Investigating the Central Nervous System's Response to Vibration Stimulation in the Human Body

Training in Transcranial Magnetic Stimulation (TMS) at the Human Neurophysiology Laboratory, University of Alberta, Canada

A report by

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Travelling Fellowship

Disclaimer

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I owe a particular debt to my host, Professor David F. Collins, Director of the Human Neurophysiology Laboratory in the Faculty of Kinesiology, Sport, and Recreation at the University of Alberta, Canada. Professor Collins welcomed me into his laboratory with extraordinary generosity and patience, gave me the freedom to ask naive questions, and made certain I left with skills I could use. I am similarly grateful to Dr Trevor S. Barss, Mr Dylan Miller, Mr Alejandro Ley who gave countless hours of hands-on help and teaching and who worked alongside me to design, deliver and analyse the experiments described in this report. Thanks also to postgraduate researchers of the same laboratory, who supported the experiments.

I also wish to thank the volunteers who took part in the experimental study, the administrative staff at the University of Alberta, and the Neuroscience and Mental Health Institute. The vibration stimulation device used in the work was developed with support from the Scottish Funding Council, whom I gratefully acknowledge. Finally, I thank my colleagues at the University of Aberdeen and the University of Hertfordshire for their continuing support of this line of research.

Abbreviations and Glossary

This report deals with neuroscience and biomedical engineering and necessarily uses some specialist terms. The following list defines those used most often, in plain language wherever possible.

CNS — Central Nervous System — the brain and spinal cord.

TMS — Transcranial Magnetic Stimulation — a non-invasive technique that uses a brief magnetic pulse over the scalp to safely activate a small region of the brain, allowing scientists to measure how readily the brain communicates with muscles.

EMG — Electromyography — the recording of the small electrical signals produced when a muscle contracts, picked up by electrodes placed on the skin.

MEP — Motor Evoked Potential — the muscle response that follows a TMS pulse. The size of an MEP indicates how excitable the pathway from brain to muscle is.

H-reflex — Hoffmann reflex — a muscle response evoked by electrically stimulating a sensory nerve. It is widely used as an indirect measure of the excitability of pathways within the spinal cord.

ULV — Upper Limb Vibration — vibration applied to the arm via the hand (e.g. by holding a vibrating handle), as distinct from whole-body vibration applied through the feet.

WBV — Whole-Body Vibration — vibration applied through the feet, typically by standing on a vibrating platform.

FCR — Flexor Carpi Radialis — a forearm muscle that bends the wrist.

Spasticity — Involuntary muscle stiffness and exaggerated reflexes commonly experienced after stroke, spinal cord injury, multiple sclerosis or cerebral palsy. Spasticity makes movement difficult and is a major contributor to disability.

Corticospinal pathway — The neural route from the motor cortex of the brain, down through the spinal cord, to the muscles. Damage to this pathway is the main cause of weakness after stroke or spinal cord injury.

Spinal pathway — Reflex circuits operating within the spinal cord, often without direct involvement of the brain.

Presynaptic inhibition — A specific way the nervous system 'turns down the volume' on incoming sensory signals, before they can excite a motor neuron.

About the Author

I am a biomedical engineer working at the intersection of engineering, neuroscience and clinical rehabilitation. My doctoral research investigated how human skeletal muscle responds to externally applied mechanical vibration when superimposed on voluntary muscle contraction. That work included the design and construction of bespoke vibration devices for laboratory use, and a series of human experiments characterising the effect of vibration parameters (frequency, amplitude, acceleration) on the activity/force a muscle can produce.

At the time of my Churchill Fellowship, I had just finished my PhD and was an early-career researcher seeking to extend my biomedical engineering work into the neuroscience of motor control. I now hold an academic appointment in the United Kingdom where I lead a programme of research on vibration-based interventions for physical rehabilitation and collaborate across UK and international universities and the NHS to translate this research into evidence-based clinical use.

Executive Summary

What was researched

Vibration therapy — the use of controlled mechanical vibration as an exercise or rehabilitation intervention — is increasingly used in UK gyms, physiotherapy clinics and communal settings. Studies have shown that it can increase muscle strength and power in athletes, improve balance in older adults, and reduce some of the effects of conditions such as osteoporosis. However, despite its growing use, the neural mechanisms by which vibration produces these benefits have remained largely unknown. Without that knowledge, researchers and clinicians have no rational basis on which to choose vibration parameters or to identify which patients are most likely to benefit.

My Churchill Fellowship was designed to begin to close that gap. I travelled to the Human Neurophysiology Laboratory at the University of Alberta in Canada, one of the world's leading laboratories for the study of the neural control of human movement, to acquire training in Transcranial Magnetic Stimulation (TMS), a non-invasive technique that allows scientists to measure how readily the brain talks to the muscles. By combining TMS with electrical reflex (H-reflex) techniques and our own purpose-built vibration device, I worked with my host laboratory to design and complete the first experimental study to ask, with the necessary precision, whether and how vibration applied to the upper limb acts on the brain, and on the spinal cord.

Major findings

- **Handheld Vibration applied to the upper limb significantly reduces transmission along reflex pathways within the spinal cord**. H-reflex amplitude was reduced by 15.7%, and middle-latency cutaneous reflexes by 20%.
- **Handheld Vibration does not alter the excitability of the corticospinal pathway** (the pathway from the brain to the muscle). Motor responses to TMS were unchanged.
- **The most likely mechanism is presynaptic inhibition** — vibration appears to dampen incoming sensory signals before they can drive the motor neuron, rather than acting on the brain itself.
- **These findings have direct implications for rehabilitation**. Conditions such as stroke, spinal cord injury, multiple sclerosis and cerebral palsy involve excessive spinal reflex activity (spasticity). Upper limb vibration may be a low-cost, drug-free way of reducing that activity within a rehabilitation session, complementing physiotherapy and other interventions.

The work was published, after peer review, as the lead study in Frontiers in Human Neuroscience in May 2021 (full citation in Appendix A). The paper has been openly available since publication and the underlying data are available on request from the authors.

Headline recommendations

- UK rehabilitation services (NHS, charities and private providers) should explore vibrotactile stimulation as a low-cost, non-pharmacological adjunct to conventional therapy for patients with spasticity following stroke, spinal cord injury or multiple sclerosis.
- UK research funders should support follow-on clinical studies to test these laboratory findings in patient populations and to identify the optimal parameters of vibration (frequency, amplitude, duration) for different conditions.
- Policymakers should consider the potential cost-saving and quality-of-life benefits of evidence-based vibration therapy as part of integrated rehabilitation pathways.

1. Background and UK Context

1.1 Why vibration therapy matters

Mechanical vibration is unusual among rehabilitation interventions. It is non-pharmacological, requires only modest equipment, can be self-administered after appropriate training, and the existing evidence base — though incomplete — points to genuine functional benefits. In sport and exercise, it has been shown to improve muscle power, jump performance and flexibility. In healthy ageing populations, it has been shown to improve balance, reduce fall risk, and contribute to maintenance of bone health. In rehabilitation, there is increasing interest in its use for stroke, spinal cord injury, multiple sclerosis, cerebral palsy and a range of other conditions involving impaired motor control.

The use of vibration in the UK is therefore growing — but the science underneath it has not kept pace. Most clinical guidance on dose, frequency and amplitude is derived from anecdote, manufacturer recommendations or extrapolation from animal work. There has been no consensus on what part of the nervous system is being affected, and that uncertainty has held back rational design of vibration-based interventions.

1.2 The UK rehabilitation challenge

The UK faces a substantial and growing rehabilitation burden. According to the Stroke Association, there are around 1.3 million stroke survivors living in the UK; the Multiple Sclerosis Society estimates that more than 130,000 people in the UK live with MS; and many thousands more live with the consequences of spinal cord injury, traumatic brain injury and cerebral palsy. A common feature across many of these conditions is spasticity — involuntary muscle stiffness and over-active reflexes — which makes everyday movement difficult, contributes to pain and contractures, and is a leading cause of long-term disability.

Pharmacological treatments for spasticity (oral medications, botulinum toxin injections, intrathecal baclofen pumps) carry side-effects and significant cost. Physiotherapy is effective but constrained by the availability of trained staff and clinic time. There is therefore a clear UK case for low-cost, non-drug interventions that can either reduce spasticity within rehabilitation sessions or amplify the effect of conventional physiotherapy. If vibration can be shown to do this safely and reproducibly, it represents an opportunity for the NHS and the wider rehabilitation sector.

1.3 The scientific gap addressed by this Fellowship

Before this Fellowship, only one published study had attempted to use neurophysiological techniques to characterise the effects of indirect upper-limb vibration on the human nervous system, and that study could not separate effects at the level of the spinal cord from effects at the level of the brain. The remaining literature concerned whole-body vibration (delivered through the feet) and produced inconsistent results across muscles and time points. There was, in short, no clear answer to the question: when a person holds a vibrating object in their hand, what is happening inside their nervous system?

Answering that question requires the combined use of techniques that can probe different levels of the nervous system at the same time. TMS can probe the excitability of the brain-to-muscle (corticospinal) pathway. Electrical stimulation of peripheral sensory nerves can be used to probe the excitability of spinal reflex circuits. Surface EMG can record the muscle's response to either. The Human Neurophysiology Laboratory at the University of Alberta is one of the few laboratories in the world where all of these techniques are used routinely, in concert, to dissect motor control. That is why I chose it as my Fellowship host.

2. Aims and Objectives of the Fellowship

My Fellowship had one primary objective and three closely linked secondary objectives, all set out in my original application.

2.1 Primary objective

To acquire training in the use of Transcranial Magnetic Stimulation (TMS) as a tool for non-invasive neurophysiological investigation, in particular as it can be combined with vibration stimulation to study the central nervous system's role in producing the responses to vibration therapy.

2.2 Secondary objectives

1. To contribute to ongoing neurophysiological research at the host laboratory, applying my skills in biomedical engineering, software programming and signal processing to projects beyond my own.
2. To plan and, where possible, to begin a substantive collaborative experiment using TMS to investigate the effects of upper limb vibration on the human nervous system.
3. To establish a longer-term research collaboration with the host laboratory, with the goal of pursuing further joint research projects and grant applications after the Fellowship period.

The aims and objectives of the Fellowship were therefore concerned not just with the acquisition of a new technique, but with the way that technique could be used to address a real and unanswered question. As detailed in the Findings section that follows, all four objectives were met.

3. Purpose of this Report

This report has three purposes. The first is to summarise, for a non-specialist reader, what was learned during my Fellowship and what it means for rehabilitation in the UK. The second is to translate the scientific findings of the peer-reviewed publication that arose from the Fellowship into a form that is useful to clinicians, commissioners, charities, manufacturers and other stakeholders who do not routinely read neuroscience journals. The third is to set out the next steps I believe should follow, and to invite the people who can help make those next steps happen to get in touch.

This report is intended to inform and to start a conversation. It is not a comprehensive scientific account; readers who require that should refer to the peer-reviewed publication listed in Appendix A.

4. Approach: The Fellowship Visit

4.1 Host institution and laboratory

The Fellowship was hosted by Professor David F. Collins at the Human Neurophysiology Laboratory, Faculty of Kinesiology, Sport, and Recreation, at the University of Alberta in Edmonton, Canada. Professor Collins is internationally recognised for his work on the neural control of human movement, with particular expertise in how sensory feedback contributes to movement control and the use of electrical stimulation to generate muscle contractions. The laboratory is part of the University's Neuroscience and Mental Health Institute and has access to state-of-the-art TMS, electrical stimulation, EMG and neuro-navigation equipment.

4.2 Duration and structure

The Fellowship was undertaken over a two-month period. The work was structured in three overlapping phases:

4. **Weeks 1–2: Foundations.** Reading, lab tutorials and observation. Understanding the theory, neurophysiological underpinnings, advantages and limitations of TMS; learning the safety screening procedures; observing experiments being run by other members of the laboratory.
5. **Weeks 3–6: Experimental work.** Hands-on TMS practice; design of the upper-limb vibration experiment; integration of my purpose-built vibration device into the laboratory's experimental rig; participant recruitment and screening; collection of data from the full participant cohort; ongoing involvement in other neurophysiological projects to which I contributed software and signal-processing expertise.
6. **Weeks 7–8: Analysis and forward planning.** Initial data analysis; review of the experiment as a whole; design of follow-on experiments; agreement of a longer-term collaboration plan with the host laboratory; outline of the manuscript that would later be published in Frontiers in Human Neuroscience.

4.3 The experimental study

The principal experiment carried out during the Fellowship was a single-session, within-subject study of 14 neurologically intact adult volunteers (10 male, 4 female; mean age 29 years). Each volunteer attended once and completed all measures under two conditions: a control condition with no vibration, and a vibration condition in which the participant held a custom-built vibration device with the right hand. The vibration was delivered at 30 Hz with a displacement amplitude of approximately 0.4 mm. Throughout both conditions, the participant maintained a small (~10% maximum) voluntary contraction of the wrist flexor muscle, with body and arm position held constant by restraints, to ensure that any change observed could be attributed to vibration rather than to position or effort.

Three classes of measurement were taken from the right forearm under each condition:

- **H-reflexes (with and without conditioning)** evoked by electrical stimulation of the median nerve, to probe the excitability of spinal reflex pathways and the degree of presynaptic inhibition acting on them.
- **Cutaneous reflexes** evoked by electrical stimulation of the superficial radial nerve, to probe how sensory information from the skin is integrated by the spinal cord.
- **Motor evoked potentials (MEPs)** elicited by Transcranial Magnetic Stimulation of the motor cortex, to probe the excitability of the corticospinal pathway from brain to muscle.

This combination is the key methodological contribution of the work. By comparing the size of H-reflexes and MEPs under identical conditions of vibration and no-vibration, while controlling for descending drive and body position, it becomes possible to localise the effects of vibration to a specific level of the nervous system. The TMS and reflexes training I had received during the first weeks of the Fellowship was central to making this possible.

5. Findings

This section presents the findings of my Fellowship under seven themes. The first two cover what I learned and how the work was framed; the next three cover the scientific results; the last two cover the wider implications for the UK and for the way research in this area is done.

5.1 Acquiring TMS as a Neurophysiological Investigation Tool

The single most important deliverable of the Fellowship, from my perspective as a researcher, was acquiring competence in Transcranial Magnetic Stimulation. TMS is a remarkable technique. A current is passed briefly through a coil held over the scalp, generating a magnetic field that, in turn, induces a current in the brain tissue immediately below. With careful positioning, this safely activates a small region of the motor cortex; the resulting muscle response, recorded with surface EMG, can be used to estimate how excitable the path from brain to muscle is. By varying the timing of the pulse relative to other inputs (sensory stimuli, voluntary contractions, paired pulses), TMS can also be used to dissect specific inhibitory and excitatory circuits within the cortex itself.

Acquiring competence is not a matter of being shown a button. It involves: understanding the underlying physics and physiology; learning to identify the optimal scalp location for activating a specific muscle in a given individual; learning to use neuro-navigation systems to maintain accurate coil placement throughout an experiment; understanding how to set stimulation intensity in a way that allows subsequent inhibition or facilitation to be detected; and, perhaps most importantly, understanding the safety screening procedures that must be applied to every participant before TMS is delivered. Two months under expert supervision is a realistic minimum for becoming a competent independent user, and that is what the Fellowship made possible.

UK relevance: TMS is used in a small but growing number of UK laboratories and clinical centres, principally for research and for the treatment of treatment-resistant depression. Its potential as a research tool in rehabilitation, however, remains under-exploited. The skills acquired during this Fellowship are now being applied to UK research and form part of the training I am able to offer my own postgraduate students.

5.2 Designing an Experiment to Distinguish Spinal from Corticospinal Effects

The conceptual contribution of the Fellowship — and the heart of the resulting publication — is the experimental design that makes it possible to ask, in a single sitting, whether vibration is acting on the brain, on the spinal cord, or both. Before the Fellowship, this question had not been answered for upper limb vibration.

The design rests on a chain of reasoning. If vibration changed the excitability of the brain (or the brain-to-muscle pathway), the muscle response to a TMS pulse should change. If vibration changed the excitability of the spinal cord, the muscle response to electrical stimulation of a sensory nerve (the H-reflex) should change. By comparing these two responses under identical conditions of body position, voluntary effort and descending drive, with and without vibration, the level at which vibration acts can be inferred.

To strengthen the inference, the design also included an H-reflex conditioning paradigm, in which a brief train of pulses is delivered to a sensory nerve in the skin shortly before the H-reflex is evoked. This conditioning paradigm is known to reduce presynaptic inhibition and so to increase the size of the H-reflex; by checking whether vibration interacts with this conditioning effect, additional information can be obtained about whether the action of vibration is presynaptic (acting on incoming sensory signals before they reach the motor neuron) or postsynaptic (acting at the motor neuron itself).

UK relevance: The same experimental design can be adapted to other rehabilitation interventions used in the UK whose mechanisms are imperfectly understood. There is in principle no reason why this approach could not be used to study the neural effects of, for example, robotic rehabilitation, functional electrical stimulation, or specific physiotherapy techniques. Wider use of this kind of multi-level neurophysiological design in UK rehabilitation research would provide a much firmer mechanistic basis for clinical practice.

5.3 Vibration Inhibits Spinal Reflex Pathways

The central scientific result of the Fellowship is straightforward to state. When participants held a vibrating handle, the size of the H-reflex measured in the wrist flexor muscle was reduced by 15.7% relative to the no-vibration condition. This reduction was statistically significant, was present in both conditioned and unconditioned reflexes, and could not be accounted for by any change in voluntary effort, body position or the size of the directly evoked muscle response (M-wave) — all of which were monitored and held constant.

In parallel, the middle-latency component of the cutaneous reflex (a different reflex pathway, evoked by stimulating the skin) was also significantly more inhibited during vibration than during the control condition — by 20%. The early- and late-latency components of the cutaneous reflex were unchanged.

The scientific interpretation is that vibration applied to the upper limb produces a generalised reduction in the excitability of reflex pathways within the spinal cord. This is consistent with what has previously been reported for whole-body vibration in the lower limbs, and with the very limited prior data on upper limb vibration. What was not previously known, and what this Fellowship established, is that the effect is reliable, reproducible, and detectable using standard neurophysiological techniques.

Why this matters: Excessive spinal reflex activity is the defining feature of spasticity. If vibration reliably reduces that activity, it has the potential to reduce spasticity. The remainder of this report explores the implications of that potential.

5.4 Handheld Vibration Does Not Alter Corticospinal Excitability

The second scientific result is, in some ways, equally important. Despite earlier suggestions in the literature that whole-body vibration can alter the excitability of the brain-to-muscle pathway, we found no significant change in the size of motor evoked potentials (recorded from either the wrist

flexor or the biceps muscle) during upper limb vibration. The corticospinal pathway, in our hands and using the parameters of vibration we delivered, was unchanged.

This is a useful negative result for two reasons. First, it tells us that the inhibition of reflexes seen in the previous section is not simply a downstream consequence of the brain becoming less active; the effect must be occurring at the level of the spinal cord or below. Second, it suggests that vibration, applied in this way, is unlikely to interfere with the brain's ability to drive voluntary movement — an important consideration for any intervention intended to be combined with active rehabilitation.

It is important to be honest about what we cannot conclude. The vibration device used in this Fellowship had a maximum displacement amplitude of approximately 0.4 mm. It remains possible that larger amplitudes, or different frequencies, or longer exposure times, might produce changes in corticospinal excitability that we did not detect. This is itself a question to be addressed in further work.

5.5 The Likely Mechanism: Presynaptic Inhibition

Putting the H-reflex, cutaneous reflex and TMS results together, the most plausible mechanism by which upper limb vibration produces its effects is an increase in presynaptic inhibition acting on incoming sensory signals — in particular on the signals carried by Ia afferents from the muscle spindles. In simpler terms: vibration appears to turn down the volume on incoming sensory information before it has the chance to drive the motor neurons of the spinal cord.

This interpretation is consistent with the conditioning paradigm results, with the absence of any change in directly evoked motor responses, and with the absence of any change in corticospinal excitability. It is also consistent with what is known about the effects of direct vibration applied to muscle or tendon — though in that case, the effects are large, while the effects of indirect vibration through the hand are smaller, more diffuse, and last for the duration of the vibration.

Why this matters: Identifying the mechanism is what allows vibration to move from a folk-remedy intervention to a rationally designed clinical tool. It allows clinicians to predict who is likely to benefit (people whose deficit involves excessive spinal reflex activity), to predict what side-effects to look out for (changes in proprioception or sensory feedback), and to design dose-response studies that can compare vibration with — or combine it with — established interventions.

5.6 Clinical and Rehabilitation Implications for the UK

Although the experimental study was carried out in neurologically intact young adults, the implications of the findings are clearest for people with conditions involving spasticity. Three groups in the UK stand to benefit most directly:

Stroke survivors

Up to two-thirds of stroke survivors experience some degree of spasticity in the months and years after their stroke, and the upper limb is most commonly affected. Spasticity in the wrist and finger flexors makes hand opening difficult, interferes with the use of the hand for activities of daily living,

and is a major contributor to long-term disability. The Fellowship's findings raise the realistic prospect that holding a vibrating handle for a period of minutes — at home or in clinic, between physiotherapy sessions, or as a warm-up to physiotherapy — could acutely reduce spasticity and so allow more functional movement during the therapeutic window.

People living with spinal cord injury

Many people with cervical spinal cord injury experience upper limb spasticity that interferes with hand function, transfers, and use of assistive technology. Pharmacological treatments are the current mainstay but carry side effects. A non-pharmacological adjunct that the individual can self-administer would be of considerable value.

People with multiple sclerosis

Spasticity is a near-universal feature of MS and a major cause of fatigue, pain and disability. It often fluctuates with heat, fatigue and stress, and individuals frequently report needing strategies they can apply themselves to manage it. Upper limb vibration, if shown to be effective in MS, would fit this requirement well.

Other groups

People with cerebral palsy, traumatic brain injury, and a range of less common spastic movement disorders may also benefit; further work in each of these populations is justified by the present findings.

Implementation: opportunities and challenges

The opportunities for implementation in the UK are substantial. Vibration devices are less expensive relative to most rehabilitation technology. The intervention can be self-administered after appropriate training. There is no need for the patient to attend a specialist centre. The treatment can be combined with conventional physiotherapy without disrupting it.

The challenges are equally real and worth being explicit about. The clinical evidence base is still small and consists mostly of laboratory studies in healthy volunteers and pilot clinical trials. Different vibration devices on the UK market deliver very different doses, and most are designed for the consumer fitness market rather than for clinical use. There is at present no UK clinical guideline that addresses upper limb vibration specifically. Robust, multi-centre clinical trials in defined patient populations are required before vibration therapy can move from laboratory promise to standard NHS practice.

5.7 Lessons in Interdisciplinary Collaboration

A less tangible but equally valuable finding from the Fellowship concerns how interdisciplinary research is best done. The work described in this report could not have been carried out by an engineer alone, by a neuroscientist alone, or by a clinician alone. It required the engineer's design and instrumentation skills, the neurophysiologist's experimental and theoretical sophistication, and the

clinical understanding of why the question matters. The host laboratory was effective because it had built habits of close collaboration across these disciplines over many years.

UK research culture is increasingly supportive of interdisciplinary working, but it remains the case that funding structures, departmental boundaries and career-progression criteria can make sustained engineering–neuroscience–clinical collaboration harder than it should be. The Fellowship has reinforced for me how important it is to invest in the long-term relationships, the shared infrastructure, and the cross-disciplinary postdoctoral training that make this kind of work possible.

6. Conclusion

My Churchill Fellowship set out to acquire training in Transcranial Magnetic Stimulation as a tool for investigating how the central nervous system responds to externally applied vibration, and to use that training to address a question that the existing literature could not answer: when a person holds a vibrating object in their hand, what is happening inside their nervous system?

Both objectives were met. Two months at the Human Neurophysiology Laboratory at the University of Alberta gave me the technical and conceptual training I needed to use TMS and study reflex activity, independently and competently in subsequent work. The collaborative experiment we designed and delivered during the Fellowship has shown, for the first time, that upper limb vibration produces a reliable and significant inhibition of spinal reflex pathways, without altering the excitability of the corticospinal pathway from the brain. The most likely mechanism is increased presynaptic inhibition acting on incoming sensory signals.

These findings were peer-reviewed and published in 2021 in Frontiers in Human Neuroscience [1], and they form the mechanistic foundation for a programme of follow-on research aimed at translating vibration therapy from laboratory promise to clinical reality. The clearest beneficiaries of that programme are people in the UK living with spasticity following stroke, spinal cord injury, multiple sclerosis or cerebral palsy — populations for whom a low-cost, drug-free, self-administered intervention that reduces spasticity would be of substantial value.

The Fellowship has also done what the Trust intended it to do: it has built a sustained relationship with a world-leading laboratory that continues to influence my UK-based research and that of my collaborators. The benefit of the Fellowship to the UK is therefore not limited to the single experiment described above; it extends to ongoing exchanges of ideas, of staff and students, and of joint funding bids.

7. Recommendations

The recommendations that follow are addressed to specific groups within the UK who are best placed to act on the findings of this Fellowship. They are listed in approximate order of immediacy.

7.1 To UK rehabilitation services and clinicians

Consider Upper Limb Vibration as a low-cost, non-pharmacological adjunct to conventional therapy for patients with upper limb spasticity following stroke, spinal cord injury or multiple sclerosis. The evidence base is at an early stage but is growing; clinicians who wish to begin using vibration in this way should do so as part of an audit or service-evaluation framework so that experience can be aggregated across services.

Who is involved: physiotherapists, occupational therapists, rehabilitation physicians, the Royal College of Physicians (Stroke and Rehabilitation faculties), the Chartered Society of Physiotherapy, the Royal College of Occupational Therapists. **What is needed:** shared protocols, simple outcome measures, and a willingness to share experience across centres. **The benefits:** potentially better functional outcomes for patients, reduced reliance on medication, lower long-term cost.

7.2 To UK research funders

Support follow-on clinical studies that test the laboratory findings of this Fellowship in defined patient populations, and that identify the optimal parameters of vibration (frequency, amplitude, duration, and combination with active therapy) for each condition. Particular value would come from multi-centre, well-powered randomised controlled trials in stroke, multiple sclerosis, cerebral palsy and spinal injury.

Who is involved: the National Institute for Health and Care Research (NIHR), the Medical Research Council (MRC), the Stroke Association, the MS Society, Spinal Research, the Engineering and Physical Sciences Research Council (EPSRC) for the engineering components. **What is needed:** calls that explicitly support the bridge between mechanistic neurophysiology and clinical trial. **The benefits:** translation of UK research strength in motor neuroscience into clinical practice in UK rehabilitation services.

7.3 To UK universities and research institutions

Invest in the cross-disciplinary capacity that makes this kind of work possible: shared engineering–neuroscience–clinical PhD studentships, joint appointments between engineering and rehabilitation departments, and access to TMS and electrical stimulation equipment beyond the small number of laboratories that currently host them. UK universities should also support early-career researchers' travel for substantive technique-acquisition visits, recognising the long-term return on such investments.

Who is involved: Pro-Vice-Chancellors for Research, heads of school, doctoral training programmes, university research-equipment funding panels. **What is needed:** long-term commitment, not one-off

gestures. **The benefits:** a stronger UK pipeline of engineer-neuroscientists capable of leading translational research.

7.4 To UK manufacturers and standards bodies

Work with researchers and clinicians to develop standardised, evidence-based vibration devices intended for clinical use, with characterised dose, validated safety profile, and consistent build quality. The current marketplace is dominated by consumer fitness products of widely varying quality. A clinically validated UK-made device would have export potential as well as direct NHS application.

Who is involved: medical-device manufacturers, the British Standards Institution, the Medicines and Healthcare products Regulatory Agency (MHRA), Innovate UK. **What is needed:** early engagement between researchers and manufacturers; co-design of devices to clinical specifications; clear regulatory pathway. **The benefits:** UK industrial leadership in evidence-based rehabilitation technology.

7.5 To UK policymakers and commissioners

Consider the cost-saving and quality-of-life benefits of evidence-based vibration therapy as part of integrated rehabilitation pathways. As the evidence base matures, vibration therapy may merit inclusion in NICE guidelines for the management of spasticity and in long-term-condition rehabilitation pathways.

Who is involved: the National Institute for Health and Care Excellence (NICE), Integrated Care Boards, the Department of Health and Social Care, devolved administrations. **What is needed:** willingness to consider non-pharmacological, technology-light interventions on the same evidential terms as drugs. **The benefits:** improved patient outcomes, reduced medication burden, potential cost savings to the NHS over the long term.

8. Next Steps

The Fellowship has not closed a question; it has opened one. The work I am taking forward, with collaborators in the UK and beyond, includes the following:

7. **Dose-response studies.** We need to know how the size of the spinal inhibitory effect changes with vibration frequency, amplitude and duration. Some of this work has already been initiated and published in 2019 [2, 3], and further studies are planned, with foundation grounded in my PhD work [4, 5, 6].
8. **Patient studies.** The most important single next step is a programme of well-designed studies in patient populations. The first targets are likely to be people with stroke, cerebral palsy multiple sclerosis and spinal injury. Some of this work has already been initiated, in stroke [7], cerebral palsy [8, 9], spinal injury (review) [10]. I am actively pursuing collaborations with UK and international clinical centres and patient organisations to make these studies possible.
9. **Mechanism studies.** Further mechanistic work is needed to confirm presynaptic inhibition as the principal mechanism, to test for postsynaptic contributions, and to investigate whether longer or repeated exposure to vibration produces lasting (plastic) changes in spinal circuits. Such changes would substantially strengthen the case for vibration as a rehabilitation tool.
10. **Device development.** I continue to develop, characterise and refine vibration stimulation devices. Building on this work, we have completed wearable vibration device design in the lab [11] and co-design this device with stroke patients [12], in collaboration with industrial and clinical partners.
11. **Engagement and dissemination.** I will continue to share these findings with clinicians, charities, patient groups and policymakers across the UK. I welcome contact from anyone working in this area or interested in collaboration; my contact details are on the inside cover of this report. Engagement with UK and international, clinicians [13] and researchers [14] has already led to growing collaborative work in neurorehabilitation.

How the Churchill Fellowship can help: I would particularly welcome the Trust's support in connecting me with other Fellows working in rehabilitation, neuroscience or medical device development, and with the Trust's networks among UK funders and policymakers. I am also keen to contribute to the Trust's wider activities and Fellow alumni programme as opportunities arise.

Appendix A — Peer-reviewed publication arising from the Fellowship and References

The principal scientific output of this Fellowship is the following peer-reviewed publication, which is open-access and free to read in full at the URL given:

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Appendix B — Host institution and mentor

Host Mentor: Professor David F. Collins

Laboratory: Human Neurophysiology Laboratory

Faculty: Faculty of Kinesiology, Sport, and Recreation

Institute: Neuroscience and Mental Health Institute

University: University of Alberta

Location: Edmonton, Alberta, Canada

The Human Neurophysiology Laboratory at the University of Alberta is internationally recognised for its research on the neural control of human movement, with particular expertise in the interaction between sensory feedback, electrical stimulation and voluntary movement. It hosts state-of-the-art equipment for Transcranial Magnetic Stimulation, neuromuscular electrical stimulation, surface electromyography, and is a member of the University's Neuroscience and Mental Health Institute.