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1 **The interaction between nutrition and exercise for promoting health and performance**

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31 **Running title:** Nutrition and exercise for health and performance

32 **Key words:** Macronutrients, exercise metabolism, obesity, diabetes, healthy ageing

33 **Abstract**

34 The theme of The Nutrition Society Spring Conference 2017 was on the interaction between nutrition and
35 exercise for promoting healthy ageing, maintaining cognitive function and improving the metabolic health of
36 the population. The importance of this theme is highlighted by the public health issues surrounding obesity,
37 diabetes and the age-related loss of skeletal muscle mass (sarcopenia). The opening symposium provided
38 a historical perspective of both invasive and non-invasive methodologies for measuring exercise
39 energetics and energy balance. Data derived from these techniques underpin current understanding
40 regarding the metabolic response to nutrition and exercise. Further symposia examined the importance of
41 skeletal muscle for healthy ageing in older men and postmenopausal women. From a nutritional perspective,
42 the potential for animal- versus plant-based protein sources to offset the age-related decline in muscle
43 mass was discussed. The day concluded by discussing the link(s) between nutrition, exercise and
44 brain function. Day 2 commenced with examples of applied equine research illustrating the link
45 between nutrition/exercise and insulin resistance to those of a human model. The final symposium
46 examined the combined role of nutrition and exercise in reducing risk of type 2 diabetes and dyslipidaemia.
47 The overall conclusion from the meeting was that the interaction between diet and physical activity
48 confers greater benefits to human health and performance than either component alone.

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67 Not since 2010 has The Nutrition Society organised a conference with an exercise theme. In the
68 intervening period, the exercise literature has continued to expand with numerous research groups,
69 worldwide, focussed on understanding the powerful, but complex, interaction between nutrition and exercise
70 for promoting human health and performance across the lifespan. Hosted by The University of Stirling, the
71 theme of the Nutrition Society Spring conference 2017 attracted 114 scientists, nutrition educators,
72 healthcare professionals, clinicians and students from the UK, Europe, North America and South America.
73 Over the two days, experts and delegates discussed the role of nutrition and exercise as non-pharmacological
74 interventions for promoting healthy ageing, preserving cognitive function and reducing the risk of type 2
75 diabetes. These topics were addressed across three symposia, two plenary lectures, 24 original
76 communications and finally a roundtable discussion.

77 The topic of symposium 1 — ‘Exercise energetics and energy balance’ — provided a historical
78 perspective of key invasive and non-invasive methodologies for measuring exercise energetics and energy
79 balance, both at the tissue (muscle) and whole-body level and within both laboratory and field settings. The
80 first speaker, Professor Lawrence Spriet (University of Guelph, Canada), covered the reintroduction (by
81 Jonas Bergstrom in the 1960’s⁽¹⁾) and continued application of the percutaneous needle muscle biopsy
82 technique as a powerful tool for measuring both substrates utilised and metabolites produced by skeletal
83 muscle in response to various exercise and nutritional stimuli. The muscle biopsy technique was described as
84 having a significant impact on current scientific knowledge regarding the role of nutrition in regulating fuel
85 selection during exercise and manipulating muscle adaptation to exercise training.

86 Next, Professor Klaas Westerterp (Maastricht University, The Netherlands), presented data exploring
87 the valuable contribution of the doubly-labelled water technique for measuring energy expenditure in free-
88 living individuals. Introduced in 1949 and developed over the following 30 years, the doubly-labelled water
89 method remains the gold standard tool for assessing energy expenditure in humans under free-living
90 conditions^[2]. In terms of application, this method allows scientists to precisely determine energy
91 requirements for the maintenance of energy balance and thus helps inform nutritional guidelines
92 for improving health and performance. The complex nature of utilising doubly-labelled water methodology
93 also was discussed, highlighting the challenges presented in accounting for background isotope
94 enrichment and accurately measuring higher rates of energy turnover in specific populations (e.g.
95 Professional cyclists competing in the Tour de France). Finally, the impact of restricting caloric intake
96 on energy balance was discussed, emphasizing the remarkable ability of the body to maintain
97 homeostasis with the effect of resetting to a lower resting metabolic rate.

98 The final topic of the symposia involved a transition into discussing the control of
99 substrate utilization and the influence that exercise and nutritional interventions can play in this process.
100 Dr Francis Stephens (University of Exeter, UK) detailed the impact of carnitine supplementation
101 on fat and carbohydrate utilization during exercise. Evidence demonstrating the role of carnitine in
fatty-acyl transport

102 into mitochondria and as a buffer in the face of excess acetyl-CoA accumulation was discussed. The methods
103 and impact of manipulating intracellular carnitine availability by dietary means was presented with the
104 conclusion that such a nutritional strategy can enhance fat catabolism at rest and increase the flux rate of
105 pyruvate dehydrogenase complex with the concomitant reduction in lactate accumulation^[3].

106 The topic of symposium 2 was the ‘Maintenance of muscle mass for healthy ageing.’ Muscle loss
107 with advancing age — termed sarcopenia — is most commonly associated with reduced strength, an
108 increased risk of falls and a decline in functional abilities (e.g. performing tasks of daily living such a
109 grocery shopping, climbing the stairs, standing from a seated position, etc.). Perhaps less well appreciated is
110 the wider role of skeletal muscle in health and disease, including cancer survivorship, obesity, osteoporosis
111 and recovery from critical illness^[4]. This symposium, opened by Professor Kevin Tipton (University of
112 Stirling, UK), made explicit reference to the powerful concept of ‘physical activity as medicine’ as
113 fundamental to increasing the ‘health-span’ of our ageing population^[5]. Rather than biological ageing *per se*,
114 recent evidence suggests that physical inactivity is a stronger predictor of muscle loss, and the associated risk
115 of morbidity, commonly experienced with advanced age^[6]. Professor Tipton advocated a ‘use it or lose it’
116 philosophy, offering practical, evidence-based, physical activity guidelines to facilitate the maintenance of
117 muscle mass for healthy ageing. Next, Dr Stefan Gorissen (McMaster University, Canada) focussed on the
118 importance of dietary protein intake for healthy ageing^[7]. Dr Gorissen addressed a ‘hot topic’ in protein
119 nutrition by comparing the anabolic potential of animal and plant-based protein sources for preserving
120 muscle mass in older adults^[8]. Interestingly, the rate of muscle loss with advancing age is typically greater in
121 women compared with men, primarily due to hormonal changes that occur during the menopause. This
122 symposium concluded with a lecture by Dr Mette Hansen (Aarhus University, Denmark) summarising
123 findings from recent studies investigating the effectiveness of estrogen replacement therapy as a novel
124 strategy alongside protein feeding and exercise to delay the onset of sarcopenia in post-menopausal
125 women^[9].

126 Day 1 closed with a plenary lecture from Professor Romain Meeusen (University of
127 Brussels, Belgium) that discussed the synergy between nutrition, exercise and brain function. Professor
128 Meeusen suggested that the positive influence of exercise on cognitive function may be mediated by an
129 increase in brain-derived neurotrophic factor. This lecture then critically evaluated the evidence behind
130 the efficacy of several dietary components, namely polyphenols, flavonols and carbohydrate mouth
131 rinsing, for improving cognition^[10]. These findings were applied to both clinical populations in terms of
132 delaying the progression of age related health disorders and to athletic populations with regards to reducing
133 the impact of central fatigue on endurance performance.

134 Day 2 commenced with the 2nd plenary lecture of the conference from Professor Pat
135 Harris (Waltham Centre for Pet Nutrition, UK) that addressed the debilitating issue of laminitis in horses
136 and the potential link with insulin resistance. The role of diet, macronutrient intake and physical
activity in the

137 process of developing laminitis were discussed both as a cause and potential cure. The comparative links
138 between diet and obesity were clearly illustrated by the effects of changing the diets of horses from rich to
139 poor bioavailability of starch on markers of adipose tissue storage^[11]. Further examples illustrated the
140 complex nature of classifying metabolic disorders and their root cause(s) with the conclusion that whilst it
141 was possible to identify certain breeds of horse and pony that are susceptible to the condition there is a large
142 degree of inherent variability in laminitis susceptibility.

143 Continuing with the theme of 'Nutrition and exercise interactions for metabolic health', Professor
144 Emma Stevenson (Newcastle University, UK) opened symposium 3 by discussing the role of diet and
145 exercise in postprandial glycaemic control. The merit of constant glucose monitoring of interstitial fluid was
146 illustrated in the 24 hour excursions of glucose as a consequence of being in both a post-prandial and post-
147 absorptive state. Furthermore, it was established that post-prandial glucose monitoring is an excellent
148 variable for predicting HbA1C and cardiovascular events. While the beneficial effects of exercise on blood
149 glucose control are understood^[12], Professor Stevenson presented data illustrating that cessation of daily
150 exercise results in a decay in insulin sensitivity over a 5-10 day period that strengthens the case for increased
151 daily activity as an essential component of normal daily living.

152 The final two presentations of the conference focused on the interplay between dietary fat intake,
153 exercise and metabolism. Utilizing a post-prandial model, Dr. Jason Gill (University of Glasgow)
154 emphasized the beneficial effects of a single bout of exercise on reducing the post-prandial excursion in
155 plasma lipid concentration after a high-fat meal. The impact of prior exercise on reducing the plasma
156 concentration of lipids, increasing the concentration of high-density lipids and increasing the size of low
157 density lipids also was discussed^[13]. Professor Jorn Helge (University of Copenhagen) discussed the role of
158 bioactive lipids in relation to insulin resistance. This lecture used examples from athletic populations to
159 introduce the argument that limited evidence exists to suggest that the accumulation of excess intramuscular
160 triglyceride leads to insulin resistance. Other discussion points included the variability in ceramide
161 concentrations in response to changes in diet and caloric intake and how these changes are thought to relate
162 to changes in intracellular signaling^[14,15]. Finally, Professor Helge highlighted that while exercise training
163 increased intracellular ceramide concentration it did so at the same time as improving insulin sensitivity, thus
164 raising questions concerning the role of alternative phospholipids.

165 The scientific programme concluded with a roundtable discussion that highlighted the importance of
166 participating in physical activity on a daily basis throughout the lifespan and how best to communicate this
167 message to the general population. A second topic of discussion concerned the relative importance
168 of nutrient timing in relation to exercise compared with total nutrient intake *per se* for promoting
169 various aspects of health and performance. Finally, the ongoing debate concerning what constitutes an
170 essential nutrient was discussed.

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