODEN: AAJMBG

Improved insulin sensitivity following a short-term whole body vibration intervention

John Babraj[1] and Adam Hawkey[2, 3*]

[1]Division of Sport and Exercise Sciences, Abertay University, Dundee, United Kingdom, [2]Centre for Health, Exercise and Sport Science, Southampton Solent University, Southampton, SO14 0YN, United Kingdom and [3]School of Medicine, University of Dundee, Dundee, DD1 9SY, United Kingdom

Abstract: *Background and Objective:* Despite being recommended for reducing the risk of type 2 diabetes (T2D) the majority of the population do not partake in the advised amount of regular exercise. While high intensity type training has been shown to produce improvements in insulin sensitivity its uptake in high risk populations has been questioned. Contrastingly, whole body vibration training (WBVT) is reported to benefit a range of outcomes in a variety of populations. Limited data exists regarding this training modality on insulin sensitivity. Current study assessed the effect of WBVT on oral glucose tolerance response. *Method:* Following institutional ethics approval, five young healthy sedentary individuals undertook oral glucose tolerance test (OGTT) prior to and on completion of 5-week progressive WBVT. *Result:* There were no changes in fasting plasma glucose concentrations before and after the 6 weeks of WBVT. Both pre- and post-training OGTT revealed no significant changes in plasma glucose concentrations over time. There was a 9% reduction in plasma glucose area under the curve (AUC) post training. The Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) decreased by 21% and Cederholm index of insulin sensitivity was increased by 18% following WBVT. *Conclusion:* Results suggest WBVT is associated with improved insulin sensitivity and could produce clinically relevant effects on fat metabolism in sedentary young people. Large-scale studies are now necessary to assess the effectiveness of WBVT in diabetic populations.

Keywords: Exercise, Glucose, Diabetes, Vibration, Sedentary

Introduction

Exercise is a powerful therapy for the treatment and prevention of type 2 diabetes (T2D) and other chronic conditions such as cardiovascular disease [1]. It has been shown that physical activity alone, or in combination with dietary changes, reduces the risk of developing T2D in populations with impaired glucose tolerance by >50% [2-4]. Despite the acknowledged health benefits of exercise [5], only 43% of men and 32% of women in the UK achieve the recommended 30 minutes of moderate intensity exercise on 5 days of the week according to the Health and Social Care Information Centre [6]. Lack of time to exercise, because of work or family commitments, is the most common reason given for not participating [7-9].

It has been demonstrated previously that a high intensity training protocol can produce rapid improvements in insulin sensitivity with just 15 minutes of exercise per week [10]. However, motivation for strenuous exercise in overweight and sedentary individuals is low due to feelings of discomfort [8] and this type of intervention, according to Hawley & Gibala [11], is unlikely to make a substantial impact in high risk populations. Therefore, an exercise intervention for the general population needs to be as time and intensity efficient as possible (i.e. has a low time requirement with a low-to-moderate intensity).

Whole body vibration training (WBVT) has been reported to improve neuromuscular performance and mechanical strength [12-15], prevent and treat the age related loss of muscle and bone mass [16-17], and combat associated decrements in performance [18]. The main reasons for such effects have been ascribed to high neuromuscular activity arising from the vibratory stimulation [19-20] as well as marked responses in bone tissue [21-22]. It has also been reported that 12 weeks of WBVT can improve blood glucose control compared to traditional resistance exercise when undergoing a carbohydrate challenge; in addition to a trend for a reduction in long-term glucose control as measured by glycosylated haemoglobin [23]. As the time commitment associated with WBVT is significantly less than traditional resistance training [24-25], with lower levels of perceived exertion [26], physical discomfort [13], and strain on the cardiovascular system [26-27], the potential for WBVT to represent a viable non-pharmacologic alternative for affecting insulin sensitivity is promising. Therefore, the current feasibility study aimed to assess the effectiveness of a WBVT paradigm on insulin sensitivity in a sedentary population.

Material and Methods

Following institutional ethics approval and in accordance with the latest rendition of the Helsinki Declaration [28], five young healthy sedentary individuals (2 male and 3 female; age: 19 ± 2 y; BMI: 24 ± 2 $kg.m^{-2}$) were recruited to participate in the current study. All participants self-reported that they were not engaged in any structured exercise training. Participants were informed of the experimental protocol both verbally and in writing before giving informed consent. Furthermore, all participants were informed about how potential life-style changes could affect the results of the study, and were requested to maintain their normal diet and levels of physical activity throughout the duration of the study.

Experimental Procedures:

Baseline Oral glucose tolerance test (OGTT). Participants refrained from performing any strenuous physical activity for 2 days prior to the OGTT, and attended the laboratory at 9am having fasted overnight. Venous blood samples were collected by venepuncture before, 60mins and 120mins after ingestion of 75 g glucose (Fisher Scientific, Loughborough, UK) dissolved in 100 ml of water. Plasma was separated by centrifugation (10 min at 1600 g) and stored at -20ºC until glucose, insulin and non-esterified fatty acid (NEFA) concentrations were analysed. Plasma glucose concentrations were measured using an automatic analyzer (YSI Stat2300, Yellow Spring Instruments, Yellow Spring, OH). Plasma insulin concentration was determined by ELISA (Invitrogen, UK). Plasma NEFA concentrations were determined by a colorimetric assay (Wako Chemicals, Germany). All concentrations were analysed in accordance with Babraj *et al.* [10].

Whole Body Vibration Training:

The vibration training involved holding a static squat (90^{o}) on a vibration platform (NEMES–LC, Nemes: Italy, produced in 2002; synchronous vibration; amplitude 2mm [peak-to-peak displacement 4mm]). The sinusoidal behaviour of the platform, as well as the vibratory parameters, were quantified in a previous pilot study and were stable up to a frequency of 40Hz and with a load on the platform up to 110kg with the procedures recommended by Rauch *et al*. [29]. For this reason, we recruited participants below a body mass of 110Kg and designed a training progression up to a frequency of 40Hz. Participants exercised with their socks on but no shoes to avoid any effect of footwear on damping the vibratory stimulation, as reported by Marin *et al* [30].

Participants were required to put their hands on the handlebars of the machine to ensure balance was maintained. Each participant completed three training sessions each week for six weeks; completing eighteen sessions in total. The intensity of vibration increased each week in accordance with the overload principle as described by Ingham [31] (see Table 1). For the purpose of compliance and standardisation, all sessions were supervised and a rate of perceived exertion (RPE) was obtained after sessions 1,4,7,10,13 and 16 using the Borg Scale [32].

Post-training assessment: A second OGTT was performed 72 hrs after completion of the last training session in accordance with recommendations regarding recovery from resistance training [33-34]. This second OGTT followed the same protocol as the original test and was conducted at a similar time of day (± 1 hr.) as the baseline assessment to avoid the confounding influence of circadian variation [35-36].

Table-1: The 6-week training protocol showing change in intensity of whole body vibration

Sessions	Reps/ Set	Time/ Rep (Secs)	Frequency (Hz)	Peak-to-peak displacement (mm)	Peak acceleration (g) (1g=9.81m.s^{2})	Rest/ Rep (Secs)	Rest/ Set (Mins)	RPE (mean ± SD)
1-3	5	30	30	4	7.2	60	3	7 ± 2
4-6	5	60	30	4	7.2	60	3	9 ± 2
7-9	10	60	30	4	7.2	60	3	10 ± 2
10-12	10	60	35	4	9.9	60	3	10 ± 2
13-15	10	60	40	4	12.9	60	3	11 ± 2
16-18	10	60	40	4	12.9	30	3	10 ± 2

Calculations and statistical analysis: Area under the [plasma] curve (AUC), described by Sowunmi *et al* [37] as a frequently used clinical method of estimating the plot of plasma versus time, was calculated using the conventional trapezoid rule. Plasma glucose, insulin, and NEFA responses to the baseline and post-intervention OGTTs were analysed using 2 factor repeated measures ANOVA with *post hoc* Student Newman-Keuls tests. Given the small sample size used in the current study conventional inferential statistics were not the most appropriate method to make an inference about the true effect of the intervention and, accordingly, an approach recommended by Hopkins [38] was utilised. Pre-post t-tests were carried out for each AUC and insulin sensitivity measure. The resulting P-values and mean change were used to calculate 90% confidence intervals and clinical inferences. For all measures a 10% change was deemed clinically meaningful. All data are presented as mean ± standard error of the mean (SEM).

Results

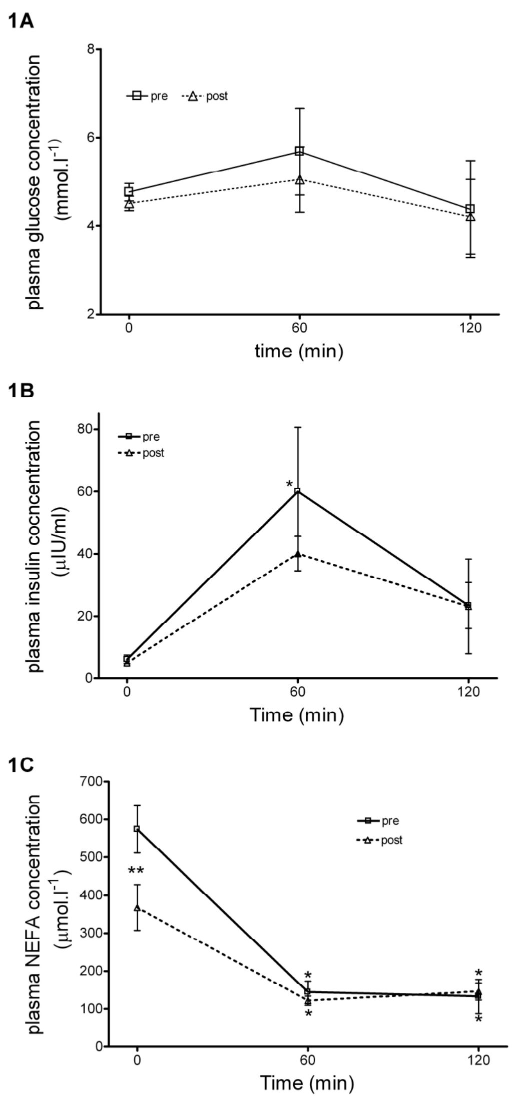
Glucose Responses: There were no changes in fasting plasma glucose concentrations before (4.77 ± 0.09 mmol.l^{-1}) and after (4.52 ± 0.07 mmol.l^{-1}) the 6 weeks of WBVT (Figure 1a). In both pre- and post-training OGTT, there were no significant changes in the plasma glucose concentrations over time (Figure 1a). There was a 9% reduction in plasma glucose area under the curve (AUC) post training (Table 2).

Table-2: Qualitative outcomes for area under the curve (AUC) and insulin sensitivity. [1] Qualitative outcomes reflect the chance that change in each measure is likely to be beneficial, trivial or harmful to participants. For this study a change of 10% for each measure was deemed to be clinically meaningful

	Pre mean	Post mean	Change	90% Confidence limit of change	Qualitative Outcome[1] Percentage change that the change is clinically meaningful		
					Substantially beneficial	Negligible or trivial	Substantiall y harmful
Glucose AUG (mmol.min.l^{-1})	550 ± 69	501 ± 65	49	8 - 88	46% possibly	54% possibly	0.2% most unlikely
Insulin AUC (µIU.Ml^{-1}.min^{-1})	3264 ± 1361	2448 ± 788	816	-584 - 2216	78% likely	13% unlikely	9% unlikely
NEFA AUC (µmol.l^{-1}.min^{-1})	32780 ± 5072	23139 ± 2682	9641	2084 - 17198	95% very likely	4% very unlikely	1% very unlikely
HOMA-IR	1.3 ± 0.3	1.0 ± 0.1	0.27	-0.7 - 1.2	63% possibly	13 unlikely	23% unlikely
Cederholm Index (mg-l^{2}- mmol^{-1}.mU^{-1}.min^{-1})	106 ± 18	125 ± 19	19	-14 - 52	70% possibly	24% unlikely	7% unlikely

Insulin Responses: There were no changes in fasting plasma insulin concentrations before (6.0 ± 1.5mmol.l^{-1}) and after (5.0 ± 0.7 μIU.ml^{-1}) the 6 weeks of WBVT (Figure 1b). In the pre training OGTT, plasma insulin concentration was significantly elevated 60 minutes after the 75g glucose load (Figure 1b; 0 min: 6.0 ± 1.5 v 60min: 60.1 ± 20.6 μIU.ml^{-1}, P < 0.05) but not in the post training OGTT (Figure 1b; 0min (n = 5): 5.0 ± 0.7 v 60min 40.1 ± 5.5 μIU.ml^{-1}). There was a 25% reduction in plasma insulin AUC post WBVT (Table 2).

Figure-1: Changes in blood concentration over time A: blood glucose; B: blood insulin; C: blood NEFA. * P<0.05 compared to 0 min time point; ** P<0.05 pre training compared to post training.



NEFA responses: There was a decrease in baseline plasma NEFA levels after 6 weeks of WBVT (Figure 1c; Pre-training:574 ± 140.2 v post-training: 368 ± 135.9μmol·l^{-1}: P<0.05). Plasma NEFA levels were decreased significantly at 60 min and also 120 minutes compared to baseline in the pre and post-training OGTT (Figure 1c; pre- 0 min: 574 ± 140.2 v 60min: 143 ± 66.1; P<0.05 v 120min: 133 ± 100.6μmol·l^{-1}; P<0.05; post- 0 min: 368 ± 135.9 v 60 min: 121 ± 24.7; v 120 min: 146 ± 45.1 μmol·l^{-1}; P<0.05). There was a 30% reduction in the plasma NEFA AUC post WBVT (Table 2).

Insulin sensitivity: The Homeostasis Model Assessment of Insulin Resistance (HOMA-IR), as described by Gayoso-Diz [39], decreased by 21% following training (Table 2) and Cederholm index of insulin sensitivity was increased by 18% (Table 2) following training.

Discussion

The current study provides novel information regarding the usefulness of WBVT in treating metabolic disease. The 6 week WBVT programme produced a lower glucose response (9% reduction in AUC suggesting a possible positive effect), insulin (25% reduction in AUC suggesting a likely positive effect), and NEFA (36% reduction in AUC suggesting a very likely positive effect) to a 75g glucose load in young sedentary individuals. The decrease in glucose AUC was similar to that seen by Baum *et al* [23] in patients with type 2 diabetes. There was also a decrease in insulin resistance as measured by HOMA-IR (21% suggesting a possible positive effect) and an increase in insulin sensitivity (18% suggesting a possible positive effect) following WBVT.

Insulin sensitivity has been shown, in part, to be regulated by plasma NEFA concentration. In older adults fasting NEFA concentrations are elevated in those with impaired post carbohydrate challenge with a loss of suppression of lipolysis in response to insulin [40]. In lean and obese non-diabetic middle aged subjects decreasing plasma NEFA levels improved oral glucose tolerance with both decreased plasma glucose and insulin AUC [41]. Conversely, elevating plasma NEFA concentration through lipid infusion lowers the glucose infusion rate during peripheral insulinemia-euglycemia in young men [42].

The most interesting finding of the current feasibility study was that WBVT was associated with a 36% decrease in fasting plasma NEFA concentration without a concomitant change in fasting insulin, as well as a 29% reduction in NEFA AUC following WBVT despite a 25% reduction in the plasma insulin AUC. This is in contrast with studies in which 10 weeks of aerobic training failed to affect fasting plasma NEFA concentration [43], and only elicited a small effect on plasma NEFA AUC (2%) and plasma insulin AUC (5%) following a glucose load in young healthy participants [44].

This suggests that insulin was able to inhibit lipolysis to a greater extent following WBVT than is seen with traditional exercise modalities. The results of the current study suggest that WBVT is associated with improved insulin sensitivity and could produce clinically relevant effects on fat metabolism in sedentary young people. Unlike traditional exercise modalities WBVT has a low rate of perceived exertion, which suggests it may be a suitable exercise paradigm in people with type 2 diabetes. Additionally, due to the lower perceived exertion levels, discomfort and strain placed on the heart, WBVT could be a useful training tool for people with cardiovascular disease or secondary complications associated with type 2 diabetes; factors which often limit participation in more traditional forms of exercise. More large-scale studies are now necessary to assess the effectiveness of WBVT in diabetic populations as well as define the safest and most effective training protocol.

References

1. Pedersen BK & Saltin B. Evidence for prescribing exercise as therapy in chronic disease. *Scandinavian Journal of Medicine & Science in Sport.* 2006; 16:3-63.
2. Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA *et al*. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *New England Journal of Medicine.* 2002; 346(6):393-403.
3. Laaksonen DE, Lindstrom J, Lakka TA, Eriksson JG, Niskanen L, Wikstrom K *et al*. Physical activity in the prevention of type 2 diabetes - The Finnish Diabetes Prevention Study. *Diabetes.* 2005; 54(1):158-165.
4. Pan XR, Li GW, Hu YH, Wang JX, Yang WY, An ZX *et al*. Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance - The Da Qing IGT and diabetes study. *Diabetes Care.* 1997; 20(4):537-544.
5. Reiner M, Niermann C, Jekauc D & Woll A. Long-term health benefits of physical activity - a systematic review of longitudinal studies. *BMC Public Health.* 2013; 13: 813.
6. Health and Social Care Information Centre. Statistics on Obesity, Physical Activity and Diet. Leeds. *Health and Social Care Information Centre.* 2015.
7. Health and Social Care Information Centre. Health Survey for England: Healthy Lifestyles: knowledge, attitudes and behaviour. Leeds. *Health and Social Care Information Centre.* 2008.
8. Korkiakangas E, Alahuhta M & Laitinen J. Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. *Health Promotion International.* 2009; 24(4):416-427.
9. Kowal J & Fortier MS. Physical activity behaviour change in middle aged and older women: The role of barriers and of environmental characteristics. *Journal of Behavioral Medicine.* 2007; 30:233-242.
10. Babraj J, Vollaard N, Keast C, Guppy F, Cottrell G & Timmons J. Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. *BMC Endocrine Disorders.* 2009; 9:3.
11. Hawley JA & Gibala MJ. Exercise intensity and insulin sensitivity: how low can you go? *Diabetologia.* 2009; 52(9):1709-1713.
12. Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J *et al*. Hormonal responses to whole-body vibration in men. *European Journal of Applied Physiology.* 2000; 81(6):449-454.
13. Delecluse C, Roelants M & Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Medicine and Science in Sports and Exercise.* 2003; 35(6):1033-1041.
14. Fagnani F, Giombini A, Di Cesare A, Pigozzi F & Di Salvo V. The effects of a whole-body vibration program on muscle performance and flexibility in female athletes. *American Journal of Physical and Medical Rehabilitation.* 2006; 85(12):956-962.
15. Roelants M, Delecluse C, Goris M & Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *International Journal of Sports Medicine.* 2004; 25(1):1-5.
16. Blottner D, Salanova M, Puttmann B, Schiffl G, Felsenberg D, Buehring B et al. Human skeletal muscle structure and function preserved by vibration muscle exercise following 55 days of bed

rest. *European Journal of Applied Physiology.* 2006; 97(3):261-271.
17. Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D & Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: A randomized controlled pilot study. *Journal of Bone and Mineral Research.* 2004; 19(3):352-359.
18. Hawkey A, Griffiths K, Babraj J & Cobley JN. Whole body vibration training and its implications to age-related performance decrements: an exploratory analysis. *Journal of Strength and Conditioning Research.* 2016; 30(2):555-560.
19. Cardinale M & Wakeling J. Whole body vibration exercise: are vibrations good for you? *British Journal of Sports Medicine.* 2005; 39(9):585-589.
20. Pujari AN, Neilson RD & Cardinale M. A novel vibration device for neuromuscular stimulation for sports and rehabilitation applications. *Conf Proceedings of IEEE Engineering in Medicine and Biology Society.* 2009; 839-844.
21. Cardinale M, Leiper J, Farajian P & Heer M. Whole-body vibration can reduce calciuria induced by high protein intakes and may counteract bone resorption: A preliminary study. *Journal of Sports Sciences.* 2007; 25(1):111-119.
22. Torcasio A, van Lenthe GH & Van Oosterwyck H. The importance of loading frequency, rate and vibration for enhancing bone adaptation and implant osseointegration. *Eur Cell Mater.* 2008; 16:56-68.
23. Baum K, Votteler T & Schiab J. Efficiency of vibration exercise for glycemic control in type 2 diabetes patients. *International Journal of Medical Sciences.* 2007; 4(3):159-163.
24. Hawkey A. Whole body vibration training improves muscular power in a recreationally active population. *SportLogia.* 2012; 8(2):202-212.
25. Wyon M, Guinan D & Hawkey A. Whole body vibration training increases vertical jump height in an undergraduate dance population *Journal of Strength and Conditioning Research.* 2010; 24(3):866-870.
26. Rittweger J, Beller G & Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clinical Physiology.* 2000; 20(2):134-142.
27. Hazell TJ, Thomas GW, Dequire JR & Lemon PW. Vertical whole-body vibration does not increase cardiovascular stress to static semi-squat exercise. *European Journal of Applied Physiology.* 2008; 104(5): 903-8.
28. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *Journal of the American Medical Association.* 2013; 310:2191-2194.
29. Rauch F, Sievanen H, Boonen S, Cardinale M, Degens H, Felsenberg D, Roth J, Schoenau E, Verschueren S and Rittweger J. Reporting whole body vibration intervention studies: Recommendations of the International Society of Musculoskeletal and Neuronal Interactions. *Journal of Musculoskeletal and Neuronal Interactions.* 2010; 10(3):193-198.
30. Marín P, Bunker D, Rhea M & Aylloín F. Neuromuscular activity during whole-body vibration of different amplitudes and footwear conditions: implications for prescription of vibratory stimulation. *Journal of Strength and Conditioning Research.* 2009; 23(8):2311-2316.
31. Ingham S. The physiology of strength training. In: G. Whyte, The physiology of training. London. *Elsevier.* 2007; 146.
32. Borg G. Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation Medicine.* 1970; 2(2-3):92-98.
33. McLester JR, Bishop PA, Smith J *et al*. A series of studies - A practical protocol for testing muscular endurance recovery. *Journal of Strength and Conditioning Research.* 2003; 17(2):259-273.
34. Westcott WL. How often should clients perform strength training? *ACSM's Certified News.* 2010; 20(2):10-11.
35. Drust B, Waterhouse J, Atkinson G, Edwards B & Reilly T. Circadian rhythms in sports performance: An update. *Chronobiology International.* 2005; 22:21-44.
36. Teo W, Newton MJ & McGuigan MR. Circadian rhythms in exercise performance: implications for hormonal and muscular adaptation. *Journal of Sports Science and Medicine.* 2011; 10(4):600-606.
37. Sowunmi A, Gbotosho GS, Happi CT, Folarin O, Okuboyejo T, Michael O. & Fatunmbi MPH. Use of AUC to evaluate the effects of antimalarial drugs on malaria associated anemia after treatment. *American Journal of Therapeutics.* 2011; 18(3):190-197.
38. Hopkins WG, Marshall SW, Quarrie KL and Hume PA. Risk factors and risk statistics for sports injuries. *Clinical Journal of Sports Medicine.* 2007; 17:208-210.
39. Gayoso-Diz P, Otero-Gonzalez A, Rodriguez-Alvarez MX, Gude F, Garcia F, De Francisco A & Gonzalez Quintela A. Insulin resistance (HOM-IR) cut-off values and the metabolic syndrome in a general adult population: effect of gender and age: EPIRCE cross sectional study. *BMC Endocrine Disorders.* 2013; 13:47.
40. Carlson OD, David JD, Schrieder JM, Muller DC, Jang HJ, Kim BJ & Egan JM. Contribution of nonesterified fatty acids to insulin resistance in the elderly with normal fasting but diabetic 2-hour postchallenge plasma glucose levels: the Baltimore Longitudinal Study of Aging. *Metabolism.* 2007; 56(10):1444-51.
41. Santomauro AT, Boden G, Silva ME, Rocha DM, Santos RF, Ursich MJ *et al*. Overnight lowering of free fatty acids with Acipimox improves insulin resistance and glucose tolerance in obese diabetic and nondiabetic subjects. *Diabetes.* 1999; 48(9):1836-1841.
42. Krebs M, Krssak M, Nowotny P, Weghuber D, Gruber S, Mlynarik V *et al*. Free fatty acids inhibit the glucose-stimulated increase of intramuscular glucose-6-phosphate concentration in humans. *Journal of Clinical and Endocrinology Metabolism.* 2001; 86(5):2153-2160.
43. Friedlander A L, Casazza GA, Horning MA, Usaj A & Brooks GA. Endurance training increases fatty acid turnover, but not fat oxidation, in young men. *Journal of Applied Physiology.* 1999; 86(6):2097-2105.

44. Ostergard T, Ek J, Hamid Y, Saltin B, Pedersen OB, Hansen T *et al*. Influence of the PPAR-gamma2 Pro12Ala and ACE I/D polymorphisms on insulin sensitivity and training effects in healthy offspring of type 2 diabetic subjects. *Hormone and Metabolic Research.* 2005; 37(2):99-105.

*All correspondences to: Mr. Adam Hawkey. CSci SFHEA FBIS, Centre for Health, Exercise and Sport Science, Southampton Solent University, Southampton, SO14 0YN, United Kingdom. E-mail: adam.hawkey@solent.ac.uk