

Institution: University of Nottingham
Unit of Assessment: Sport and Exercise Sciences, Leisure and Tourism (UoA24)
<p>Section 1: Unit Context and Structure, research and impact strategy</p> <p>(1a) Context and structure</p> <p>The University of Nottingham (UoN) has a historically outstanding and multidisciplinary background in exercise, nutrition, metabolism and skeletal muscle research, and this has been enhanced by new academic appointments and large-scale investment in Sports and Exercise infrastructure since REF2014. We are therefore returning in UoA24 for the first time. UoN academics returning in this unit of assessment (henceforth referred to as the 'UoA24 Group') are embedded within the Faculty of Medicine and Health Sciences, drawing on its state-of-the-art facilities to research human health and performance. The return comprises research priorities in musculoskeletal health in ageing and well-being, underpinned by institutional, cross-research council and NHS investments in this area of research excellence. This includes the MRC Versus Arthritis Centre for Musculoskeletal Ageing Research, a £2M collaborative venture between the Universities of Birmingham and Nottingham established in 2012, and renewed for a further 5 years in 2017; the Musculoskeletal Disease theme of the NIHR Nottingham Biomedical Research Centre (BRC) established in 2017 and supported by £4M of a £23.5M award; the Centre for Sport, Exercise and Osteoarthritis Research Versus Arthritis, a £2M partnership across the Universities of Bath, Leeds, Loughborough, Nottingham, Oxford and Southampton (led by Nottingham University Hospitals NHS Trust), which was founded in 2013 and renewed in 2018; the Sir Peter Mansfield Imaging Centre (SPMIC) supported by £7.7M investment in 2014 from a MRC-led Clinical Research Capabilities and Technologies Initiative in Imaging to fund novel equipment and capabilities to advance new areas in clinical research. This imaging initiative has stimulated new innovative research in architectural, cardiovascular and metabolic adaptation in human ageing, health and disease under controlled physiological conditions.</p> <p>The UoA24 Group is a strategic organisational coupling of academics in the Schools of Life Sciences (SoLS) and Medicine (SoM), uniting researchers in physiological/exercise (cardiovascular, metabolic, functional and motor), nutritional (appetite, energy balance and obesity), psychological (behaviour and motivation) and physical (MRI) sciences; a heterogeneity which fosters a multidisciplinary environment underpinned by shared postgraduate students and grant capture. Our research strategy focuses on these actions and areas of strength, building on ongoing successes, whilst also laying foundations for further development in relevant areas of health- and disease-related research in the future. Informed by analysis and reflection and in line with UoN Global Strategy, we aim to further capitalise upon our position and cement UoN as a world-leader in Sport and Exercise Science research by:</p>

- Strengthening and enriching core activities of research and training in health-related exercise, nutrition, metabolism and musculoskeletal science, and its progression to disease, as part of the UoN multidisciplinary Health and Wellbeing Global Research Theme.
- Engaging our infrastructure and state-of-art research platforms (section 3b) to develop outstanding researchers, and producing and effectively sharing, high-quality research in these core scientific areas.
- Focusing research funding applications and investment in our research strengths, and the technology platforms that underpin our science.
- Focusing on enhancing quality by key appointments (at all career stages) and collaborations across our multidisciplinary research environment.
- Differentiating UoN on the basis of outstanding postgraduate student research experience.

The following demonstrates our progression within these strategic areas during the assessment period:

(i) We established interdisciplinary research structures, clustered around four themes of research excellence. a) Cardiovascular and Respiratory Physiology; b) Human Nutrition, Obesity and Body Composition; c) Regulation of Muscle Function, Size and Metabolism; and d) Behaviour Modification. These four themes focus on specific topics that were predominant in the assessment period (identified in the centre of Figure 1), with skeletal muscle, exercise, metabolism and nutrition research at the forefront.

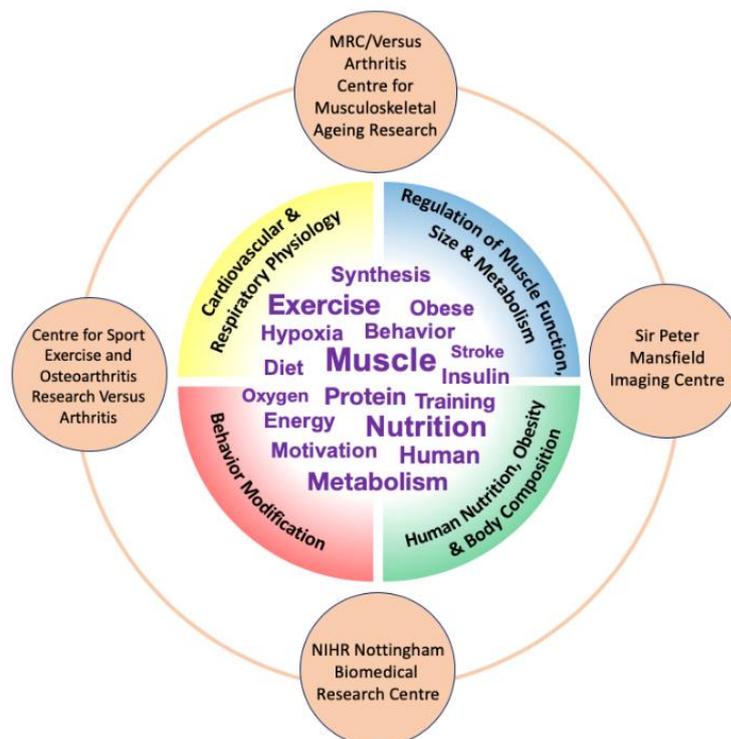


Figure 1 UOA24 Return Context and Structure

(ii) We made strategic high-quality appointments, at all career stages. A new BSc in Sport and Exercise Science has allowed us to attract and fund high quality academic appointments, including significant investment in young researchers. We enhanced and extended existing expertise in metabolism, MRI, molecular biology, nutrition, physiology, and psychology in the context of exercise, health and disease, which facilitated several of our PhD students to take up post-doctoral positions within the UoA24 Group (section 2b). Moreover, six 'rising star' academic appointments across disciplines were made, which embraced our research themes focused on human volunteer research: **Phillips** (2015, pathophysiology in ageing and chronic disease and interventions to mitigate functional consequences); **Wilkinson** (2016, development of minimally invasive approaches to monitor skeletal muscle metabolism); **Blockley** (2018, assessment of in vivo human brain metabolic function using MRI); **Brook** (2018, application of stable isotope tracers to quantify human metabolism); **Hancox** (2018, maintenance and promotion of health-related behaviour and well-being); **Piasecki** (2018, neuromuscular decline in ageing and disease). A strategic Associate Professor appointment in human nutrition (**Siervo**, 2019) further increased critical mass. Additionally, four colleagues were awarded personal chairs (**Atherton**, 2016; **Smith**, 2017; **Szewczyk**, 2017 and **Tsintzas**, 2020), demonstrating retention and traction in areas of strength. We have balance across staffing levels ensuring leadership and sustainability (section 2a).

(iii) We delivered excellent multidisciplinary post-graduate training activity to meet skills gaps. For instance, boundaries between disciplines (such as physics and biology) were crossed through co-supervised PhD studentships, which were key to attracting funding to establish our centres of excellence. Post-graduate training incorporated multiple specialist centre-specific training initiatives for clinical and non-clinical scientists (e.g. ageing research specific research opportunities in the MRC/Versus Arthritis Centre for Musculoskeletal Ageing Research). Furthermore, overarching skills training and networking opportunities were supported by the Centre for Doctoral Training in Musculoskeletal Health and Pain in Ageing and Wellbeing across our four centres of musculoskeletal research excellence. This strategy-specific approach was complemented by specific UoN Research Academy training (section 2b).

(iv) Our structure, straddling across schools and across institutional centres of excellence, facilitated significant and productive collaboration beyond our institutional boundary; reflected by over 91% of our scholarly output including inter-institutional collaborations (section 4a).

(v) We secured external research funding awards totalling £7.35M (section 3a), **and research across areas of strength were underpinned by the establishment and integration of novel, large-scale technology platforms focussed on the human condition;** particularly magnetic resonance imaging (MRI) and stable isotope tracer-based quantification of substrate metabolism (section 3b).

(vi) All 18 academics, across career stages, produced and shared high-quality research outputs. We collectively published 277 peer-reviewed journal articles. Over 80% of our publications were in top-quartile journals and over 55% were in the top 10% by field-normalised SCImago Journal Rank.

In accordance with UoN Policy (REF5a), all researchers are committed to open research. All research outputs were made available in an open access form, either Gold open access using block funding (where appropriate) or via the UoN institutional repository (RIS). Our researchers also supported open science by publishing findings early on key preprints servers, e.g. bioRxiv (**Atherton** and **Siervo**).

(1b) Research and impact

The UoA24 Group has delivered against the 5 aims of our Institutional Knowledge Exchange Strategic Delivery Plan (REF5a).

Our **impact case studies** were developed, selected in open competition and advanced further with support of a team of Faculty impact officers. This also identified a pipeline of impact for the future, e.g. **Phillips** - higher risk of Diabetes in Asian populations, **Siervo** – dietary nitrate intake in Tanzanians.

The UoA24 Group has a broad portfolio of impacts typified by:

- **Aiding and contributing to government expert advisory panels to affect policy change** e.g. membership of the Scientific Advisory Committee for Nutrition; presenting evidence at the 2019 House of Lords Science and Technology Committee inquiry into Ageing; chairmanship of the Carbohydrates Working Group that authored the report “Carbohydrates and Health” published in 2015 [REF3 ICS1].
- **Participating in expert think-tanks** e.g. “Influencing the Trajectories of Ageing”, The Academy of Medical Sciences (2016).
- **Creating, developing and commercialising intellectual property** e.g. USA patent number US9662344B2 – carnitine retention [REF3 ICS2].
- **Conducting notable public outreach** e.g. the Physiological Society report “Growing Older, Better” launched in the Houses of Parliament 2019; SpaceX-16 research highlighted by BBC Breakfast News, 2018; BBC “Trust Me I’m a Doctor”, 2016; BBC “The Truth About Getting Fit”, 2018.
- Members of the UoA24 Group hosting and delivering **educational events**, including both single and multi-day annual events for primary and secondary school students. Widening participation activities included sessions enhanced by external outreach funding, awarded to deliver activities across local primary schools annually (e.g. Physiological Society “Mighty Muscles” and “Eating for Energy”).

- **Community outreach efforts** included talks at individual society events, particularly those with members to whom our research directly relates (e.g., U3A, Rotary, WI). Members of the UoA24 Group also actively contributed to larger-scale events such as the Physiological Society Presidents Lecture Day at the Royal Institution, London 2019, The Big Bang Fair and UoN's 'Wonder' (the latter two having reach of ~2,000 and 5,000 visitors, respectively).
- The UoA24 Group hosted **research celebration events for members of the local community and past research participants**, raising research awareness and presenting key findings. These activities also provided our post-graduate (PGR) students opportunities to participate in outreach and enhance presenting skills to diverse audiences.
- Members of the UoA24 Group played a central role in **organising the 'International Biomedical Basis of Elite Performance' conference** of the Physiological Society in 2012 and 2016, the latter being hosted at UoN.

(1c) Future development from 2020

Our overarching objective is to continue to create a world-class multidisciplinary translational research environment and infrastructure that will further connect our institutional Schools and research centres of excellence, and NHS Trusts (section 1a). It will cross institutional boundaries, involving our current and new partners in the UK and beyond (section 4a). Our strategic vision is to increase capacity and standing in areas of historical research excellence (**exercise, nutrition, metabolism and skeletal muscle research in the context of health and disease**), while committing significant investment in young researchers in areas of new strategic importance to foster sustainability and continued growth in our multidisciplinary research. Specifically, these important emerging areas, that dovetail with existing strengths in metabolism and nutrition, include **dynamic proteomics** and **metabolomics (Wilkinson)**, **imaging (Blockley, brain; Piasecki, neuromuscular)**, **epidemiological nutrition (Siervo)** and **behaviour modification (Hancox)**. Additionally, as the BSc Sport and Exercise Science develops further, we will integrate **biomechanics** into existing research in the UoA24 Group, which will add to our multidisciplinary and translates well from our existing themes. We aim also to increase interactions and outputs in exercise, nutrition, physiological and adherence health research with **clinical researchers** e.g. from across the musculoskeletal, gastrointestinal, and respiratory disease themes of our BRC and local NHS Trusts.

We will actively support our Early-Career Researchers (ECR) by managing teaching loads and allocating flexible research funds. This will include School start-up funding of £10,000-20,000 per person and matched PhD funding, prioritisation of pump-priming fund allocation and PhD studentships from our centres of excellence, provision of independent laboratory space, and access to state-of-art research platforms (section 3b) at minimal/no cost.

While research income from industry, commerce and public corporations has been healthy in the current REF period (totalling £1.417M; section 3a), we will strive to maximise the commercialisation of our future research in the context of the global financial challenge. We will exploit our strong links with the pharmaceutical and nutrition industries, and our previous experience of generating and commercialising IP (section 4c and REF3).

We will further the dissemination of research findings, maximise the visibility of our research and promote national and international networking by presenting at national and international meetings. Synergies with other centres of excellence, key policy influencers and industry will also be exploited to determine routes to translation of our primary findings. Research and impact activities will increase around the themes and research topics depicted in Figure 1, under the provenance of the overarching institutional, cross-research council and NHS structures. We will build on existing research infrastructure through further capital investment bids, such as the BBSRC ALERT. Researchers across a variety of disciplines will continue to benefit not only from the new multidisciplinary knowledge produced across our research themes, but also by accessing constantly evolving world-leading technical facilities, well-defined volunteer cohorts and archived tissue banks that UoN and our collaborators have access to.

We will continue to publish in high impact physiology/metabolism (J Physiology, AJP journals), nutrition (AJCN, Clinical Nutrition) and exercise (MSSE, SJMSS) peer-reviewed journals of direct relevance to UoA24. Additionally, we will target broader scope basic science journals (such as Cell/Nature Metabolism) and clinical journals (e.g. Annals of Surgery and Thorax) to increase impact of our physiological research to wider health research agenda.

(1d) Mechanisms to establish, deliver and review research strategy

All senior researchers in the UoA24 Group occupy management roles in the centres of excellence and platforms underpinning this return: MRC/Versus Arthritis Centre for Musculoskeletal Ageing Research (Deputy Director – **Greenhaff**, Management Board - **Atherton, Macdonald, Phillips**); NIHR Nottingham Biomedical Research Centre (Gastroenterology theme Deputy Director – **Macdonald**, Musculoskeletal theme Deputy Director – **Greenhaff**); Centre for Sport, Exercise and Osteoarthritis Versus Arthritis (Deputy Director – **Greenhaff**); Sir Peter Mansfield Imaging Centre (Science Committee chair – **Macdonald**, Science Committee member and musculoskeletal theme lead – **Greenhaff**); Stable Isotope Mass Spectrometry Facility (Manager – **Smith**). This ensures effective mechanisms to establish, deliver and review research strategy, including succession planning, integrity and ethics. In addition to these leadership duties, all members bring complementary scientific expertise and actively contribute to monthly site-specific strategy meetings and quarterly meetings of the whole UoA24 Group. Additional *ad hoc* meetings take place to respond to research strategy and funding calls in a coordinated and collaborative fashion.

All our research is subject to rigorous standards. UoN's **Code of Research Conduct and Research Ethics** (REF5a) provides a comprehensive framework for research conduct and governance. Research Ethics is fundamentally linked with integrity, and approval from an institutional Ethics Committee is mandatory for all healthy human volunteer research, with studies involving patients and/or radiation being reviewed by the Health Research Authority and National Research Ethics Services. UoA24 Group members (**Phillips, Tsintzas**) have leadership positions in the Faculty of Medicine and Health Sciences Ethics Committee, steering ethics strategy and approval processes, and advising the UoA24 Group on Ethics matters. Researchers conducting *in vivo* pre-clinical studies aim to Reduce, Refine and Replace (3Rs) the use of animals and their published results conform to ARRIVE guidelines.

UoN is a signatory of the **Concordat to Support Research Integrity**, and research integrity is central to staff induction processes and PhD programmes. The Research Academy provides core researcher training for PGRs and ECRs, including mandatory research integrity training, (REF5a). Research governance is further built into local doctoral training through a bespoke *N-Trans* programme for clinical-translational research, covering essential research skills and including a series of Research Governance modules: use of humans and animals in biomedical research; embedding the 3Rs in Research; exploring ethics in research; good clinical practice training; Patient and Participant Involvement in research; research data management; and Research Integrity. Data Protection training is compulsory, with staff completion monitored. UoN has a Code of Practice on Handling Allegations of Research Misconduct in line with UKRIO and UUK recommendations.

Annual reports on research ethics and integrity are submitted by Schools and Faculties to the UoN Research Integrity Manager.

Section 2: People

(2a) Staffing strategy:

Balanced distribution of staff across senior and junior academic levels (Table 1) promotes stability in addition to ensuring succession planning and sustainability.

Table 1 Distribution of academic levels:

HESA contract level	Headcount	Individuals
F1	6	Atherton, Greenhaff, Macdonald, Smith, Szewczyk, Tsintzas
I0	5	Billeter-Clark, Phillips, Taylor, Siervo, Constantin-Teodosiu
J0	7	Blockley, Cole, Hancox, Piasecki, Wilkinson, Brook, Simpson

Promotions over the period reflect increased research traction; **Atherton, Smith, Szewczyk** and **Tsintzas** were promoted to Chair positions, and **Phillips** to Associate Professor. Strategic appointments strengthened our junior faculty in both core and new areas (section 1a). These strategic investments in academic staffing have been bolstered by research support and pump-priming funds from our Schools and research centres of excellence, and access to skilled technical support staff who underpin research endeavour on both medical school sites (section 3). This strategy fosters new research innovation and supports progression of next generation research leaders. Succession planning is also supported by a University Research Leaders Programme that promotes the strategic and inspirational research leadership skills of 15-20 selected UoN academics per annum (attended by **Atherton** and **Hancox**).

Quality training and development at all career stages is reflected in internal appointments from PGR to Postdoctoral Research Assistants (PDRA; e.g. **Crossland** and **Bass**) and from PDRA to academic staff (e.g. **Phillips** and **Brook** were appointed to academic positions in open competition, having previously completed PhDs with our grouping). Similarly, **Blockley** returned to Nottingham in 2019 having completed his PhD in the SPMIC in 2007. Strategies contributing to our success in staff development are outlined below.

All staff, including PDRAs and ECRs, regardless of contract type and duration, benefit from UoN's staff policies, practices and professional development opportunities (REF5a). All undergo professional development and performance review in the form of Appraisal and Development Conversations (ADC). This process monitors progress and supports areas of professional development and mentoring towards goals beyond fixed-term contracts. ADC, crucially, is not focused around performance-related pay, but provides a framework encouraging regular discussion across the year, concluding with an annual review linking University goals and individual objectives, and providing focus for discussions around staff development, wellbeing, workload, and work-life balance. Decoupling development discussion from pay award allows our colleagues to be ambitious in discussing their research and forward-looking objectives, and avoids short-termism in individual research strategy. Reward is a separate scheme and financial reward can be given to both individuals and teams, and is graduated to reflect the sustainment and significance of colleagues' achievements. Excellence in research, impact, or external engagement are rewarded through this route.

PDRAs are central to our environment and research outcomes, and to PGR support and training. Historically, they have been funded by external grants that allow fixed periods of training and research productivity before moving on in career progression. Our 18 PDRAs were funded through UKRI (e.g. BBSRC, MRC), charities (e.g. Dunhill Medical Trust, Diabetes UK), NIHR (Nottingham BRC), industry partnerships (e.g. Abbott Nutrition, Fresenius-Kabi, GlaxoSmithKline) and the Ministry of Defence (MoD). Of these, 4 progressed into PDRA positions at other HEIs, 1 into industry, 1 into NHS research management, and 5 took up university lectureship posts (3 at UoN). We had 6 PDRAs in post on the census date, 2 of whom

have been retained for a decade or more because of their exceptional skills (**Constantin** and **Crossland**). PDRAs are supported to attend and present at conferences (typically 1-2 per year each) and are awarded costs to cover conference travel.

We have strong ECRs within the UoA24 Group (**Brook, Hancox, Piasecki**). **Brook** gained independent fellowship funding (ESPEN Fellowship 2019) as a result of our supportive environment. Mentorship comes in the form of School-level mentorship schemes, and the ADC scheme, which both take place with experienced senior staff. Grant writing schemes are provided in SoLS and SoM, and peer review of ECR grant applications by senior staff is mandatory. The success of our approaches and mechanisms to support and develop ECRs is evidenced by their career progress and promotions as described above.

The Research Academy training and development programme empowers PDRA and ECR staff to develop the skills required in their research and future careers through training courses, placements, public engagement opportunities and activities for part-time and distance learning. Flexibility to work with different UoA24 Group PIs is encouraged to enhance staff development.

Specialist technical research staff: UoN is a sector leader in recruiting, developing, supporting and retaining world-class technicians whose work strengthens our research ecosystem and the delivery of our research (REF5a). Technical colleagues' development is supported through the Technician Network and creation of a [Technical Skills and Conference Fund](#), enabling technical colleagues to apply for dedicated funding to facilitate attendance at appropriate courses and conferences for professional development.

(2b) Postgraduate research students (PGRs)

Over the census period, 42 PGRs associated with the UoA24 Group graduated (equivalent to 25 by supervision share; all students have two or more supervisors, and co-supervision can be with those from different units). All were PhDs, with no research-based professional doctorates. As of the census end date, 35 PhD students were registered with a primary supervisor from the UoA24 Group, reflecting strategic growth (section 1c). Major financial support for these PGRs came from our centres of excellence (section 1a; particularly the MRC Versus Arthritis Centre for Musculoskeletal Ageing Research, which currently supports 8 PhD studentships).

Our research strategy focuses on research excellence in recruitment of PGR students.

Complementing our recruitment of PGR home students (e.g. through UKRI initiatives), over the census period we successfully secured 4 Vice-Chancellor's International Scholarships for Research Excellence. This competitive scholarship scheme recognises and rewards outstanding international students who apply to study a PhD at UoN and has allowed us to competitively recruit PhD students from China, Iran, India and Saudi Arabia. We also attracted international

PhD students funded by scholarships from their home government (e.g. Nigeria, Taiwan and Saudi Arabia), and have an exchange programme for PDRA and PGR students with Japan (led by **Atherton** and **Philips**).

Commitment to PGR development is evidenced through the numerous opportunities we provide including: the opportunity to gain N-trans accreditation; a dedicated Medicine and Health Sciences Graduate Centre (which forms part of the Research Academy); a comprehensive multi-domain researcher development programme (including online learning, face-to-face courses and public engagement opportunities) based on the RCUK joint skills statement; and a wide range of courses (from practical IT to interpersonal skills) run by the Research Academy which can be tailored to the students' needs in order to meet compulsory training requirements (each student completes 120 credits of PGR training throughout their programme). Furthermore, MRC/Versus Arthritis Centre for Musculoskeletal Ageing Research students access PGR mentorship, training and development led by academics from both Birmingham and Nottingham Universities.

PGRs, like research staff, have access to all research facilities across our sites, and have their own desk space and computer away from the laboratory. PGRs benefit greatly from specialist centre-specific training directives and initiatives for clinical and non-clinical scientists led by **Phillips**. Topics include: health and safety; research integrity and legislation (e.g., HTA, ICH-GCP); research design; PPI; data analysis and dissemination; research technologies and techniques. Furthermore, PGRs have the opportunity to present to diverse audiences (via internal presentations, public and educational outreach and scientific presentations at national/international conferences to achieve public and scientific impact), with these activities forming a compulsory part of the PGR training programme. All PDRA and PGRs are offered possibilities to work in collaborator laboratories locally and internationally (e.g. Crossland spent a month at the University of Jyväskylä and Chivaka spent 2 months at the University of Copenhagen, both working on muscle-related research projects). MRC/Versus Arthritis Centre for Musculoskeletal Ageing Research students are provided with funding to spend up to 6 months training in industry, or at a partner institution, in areas complementary to their research, and we host an iCASE studentship in the MRC-IMPACT doctoral training partnership.

Centre-specific endeavour is complemented by overarching skills training and networking opportunities across our four centres of musculoskeletal research excellence, supported by the Centre for Doctoral Training (CDT) in Musculoskeletal Health and Pain in Ageing and Wellbeing. This CDT is a combined initiative with leadership from academic members of our 4 independent centres of MSK research excellence. Collectively, this demonstrates a major commitment to ensuring that each PGR student gains experience in the skills needed for a career in research.

Interaction between PGR students across all stages of training is actively encouraged (e.g. via student seminars and journal clubs). Each student has a minimum of 10 documented formal supervisory mentorship meetings each year, with attendance and goal-setting monitored at the

school level, supported by our “PGR-Web” IT platform. Meetings provide an opportunity for discussion about issues relating to the PGR project *per se* and any pastoral issues or concerns, and ensures robust PGR mentorship. All PGRs within their final year are encouraged to contribute to teaching activity, such as participating in undergraduate practical demonstrations, which is formalised through the student monitoring system.

We take PGR health and wellbeing seriously and encourage students to speak to supervisors (or PGR academic leads) about any mental or physical health issues, so that appropriate supportive steps can be taken. During the Covid pandemic this has included diarised online meetings. PGRs have their own representatives on School committees to voice issues and a formal UoN student support service which signposts services for numerous aspects of student concern, e.g. mental wellbeing, financial advice and careers guidance.

We underwrite learned society membership costs for all PGR students; in particular the Physiological Society, European Congress for Sports Science and the British Mass Spectrometry Society. This affords PGRs opportunities to apply for additional travel funds/awards, and in doing so, develops external funding application skills. Attendance at research meetings has significantly enhanced PGR training and resulted in a number of prestigious young investigator awards at international conferences. Some examples include:

- **Christopher J Gaffney** - Universitas 21 Global Ingenuity Challenge winner 2014.
- **Chris Shannon** - European College of Sports Science Annual Meeting 2014 Young Investigator Award (Equal 5th place oral presentation).
- **Andrew Hale** - European College of Sports Science Annual Meeting 2017 Young Investigator Award (4th place oral presentation).
- **Joseph Bass** - European College of Sports Science Annual Meeting 2017 Young Investigator Award (Equal 5th place oral presentation).
- **Matthew Brook** - Journal of Physiology Early Investigator Prize 2017. American Physiological Society select award 2017.
- **Jessica Cegielski, Colleen Deane, Joseph Bass** - Awarded organisation of the annual 2017 Young Life Scientists' symposium (Frontiers in Musculoskeletal Health, Ageing and Disease).
- **Nima Gharahdaghi**; International Sarcopenia, Cachexia and Muscle Wasting Conference 2017 (1st Place poster presentation).
- **Natalie Shur**; European Society for Enteral and Parenteral Nutrition 2017 Fellowship.

(2c) Equality & Diversity

UoN has led the development and implementation of major national initiatives that ensure researchers (staff and PGRs from recruitment to retirement) are supported by, and benefit from,

best practice in equality, diversity and inclusion (EDI). It has also ensured that construction of its REF 2021 submission addresses EDI in accordance with the institutional code of practice.

At a local level, returning researchers are members of the Faculty of Medicine and Health Sciences EDI group, which includes EDI Directors from SoLS and SoM. Its role is to embed EDI in all aspects of Faculty work; promote good practice and identify areas for development; contribute to Faculty EDI plans. Using appropriate data, it monitors all aspects of EDI, e.g. auditing progress, celebrating success and recommending priorities for development. The UoA24 Group's REF coordinators (**Greenhaff** and **Atherton**) underwent formal training in EDI, while all academic staff in our UoA undertook on-line EDI training. Allocation of REF outputs was determined by the coordinators, both of whom attended workshops on unconscious bias.

Improving equality in health and wellbeing: In our research we embrace recruitment of minority ethnic groups and both sexes onto clinical trials and we actively research into issues pertaining to ethnicity and social health risks both in the UK and internationally. For instance, we have collaborative research in the UK (**Phillips**, higher risk of Diabetes in Asian groups), in India (**Simpson**, addressing fatty liver disease via lifestyle interventions) and in Malaysia and Tanzania (**Siervo**, Dietary Nitrate intake and vascular health).

Embedding key charters: Both SoLS and SoM hold Athena SWAN Silver awards, recognising work and progress in promoting gender equality. We also promote and uphold UoN's position as a signatory of the ECU Race Equality Charter and Stonewall Diversity Champion. UoN is a registered Disability Confident employer, and signatory to the Working Forward Pledge. The UoA24 Group follows rigorous recruitment and promotions processes, with embedded values of EDI, and there are no barriers to inclusion for protected characteristic groups. Our job advertisements overtly encourage applications from people with protected and underrepresented characteristics, and aim to attract diverse applicants by explicitly advertising inclusion policies. Selection processes are transparent and objective, both at shortlisting and interview stages, to minimise unconscious bias, and all interview panel members undertake EDI training. Age distribution of existing UoA24 Group members is balanced: 26-35 years (22%), 36-45 years (17%), 46-55 years (33%), 56-65 years (17%) and >66 years (11%). However, it is acknowledged that the gender balance (22% female/78% male) within the Group is skewed. One-third of the new academic appointments in this REF census period were allocated to excellent female researchers and further efforts will be made to address this in future.

Section 3: Income, Infrastructure and facilities

Our successes in research outputs and impact are underpinned by a strongly and diversely funded research programme world-leading research facilities and an excellent infrastructure (detailed below).

(3a) Research income

Research income awarded over the census period was £7.35M (REF4B). The breadth of funders and quantity of income reflects the overall quality and broad-based nature of this research grouping. We secured competitive research income through establishing MRC, NIHR and Versus Arthritis research centres of excellence, and project-level initiatives from a wide array of grant and contract funders. The major share of total research income was from UK Research Councils (40%), with further funding from UK based charities (16%); overseas industry, commerce and public corporations (e.g. GlaxoSmithKline, Abbott Nutrition, Fresenius-Kabi, Novartis; 18%); UK government, local authorities, health and hospital authorities (13%, including NIHR); the European Government (10%); UK industry, commerce and public corporations (1.5%). Furthermore, in-kind contributions of £1.0M were secured from the UK Space Agency for European Space Agency (ESA) bed-rest research. These collectively illustrate the research traction within the UoA24 Group and the diversity of funding acquisition, which mirrors the diverse portfolio of research income seen at an institutional level (REF5a).

(3b) Infrastructure and Facilities

Research outputs and impact across UoN are enabled by a long-term investment in estate, facilities and infrastructure (REF5a), as well pump-priming of research priority areas (£135,291 over the census period to members returning in UoA24). Advances in non-invasive techniques (such as MRI), combined state-of-art miniaturised dynamic flux measurements and 'omics technologies, now allow us to perform comprehensive and integrated mechanistic studies in humans. We perceive the human to be the pre-eminent model to investigate human health, ageing and disease. To this end, advanced facilities were established for human nutrition, metabolism and physiological investigation on UoN Nottingham and Derby Medical School sites. This facilitated substantive UoN and NHS Trust collaborations within the UoA24 Group (section 4a). We promote "freedom of movement" and open exchange of techniques and infrastructure across our sites. We hold bi-monthly cross-site journal club that includes staff and PGRs, and discussion forum meetings to discuss research plans, strategy, and collaboration requests between researchers, with agreements being made around cost sharing for use of equipment and techniques. Additionally, pump-priming funds are available to ECRs via our research Centres, and funds (matched by School funding) are available to encourage PGRs and ECRs to travel and work at collaborator sites, which has culminated in 91% of our scholarly output involving collaborators external to UoN (section 4a).

Below is an overview of our general capacity and capabilities, in addition to the flagship facilities and specialist expertise within the UoA24 Group.

Flagship: Human Physiology Units

Bespoke human physiology laboratories were established in Nottingham and Derby Medical School sites, which are staffed by skilled human studies technicians, research nurses and medical doctors who work side-by-side with PIs, PDRAs and PhD students. Staff are maintained as part of the core infrastructure of the UoA24 Group to ensure skills, know-how and techniques are retained. This provides the capability to conduct detailed volunteer screening, plus acute and chronic studies (with nutritional, exercise, drug and hormone interventions), in tandem with detailed physiological assessments. These assessments include quantification of whole-body, limb and muscle metabolism under resting, and exercise conditions, using techniques such as the euglycaemic, hyperinsulinaemic clamp; conchotome muscle biopsy, needle biopsy and micro-biopsy methods; stable isotope tracer infusions. Capabilities also encompass performing human limb and bed-rest immobilisation studies; endurance and resistance exercise training studies; specific motor control and postural balance training. These are dovetailed with our ability to perform comprehensive and novel biochemical and molecular assessments of biological samples to provide new and impactful research insight. Both Human Physiology units are overseen by a Unit Manager and a Clinical Director who meet monthly with PIs to discuss facility requirements, clinical governance issues and grant submissions.

Flagship: Stable isotope mass spectrometry facility

Our cutting-edge Stable Isotope Mass Spectrometry (SIMS) facility houses 4 gas chromatography mass spectrometers (for targeted substrate profiling; providing both quantitative and enrichment analyses of stable isotopes), 2 GC-pyrolysis-isotope ratio mass spectrometers (for deuterium analysis), a GC-combustion-IRMS (for ^{13}C and ^{15}N analyses), and a highly sensitive GC-MS-MS (for low level stable isotope enrichment and concentration measurements). Two breath gas continuous flow systems are available for substrate oxidation studies, and two high temperature Elemental Analysers – coupled to IRMS, for the analysis of deuterium, ^{13}C , ^{15}N and ^{18}O isotopes. Our state-of-the-art Q-Exactiv Orbitrap liquid chromatography-high resolution MS can perform targeted and untargeted metabolomics, proteomics (protein identification and quantitation) and individual protein synthesis measures when coupled with D_2O labelling. The facility is dedicated for the use of UoA24 Group members and collaborators, and provides access to an unparalleled array of MS instrumentation. Fundamental to the success of this facility is the technical expertise of **Smith** (~30 years) and now **Wilkinson** (~7 years) and **Brook** (5 years), who support the analytical endeavours of the UoA24 Group and ensure vitality and future sustainability of the SIMS. Furthermore, to facilitate stable isotope delivery in humans, we developed strong links with Stockport Pharmaceuticals (Stepping Hill Hospital), that provide a quality control and manufacturing service for our sterile isotope tracer infusions, ensuring robust safety standards for volunteer studies.

Flagship: MRI at the Sir Peter Mansfield Imaging Centre (SPMIC)

World-leading expertise in the development and clinical application of MRI is a chief research strength at UoN. UoA24 Group members have direct access to state-of-art human imaging and spectroscopy facilities dedicated for research, and also contribute to management of the SPMIC;

Macdonald – Chair SPMIC Scientific Committee, **Greenhaff** – musculoskeletal lead. SPMIC houses a range of MRI scanners; a 0.5 Tesla Paramed Upright, 1.5 Tesla GE HDxt, 3.0 Tesla GE Discovery MR750, 3.0 Tesla Philips Achieva, 3.0 Tesla Philips Ingenia Wide Bore, a 7.0 Tesla Philips Achieva, and a CTF MEG scanner. In addition, there is a mock scanner used for ‘sham’ experimental designs, for education and outreach purposes and volunteer familiarisation. SPMIC also contains a GE SPINlab MRI hyperpolariser, a Krypton hyperpolariser and a Xenon Hyperpolariser which provide scope to enhance MR scanning protocols in humans. The Ingenia Wide Bore scanner allows imaging to be performed during supine cycling (Lode, electrically braked MRI-compatible ergometer) and stepping exercise (Ergospect Diagnostic Pedal) at exercise workloads pre-determined using indirect calorimetry, while all whole-body magnets can accommodate plantar flexion/ extension exercise protocols using the Ergospect Trispect system. The imaging facilities are used by UoA24 Group researchers to study volunteers at rest (tissue volumes and architecture) and during controlled experimental interventions, such as using substrate infusions and exercise to quantify tissue (e.g. brain, liver, muscle) metabolism and physiology. Moreover, UoA24 Group members have been integral to the development and validation of in-magnet exercise methods.

Underpinning: Technicians, research nurses and medical doctors

The UoA24 Group has a team of skilled technicians, research nurses and medical doctors (Clinical Fellows undertaking PhDs) working alongside non-clinical staff and students and underpinned by SoM, SoLS, and Hospital Trusts. This team comprises:

- **Human studies research technicians** - technical specialists coordinating, supporting and executing human volunteer research (including exercise intervention studies), ‘wet laboratory’ analysis, collaborative development of study designs and ethics approval.
- **Wet laboratory managers and principal research fellow (Constantin-Teodosiu)** - technical specialists undertaking method development and sample analysis; training; sourcing, maintenance and operation of laboratory equipment; HTA management; radiation safety.
- **Research nurses, clinical fellows and senior research fellow (Simpson)** - provide clinical cover and care for volunteers during research protocols, deliver specialist technical support (including execution of hyperinsulinaemic clamps, cannulation, muscle biopsies (doctor only), drug and infusion management), volunteer screening, University IR(ME)R practitioner (responsible for University-wide DEXA facilities).

These colleagues also support the UoA24 Group extensively through analysis of data; drafting and reviewing reports and papers; developing new techniques; writing SOPs, risk assessments and implementation of standard procedures; health and safety responsibility; support and training of students, newly-appointed PDRAs, and visiting scientists; and organising/supporting widening participation and research events.

Underpinning: Key enabling technologies

- **Body composition, muscle and cardiovascular imaging:** We have capacity for the measurement of body composition, including DEXA for accurately detailing body fat and lean mass, and bone mineral density and content (Nottingham and Derby site). We maintain two Easote X-vision ultrasound machines, for a range of imaging assessments focussed on muscle groups, while two Toshiba Aplio and a Phillips IU22 ultrasound provide standard clinical imaging capabilities across body systems, but additionally permit the quantification of muscle (and other organ) microvascular blood flow by contrast-enhanced ultrasound. In addition, the UoA24 Group has expertise in cardiac echocardiography and vascular doppler ultrasound (including flow-mediated dilatation).
- **Neuromuscular imaging:** In line with our strategy to develop areas of new strategic importance (section 1c), recently acquired motor unit assessment equipment (aligned to appointment of **Piasecki**) includes a purpose-built electromyography (EMG) package that enables simultaneous recording of surface and intramuscular EMG at sampling rates higher than that possible by most commercially available systems. Muscle and nerve stimulation can be applied at a range of intensities to assess peripheral neuromuscular function via involuntary contractions, with accompanying contractile force assessed via a series of multi-directional isometric force transducers.
- **Pre-clinical facilities:** While predominantly focussed on the human condition, we recognise the need for model organisms and animal studies in certain contexts. Equipment required for nematode models (led by **Szewczyk**) includes three dissecting microscopes, a fluorescence dissecting microscope, two upright fluorescence microscopes with digital movies imaging, five incubators and a full genome RNAi library. We have dedicated and aligned cell culture facilities on SoM and SoLS sites; class II cabinets for primary cell culture (biopsy-derived satellite cells) and immortalised cell lines (typically muscle L6/C2C12 cells); Flex cell and C-pace for cell stretching (bone cells, tendon cells, skeletal muscle cells) and contraction (skeletal muscle cells) experiments, respectively. Nottingham Medical School houses an animal facility and our members hold personal (e.g. **Brook**, **Constantin-Teodosiu**) and project (**Cole**) licences.
- **Broad analytical biochemistry facilities:** Underpinning our human nutrition, metabolism and physiology research are supportive gene, protein and organelle (e.g. mitochondrial ATP production) analytical capabilities. Equipment (on both sites) used to facilitate this includes Criterion/ Chemidoc systems for Western blotting; 2 ABI 7900HT and an ABI QuantStudio7 micro-fluidics RTPCR for low-density array card mRNA analysis and genotyping (specifically by tetra-primer ARMS), and an EVOS M7000 imaging system for live cell imaging. Furthermore, biochemical analysis of tissues and biological fluids is supported by a range of equipment including a Biochrom amino acid (AA) analyser; IL-600 clinical chemistry analyser, five yellow-springs glucose/ lactate analysers, high-performance liquid chromatography analysers, multiple plate readers, acid-base analysers and high throughput centrifugal auto-analysers to measure blood metabolites (triglycerides, free fatty acids etc.).

Facilitating research: bio-banking as a research resource

We have developed extensive HTA-compliant tissue and bio-fluid bio-banks, including archived muscle biopsy tissue and isolated muscle satellite cells (for cell culture). In addition, a library of cell-free plasma, serum RNA and protein extracts and DNA samples are stored (with research participant consent) as a research resource. These samples are pseudo-anonymised, allowing linkage to detailed phenotyping data such as body composition, handgrip strength and physical function measures.

4. Collaboration and contribution to the research base, economy and society

(4a) Interdisciplinary research collaborations

The UoA24 Group unites researchers in physiological/exercise (cardiovascular, metabolic, functional and motor), nutritional (appetite, energy balance and obesity) and psychological (behaviour and motivation) sciences with those from the physical sciences (e.g. MRI Imaging) and clinical researchers, to collectively contribute to the UoN Health and Well-being Interdisciplinary Global Research Theme.

As detailed in section 1a, major research progression and impact over the census period has been underpinned by active interdisciplinary collaborations via our research centres of excellence. This includes numerous partners that extend well beyond the institutional boundary. Indeed, the majority of our UoA24 research involves national (36.4% of scholarly output) and international (54.9%) collaboration beyond the institution (Figure 2)

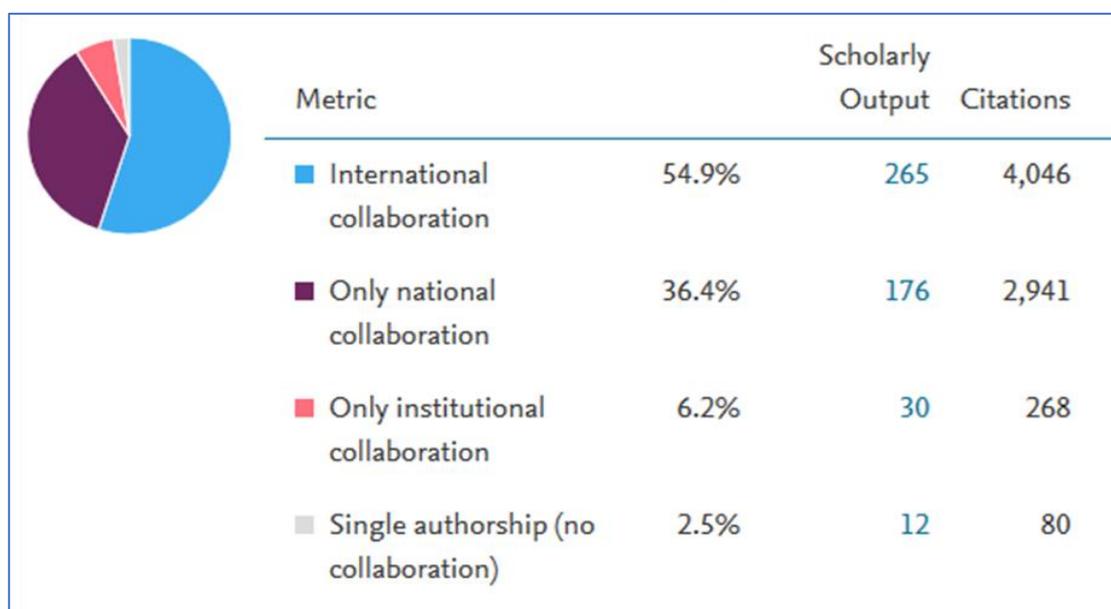


Figure 2 Collaboration in Scholarly Outputs

The fact that only 2.5% of scholarly output involves single authorship work reflects the collaborative nature of human volunteer research, which characteristically requires partnership between scientists from different disciplines and clinicians. The scholarly outputs also reflect

strategic external collaborations with key researchers working in similar areas (e.g. with Profs Thompson and Betts, University of Bath), and with other internationally recognised centres of research excellence (e.g. with Prof Eiken, KTH Royal Institute of Technology, Sweden; Prof Mekjavic, Jozef Stefan Institute, Slovenia; Prof Kadi, Orebro University; Prof Phillips, McMaster University, Canada; Profs Dela, Helge and Raben, University of Copenhagen, Denmark. Moreover, Prof Johannes van Lieshout (Amsterdam University Medical Centre) holds an honorary chair in SoLS, and provides an external viewpoint to members of the UoA24 Group as well as contributing expertise in cardio- and cerebrovascular regulation.

International collaborations have also been initiated or strengthened by our MRC/Versus Arthritis Centre for Musculoskeletal Ageing Research PhD students spending up to 6 months of their training at external institutions (e.g. Dr Mackey and Dr Prats, University of Copenhagen), or with industrial partners (e.g. Novartis, Basel, Switzerland), and all of these PhD studentships (22 in total; 8 registered at UoN) involve cross-collaboration and joint student supervision between the Universities of Birmingham and Nottingham. Pump-priming funds are available via our centres of excellence, allowing researchers to establish new collaborations with academic and industrial partners. In the census period, these included Profs Hellerstein and Evans (University of California, Berkeley) and several pharmaceutical (GlaxoSmithKline, Novartis) or nutritional (Abbott Nutrition, Nestlé) partners. Thus, strong national and international collaborations are embedded into the practice of our future research leaders.

Research collaboration was further reflected in research funding; £1.42M was secured through industrial collaborations and contracts, with by far the largest share (£1.31M) coming from overseas industry, commerce and public corporations. This includes significant funding from nutrition (e.g. Abbott Nutrition, Fresenius-Kabi) and pharma (e.g. GlaxoSmithKline) industries, with industrial collaborations also being bolstered through PhD studentships (section 2b), e.g. Nestlé (Tsintzas), Novartis (Wilkinson) and ARLA Foods (Atherton). Furthermore, substantive in-kind contributions of £1.0M were secured from the UK Space Agency for ESA bed-rest collaborative research. Our standing is also evident from consultancy roles with industry occupied by senior investigators (Table 2).

The interdisciplinary nature of our research is reflected in its broad impact, illustrated by our Impact Case Studies (ICS) highlighting major public health influence. Specifically, **Macdonald's** membership of the Government's Scientific Advisory Committee for Nutrition, and his chairmanship of the Carbohydrates Working Group that authored the report 'Carbohydrates and Health' published in 2015. Recommendations in this report generated widespread media interest and culminated in the Government introducing the Soft Drinks Industry Levy in 2018. These impacted on the sugar-sweetened drink industry, resulting in widespread product reformulations towards lower sugar content, and consumers opting for zero and low sugar-content drinks. Similarly, **Greenhaff** chaired the Physiological Society expert panel that generated the 'Growing Older, Better' report, which was launched in a public event in the Houses of Parliament in 2019.

This led to Greenhaff giving evidence to the House of Lords Science and Technology Committee inquiry into ageing in the UK population, addressing, amongst a number of things, UK Government's target of "at least five extra healthy, independent years of life by 2035, while narrowing the gap between the experience of the richest and poorest". A second ICS describes how IP generated by UoN from the research of **Constantin-Teodosiu** and **Greenhaff** is being actively exploited by their IP Commercialisation Office, and looking towards the future and life beyond this planet, **Szewczyk's** research is setting scientific priorities for space-life research in Europe and the USA.

Taken altogether, the UoA24 Group has a broad portfolio of interdisciplinary research and is actively contributing to the research base of the UK and beyond, the economy and society.

(4b) Influencing and supporting the discipline

All members of the UoA24 Group have given invited lectures at academic institutions, symposia and conferences, many as invited keynote presentations. Similarly, all are active and engaged members of learned societies (in particular the Nutrition Society, the Physiological Society and the European College of Sports Science). Colleagues contributed significantly over the period to influence, support and highlight the discipline of Sport and Exercise Sciences, as outlined below.

Table 2 Influencing, supporting and highlighting the discipline:

Journal Editorial Board Membership (*senior editorial roles in italics*)

Atherton - Experimental Physiology (2015-present); Applied Physiology, Nutrition and Metabolism (2013-present).

Constantin-Teodosiu - Int J Molecular Sciences [Molecular Endocrinology & Metabolism] (2019 – present).

Greenhaff - Acta Physiologica (2005-present); Scandinavian J Medicine and Science in Sports (*Section Editor*, 2009-Present); Journal of Physiology (3rd term as Reviewing Editor 2016-present).

Macdonald - International Journal of Obesity (*Joint Editor-in-Chief*, 2001-present).

Phillips - Applied Physiology, Nutrition and Metabolism (2017-present).

Siervo - Clinical Obesity (2012-present); Proceedings of Nutrition Society (2013-present); Nutrients (2019-present); European Journal of Clinical Nutrition (2019-present).

Szewczyk - Biological Sciences in Space (2013-Present); Frontiers in Physiology (Environmental, Aviation, and Space section, 2017-present); Journal of Experimental Biology (2019-present).

Taylor - Journal of Human Nutrition and Dietetics (2013 to 2019).

Wilkinson - Experimental Physiology (*Senior Editor*, 2019-present).

Contribution to Professional Associations and Learned Societies

Atherton - European Society for Parenteral and Enteral Nutrition 'Intensive course in Tracer Methodology in Metabolism' (2016).

Blockley - International Society for Magnetic Resonance in Medicine Chapter Committee (2016-2017) and Historical Archives Committee (2017-present); Imaging Cerebral Physiology Network Organising Committee (2015-present).

Greenhaff - European College of Sports Science Scientific Board (2010 – present); Physiological Society Scientific Organising Committee for Biomedical Basis of Elite Performance Conference (Chair 2015-2016), and Expert Panel 'Growing Older, Better' report (Chair 2017-2019).

Piasecki - Physiological Society Council (2015-2018), Meetings Committee (2015-present) and Affiliate Working group (Chair 2017-2018).

Smith - European Society for Parenteral and Enteral Nutrition 'Intensive course in Tracer Methodology in Metabolism' (2016).

Taylor - British Dietetic Association 'Pat Judd Prize' judging panel.

Tsintzas - Physiological Society 'Human and Exercise Physiology' theme lead (2014-present), H3 symposium organiser 'Integrative physiology of physical inactivity across the life span' (2017), Conference Organiser 'Experimental Models in Physiology' (2018).

External Expert Panel Membership

Atherton - Consultancy roles with Abbott Nutrition and Fresenius Kabi.

Greenhaff - Scientific Advisory Board 'Living with Statins: a Social, Medical and Personal Perspective' University of Copenhagen (2013-2018); Scientific Advisory Board Center for Healthy Aging University of Copenhagen (2019-present); Research Evaluator for Department of Nutrition, Exercise and Sports, University of Copenhagen (2018); Consultancy role with Nestlé (2019).

Macdonald - UK Government Scientific Advisory Committee on Nutrition (2007-present) and Chair of the Carbohydrate Working Group (2008-2015); Chair of the UK Government Scientific Advisory Committee/ NHS England/ Diabetes UK joint working group 'High fat diets in diabetes management' (2018-2020).

Siervo - External Scientific Advisor (Nutrition and Energy Metabolism) Food and Human Nutrition Unit, University of Alberta (2017-present); World Health Organisation reviewer - dementia platform.

Szewczyk - Promotions Board External, School of Arts and Sciences, Rutgers University (2014).

Tsintzas - Evaluator, Nutrigenomics platform, Top Institute Food and Nutrition, The Netherlands (2014-2016).

Membership of Grant and Fellowship Awarding Bodies

Blockley - EPSRC Engineering Prioritisation Panel Member (2016).

Macdonald - MRC UK Nutrition Research Partnership (2018-2019); Academy of Finland-Life Sciences Committee (2017-2019, Chair in 2018 and 2019); BMBF (Germany) Grant review panels for Competence Cluster in Nutrition (2014-2018); NWO (Netherlands) - Foundation for sustainable production and processing chains in agriculture and horticulture (2015-2018).

Szewczyk - ESA/European Research Council partnership opportunities panel member (2015); Co-Chair, ESA Roadmap: Biology in support of human health (2015); UK Space Agency Space Exploration Committee (2012-2015); Co-Chair, ESA-Industry partnerships for human health working group (2016-2017); Italian Ministry of Health grants lead reviewer (Muscle Study Section, introducing member, 2010–present); Co-Chair, NASA GeneLab Animal Analysis Working Group (2019-present).

Patent Awards

Constantin-Teodosiu and Greenhaff - 'Carnitine Retention', US patent number 9,662,344 B2 (30th May, 2017).

Awards and Honours for Contributions to the Discipline

Macdonald - British Nutrition Foundation Prize (2017).

Greenhaff - University of Copenhagen honorary doctorate in Medicine (2018).

Phillips - Physiological Society R Jean Bannister Prize Lecture Award (2018).

Szewczyk - TechConnect Innovation Award for NemaLife device (2018).