INDICE DE TRABAJOS WBV - GALILEO

PAIS	AUTOR	CENTRO	TÍTULO - PUBLICACIÓN
Alemania	M.Runge, G.Rehfeld, E.Resnicek	Aerpah-Klinik Esslingen.	BALANCE TRAINING AND EXERCISE IN GERIATRIC PATIENTS.
			Publicación: J.Musculosket Interact 200; I:54-58.
Alemania	H.Schiessl, J.Willnecker	Stratec Medizintechnik.	NEW INSIGHTS ABOUT THE RELATIONSHIP BETWEEN BONE STRENGTH AND MUSCLE STRENGTH.
Alemania	W.Helmut	Dpto.Internal Med. And Endocrinology, Cl.Der Furstenhof – Pyrmont.	TECHNICAL DEVICES.
Alemania	J.Mester, P.Spltzenfell, J.Schwarzer, F.Selfriz	Inst.for Theory and Practice of Training and Movement, German Sport Univ.- Cologne – Germany.	BIOLOGICAL REACTION TO VIBRATION – IMPLICATINS FOR SPORT
			Publicación: Journal of Science and Medicine in Sport 2 (3) – 211-226 (1999)
Alemania	J.Rittweger, G.Beller and D.Felsenberg.	Inst.Physiology, Univ.Berlin Univ.Hosp.Benjamin Franklin,Hindenburgdamm, Berlin.	ACUTE PHYSIOLOGICAL EFFECTS OF EXHAUSTIVE WHOLE-BODY VIBRATION EXERCISE IN MAN.
			Publicación: Clinical Physiology 20, nº2 (134-142) – 2000.
Alemania	K.Isar, M.Hartard, C.Kleinmond, C.Lammel, H.Schiessl, D.Jeschke.	Klinikum re.d.Isar- Techn.Univ.Munchen and Dpt.Preventive and Rehab. Sports Medicine (Stratec/Novotec), Germany	RECOVERY EFFECTS OF GALILEO 2000: A NEW DEVICE FOR TRAINING INTERVENTIONS.
Alemania	M.Hartard, D.Hom, P.Bartenstein, H.Schiessl.	Klinikum re.d.Isar- Techn.Univ.Munchen and Dpt.Preventive and Rehab. Sports Medicine (Stratec/Novotec), Germany	CORRELATION OF STRENGTH STRAIN INDEX (SSI) AND TORQUE IN UPPER LIMBS.
Alemania	S.Haring, H.Hartard, M.Schiessl, P.Bartensteir, H.Schiessl, D.Jeschike.	Klinikum re.d.Isar- Techn.Univ.Munchen and Dpt.Preventive and Rehab. Sports Medicine (Stratec/Novotec), Germany	LONG TERM EFFECTS OF GALILEO 2000 – A NEW TRAINING DEVICE.

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PAIS	AUTOR	CENTRO	TÍTULO - PUBLICACIÓN
Alemania	J.Rittweger	Instituo de Fisiología de la Univ. Libre de Berlín	MECANISMOS FISIOLOGICOS DEL EJERCICIO POR VIBRACIONES
Alemania	P.Spitzenpfeil, J.Schwarzer, M.Fiala, J.Mester	Inst.Theory and Practice of Training and Movement, German Sport Univ. Cologne.	STRENGTH TRAINING WITH WHOLE BODY VIBRATIONS – SINGLE CASE STUDIES AND TIME SERIES ANALYSES. Publicación: 4th Annual Congress of the European College of Sport Science - Porters – Turn II, Biology. (1999).
Alemania	S.Von der Heide, R.Hilgers, G.Emons, V.Viereck	Georg-August-Univ. Goettingen, Dpto.Gynecol.and Obstetrics.	EFFECT ON MUSCLES OF MECHANICAL VIBRATIONS PRODUCED BY THE GALILEO 2000 IN COMBINATION WITH PHYSICAL THERAPY IN TREATING FEMALE STRESS URINARY INCONTINENCE. Publicación: Intern.Continence Society 33rd Annual Meeting – Florence (Oct-03)
Alemania	J.Rittweger, H.Schiessl and D.Felsenberg.	Inst.Physiology, Univ.Berlin Univ.Hosp.Benjamin Franklin,Hindenburgdamm, Berlin. Novotec Maschinen.	TOMA DE OXIGENO DURANTE EL EJERCICIO DE VIBRACION CORPORAL INTEGRAL: COMPARACION MEDIANTE UNA SENTADILLA COMO UN MOVIMIENTO VOLUNTARIO LENTO. Publicación: European Journal of Applied Physiology – (2001) 86, 169-173.
Alemania	J.Rittweger, M.Mutschelknauss and D.Felsenberg.	Inst.Physiology, Univ.Berlin Univ.Hosp.Benjamin Franklin,Hindenburgdamm, Berlin. Novotec Maschinen.	ACUTE CHANGES IN NEUROMUSCULAR EXCITABILITY AFTER EXHAUSTIVE WHOLE BODY VIBRATION EXERCISE AS COMPARED TO EXHAUSTION BY SQUATTING EXERCISE. Publicación: Clin Physiol & Func.Im (Vol 23 - pp 81-86 – 2003)
Alemania	J.Rittweger, J.Ehrig, K.Just, M.Mutschelknauss, K.A.Kirsch, D.Felsenberg.	Inst.Physuikiguem-Freie Univ.Berlin.-C.Muscle and Bone Research, Univ.Hosp.Benjamin Franklin.	OXYGEN UPTAKE IN WHOLE-BODY VIBRATION EXERCISE: INFLUENCE OF VIBRATION FREQUENCY, AMPLITUDE, AND EXTERNAL LOAD. Publicación: Sport Med. 2002. (Vol 23 – 428-432).

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PAIS	AUTOR	CENTRO	TÍTULO - PUBLICACIÓN
Alemania	J.Rittweger, K.Just, K.A.Kirsch, P.Reeg and D.Felsenberg.	Inst.Physuikiguem-Freie Univ.Berlin.- Orthop. Rückentherap. Berlin.- Cl. Anasthesiologie-Praxis and C.Muscle and Bone Reserarch. Univ.Hosp.Benjamin Franklin.	TRATAMIENTO DE DOLOR CRONICO DE ESPALDA BAJA CON EXTENSIONES LUMBARES Y EJERCICIO DE VIBRACION CORPORAL INTEGRAL. ENSAYO CONTROLADO Y RANDOMIZADO.
			Publicación: SPINE (Vol. 27 – Nº 17 pp 1829-1834).
Alemania	S.Dietman, H.Christian	Inst. Sport Sciences – Univ. Of Frankfurt.	MECHANICAL STIMULATION IN NEUROMUSCULAR DISEASES.
U.S.A.	JG.Gianutsos, LC Oakes, N.Prufer, V.Kramskii, EF Richter III and M.Hutchinson.	Dpto.Rehabilitation Medicine, Dpto. Neurology and New York Univ.School of Med.	USE OF A THERAPEUTIC RANGING/EXERCISE PROGRAM IN THE REHABILITATION OF A PERSON EITH PROGRESSIVE SUPRANUCLEAR PALSY.
U.S.A.	JG.Gianutsos, JH.Ahn, LC Oakes, EF.Richter III, BB.Grynbaum, HG Thistle.	Dpto.Rehabilitation Medicina, New York Univ.School of Medicina.	THE EFFECTS OF WHOLE BODY VIBRATION ON REFLEX-INDUCED STANDING IN PERSONS WITH CHRONIC AND ACUTE SPINAL CORD INJURY.
U.S.A.	H.Schiessl, M.Frost, S.S.Jee.	Stratec Medizintechnik, Dpto. Orthopaedie Surgery – Colorado and Div. of Radiobiology – Univ.Utah.Salt Lake	ESTROGEN AND BONE-MUSCLE STRENGTH AND MASS RELATIONSHIPS.
			Publicación: Bone Vol.22 No.1 – January 1998.
U.S.A.	KJ.McLeord, CT Rubin.	Biomedical Engineering Univ. New York.	BRIEF EXPOSURE TO LOW LEVEL, HIGH FREQUENCY MECHANICAL LOADING REDUCES POSTURAL INSTABILITY.
U.S.A.	C.Rubin, M.Pope, JC.Frittonm, M.Magnusson, T.Hansson, K.McLeord.	Biomedical Engineering Univ. New York.	TRANSMISIBILIDAD DE VIBRACIONES DE 15-HERTZ A 35 HERTZ A LA CADERA HUMANA Y COLUMNA LUBAR: DETERMINANDO LA POSIBILIDAD FISIOLOGICA DE PROPORCIONAR ESTIMULOS MECÁNICOS ANABÓLICOS DE BAJO NIVEL A LAS REGIONES DEL ESQUELETO CON UN MUY ALTO RIESGO DE FRACTURA DEBIDO A LA OSTEOPOROSIS.
			Publicación: SPINE. (Vol.28, Nº23 pp 2621-2627).

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U.S.A.	C.Rubin, R.Recker, D.Cullen, J.Ryaby, J.McCabe, K.McLeord.	Biomedical Engineering Univ. New York..	PREVENCION DE PERDIDA OSEA POSMENOPAUSICA POR ESTIMULOS MECANICOS DE ALTA FRECUENCIA Y BAJA MAGNITUD: ENSAYO CLINICO EVALUANDO CUMPLIMIENTO, EFICACIA Y SEGURIDAD.
			Publicación: Journal of Bone and Mineral Research. (Vol.19, Nº13, 2004).
U.S.A. Bélgica	Y.Jiang, J.Zhao, C.Rosen, P.Geusens, HK.Genant.	Osteop.Arthritis Research Group-Dpto. Radiol.- Univ.California. Maine C. for Osteop. Research and Education - St. Joseph Hosp. Bangor and Cl. Research C. For bone and J. Diseases - Belgium	PERSPECTIVES ON BONE MECHANICAL PROPERTIES AND ADAPTIVE RESPONSE TO MECHANICAL CHALLENGE.
			Publicación: Journal of Clinical Densitometry. Vol.2 Nº 4, (423-433)-1999.
Belgica	O.Bruyere, M.A. Wuidart.	Univ.of Liege- Belgium. And American College of Rheumatology, Orland-Fl.	VIBRATION THERAPY IMPROVES WALK, BALANCE IN ELDERLY.
			Publicación: 2003 Meeting; October 23-28; Abstract 1271.
Belgica	O.Bruyere, M.A. Wuidart, E.Di Palma, J-Y.Reginster.	Univ.of Liego – Belgium, C.P.Health Aspects of Osteoarticular and Haute Ecole A.Vésale.	CONTROLLED WHOLE BODY VIBRATIONS IMPROVE HEALTH RELATED QUALITY OF LIFE IN ELDERLY PATIENTS.
Belgica	O.Bruyere, M.A. Wuidart, E.Di Palma, M.Gourlay, O.Ethgen, F.Richy, JY.Reginster.	Univ.of Liego – Belgium, C.P.Health Aspects of Osteoarticular and Haute Ecole A.Vésale.	CONTROLLED WHOLE BODY VIBRATION TO DECREASE FALL RISK AND IMPROVE HEALTH-RELATED QUALITY OF LIFE OF NURSING HOME RESIDENTS.
			Publicación: Arch. Med. Rehábil. 2005-Feb; 86 (2):303-7
U.S.A.	A-J. Neusy.	Cl. Medicine New York Univ. School of Medicine.	THE GALILEO SYSTEM.
Italia Finlandia Estonia	C.Bosco, R.Colli, E.Introini, M.Cardinale, M.Iacovelli, J.Tihanyi, SP.Von Duvillard, A.Viru.	Univ.Rome, Dpto.Biology of Physical Activity – Univ.of Jywaskyla, Dpto.Biomechanics – Hungarian Univ. Of Physical Education.- Univ. Dakota and Inst. Exercise Biology - Univ.Tartu-Estonia.	ADAPTIVE RESPONSES OF HUMAN SKELETAL MUSCLE TO VIBRATION EXPOSURE.
Italia Estonia Hungria	C.Bosco, R.Colli, M.Cardinale, J.Tihanyi, SP.Von Duvillard, A.Viru.	Univ.Rome, Dpto.Biology of Physical Activity – Univ.of Jywaskyla, Dpto.Biomechanics – Hungarian Univ. of Physical Education, Dpto.HPER - Univ. Dakota and Inst. Exercise Biology - Univ.Tartu-Estonia.	THE INFLUENCE OF WHOLE BODY VIBRATION ON THE MECHANICAL BEHAVIOUR OF SKELETAL MUSCLE.

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Italia Estonia Hungria	C.Bosco, R.Colli, M.Cardinale, J.Tihanyi, SP.Von Duvillard, A.Viru.	Univ.Rome, Dpto.Biology of Physical Activity – Univ.of Jywaskyla, Dpto.Biomechanics – Hungarian Univ. of Physical Education, Dpto.HPER - Univ. Dakota and Inst. Exercise Biology - Univ.Tartu-Estonia.	THE INFLUENCE OF WHOLE BODY VIBRATION ON THE MECHANICAL BEHAVIOUR OF SKELETAL MUSCLE.
Italia Estonia Hungria	C.Bosco, M.Iacovelli, O.Tsarpela, M.Cardinale, M.Bonifazi, J.Tihanyi, M.Viru, A.De Lorenzo, A.Viru.	Soc.Stampa Sportiva, Rome- Univ. de Roma Tor-Vergata- C.for Study and Research of the Italian Track and Field Assoc.- FIDAL, Rome- Fed.Ital.Pugilistic.- Dpto.Of Biomechanic, Hungarian Univ. Physical Education, Budapest-Hungary- Univ.Roma, La Spienza- Inst,Fis.Umana, Univ.degli Studi di Siena- Inst.of Exercise Biology, Univ.Tartu, Estonia.	RESPUESTAS HORMONALES A LA VIBRACION CORPORAL INTEGRAL EN LOS HOMBRES. Publicación: Eur J.Appl. Physiol (2000), 81 (449-454).
Italia	C.Bosco, M.Cardinale	Univ.Rome, Dpto.Biology of Physical Activity – Univ.of Jywaskyla, Dpto.Biomechanics – Hungarian Univ. of Physucal Education, Hosp.Spinal Unit – Rome.	THE INFLUENCE OF VIBRATION ON ARM FLEXORS MECHANICAL POWER AND EMG ACTIVITY OF BICEPS BRACHII.
Italia	C.Bosco, R.Colli, M.Cardinale, O.Tsarpela, M.Bonifazi.	Univ.Rome, Dpto.Biology of Physical Activity – Univ.of Jywaskyla, Dpto.Biomechanics – Hungarian Univ. of Physucal Education, Hosp.Spinal Unit – Rome.	THE EFFECT OF WHOLE BODY VIBRATION ON MECHANICAL BEHAVIOUR OF SKELETAL MUSCLE AND HORMONAL PROFILER. Publicación: Cl.Applications of Musculoskeletal Interactions.

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Italia	C.R.Russo, F.Lauretani, S.Bandinelli, B.Bartali, C.Cavazzini, J.M.Guralnik, L.Ferrucci.	Lab.Cl.Epidem. – INRCA Ped. Dpto.Florence – Lab.Epidem., Demograp Biometry Nac.Ins. Aging and Longit.Studies aastra Cl. Baltimore.	HIGH-FREQUENCY VIBRATION TRAINING INCREASES MUSCLE POWER IN POSTMENOPAUSAL WOMEN. Publicación: Arch. Phys. Med. Rehabil. (Vol. 84 – December 2003).
Grecia	J.Flieger, Th.Karachalios, L.Khaldi, P.Raptou, G.Lyritis.	Hosp. Kifisia – Athens.	ESTIMULACION MECANICA EN LA FORMA DE VIBRACION PREVIENE POSMENOPAUSICA PERDIDA DE HUESO EN RATAS OVARIECTOMIZADAS. Publicación: Calcified Tissue International – 1998.
Austria	K.Kerschan-Schindl, S.Grampp, C.Henk, H.Resch, E.Preisinger, V.Fialka-Moser, H.Imhof.	Dpto.Physical Med.and Rehab. Univ.Viena – Dpto.Radiol., Osteology, Univ.Viena – Dpto Intern.Med., KH der Barmherzigen Schwestern,Viena.	OSCILLATING MECHANICAL INTERVENTIONS LEAD TO ALTERATIONS IN MUSCLE BLOOD VOLUME. Publicación: Oscillating mechanical interventions – alterations in blood volume.
Austria	R.Crevenna, V.Fialka-Moser, S.Rödler, M.Keilan, C.Zöch, M.Nuhr, M.Quittan, M.Wolzt.	Dpto.Physical Md.Rehab.- Dpto. Cardiothoracic Surgery Dpto.Cl. Pharmacology- Dpto.Cardiology – Univ.Viena (Austria).	SAFETY OF WHOLE-BODY VIBRATION EXERCISE FOR HEART TRANSPLANT RECIPIENTS. Publicación: Phys. Med. Rehab. Kuror - 2003 (Vol. 13; 1-5).
Austria	K.Kerschan-Schindl, S.Grampp, C.Henk, H.Resch, E.Preisinger, V.Fialka-Moser, H.Imhof.	Dpto.Physical Med.and Rehab. Univ.Viena – Dpto.Radiol., Osteology, Univ.Viena – Dpto Intern.Med., KH der Barmherzigen Schwestern,Viena.	LOS EJERCICIOS DE VIBRACION CORPORAL INTEGRAL CONDUCEN A ALTERACIONES EN EL VOLUMEN SANGUINEO MUSCULAR. Publicación: Clinical Physiology 21, 3, 377-382 (2001).
Israel	VB.Issurin, DG.Liebermann, G.Tenenbaum.	Ribstein C.for Research and Sport Med.Sciences. Winagte Inst. Israel.	VIBRATORY STIMULATION TRAINING: A NEW APPROACH FOR DEVELOPING STRENGTH AND FLEXIBILITY IN ATHLETES.
Israel	VB.Issurin, G.Tenenbaum.	Ribstein C.for Research and Sport Med.Sciences. Winagte Inst. Israel.	ACUTE AND RESIDUAL EFFECTS OF VIBRATORY STIMULATION ON EXPLOSIVE STRENGTH IN ELITE AND AMATEUR ATHLETES. Publicación: Journal of Sports Sciences – 1999 (17, 177-182).
Rusia Bélgica	AV.Zinkovsky1, IA.Zoubova1, KP.Schmidt2, KJ. Van Zwieten2.	St.Petersburg State Technical Univ.Russia-Limburgs Univ.Centru, Univ. Campus,Belgium.	TRAINING OF THE SKELETAL.MUSCLE APPARATUS OF SPORTSMEN THROUGH ELECTROVIBROSTIMULATION. Publicación: Fysische Therapie 4 (1998).

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Rusia Bélgica	AV.Zinkovsky1, IA.Zoubova1, KP.Schmidt2, KJ. Van Zwieten2.	St.Petersburg State Technical Univ.Russia-Limburgs Univ.Centru, Univ. Campus,Belgium.	TRAINING OF THE SKELETAL.MUSCLE APPARATUS OF SPORTSMEN THROUGH ELECTROVIBROSTIMULATION.
			Publicación: Fysische Therapie 4 (1998).
Finlandia	A.Heinonen, P.Kannus, H.Sievanen, M.Pasanen, P.Oja, I.Vuori	Inst.for Health Promot. Finland.	GOOD MAINTENANCE OF HIGH-IMPACT ACTIVITY-INDUCED BOEN GAIN BY VOLUNTARY, UNSUPERVISED EXERCISES: AN 8-MONTH FOLLOW-UP OF A RANDOMIZED CONTROLLED TRIAL.
			Publicación: Journal of Bone and Mineral Research- Vol.14, Nº1 (1999)
Finlandia	S.Torvinen, P.Kannus, H.Sievanen, T.A.H.Järvinen, M.Pasanen, S.Kontulainen, T.L.N.Järvinen, M.Järvinen, P.Oja, I.Vuori.	B.R.Group, Ukk Inst, Medical School and Inst.of Med.Technology, Univ.Tampere and Hosp.Univ.Tampere – Finland.	EFFECT OF A VIBRATION EXPOSURE ON MUSCULAR PERFORMANCE AND BODY BALANCE. RANDOMIZED CROSS-OVER STUDY.
			Publicación: Clinical Physiology and Funcional –Vol.22 (145-152) (2002)
Finlandia	S.Torvinen, P.Kannus, H.Sievanen, T.A.H.Järvinen, M.Pasanen, S.Kontulainen, T.L.N.Järvinen, M.Järvinen, P.Oja, I.Vuori.	B.R.Group, Ukk Inst, Medical School and Inst.of Med.Technology, Univ.Tampere and Hosp.Univ.Tampere – Finland.	EFFECT OF FOUR-MONTH VERTICAL WHOLE BODY VIBRATION ON PERFORMANCE AND BALANCE.
			Publicación: Medicine & Science in Sports & Exercise. 0195-9131/02/3409-1523/93.00/0. (2002).
Rusia	A.Nemchenko, E.Kushnirenko.		EFFECT OF VIBROSTIMULATION ON ATHLETES PERFORMANCE.
	S.MP Verschueren, M.Roelants, Ch.Delecluse, S.Swinnen, D.Vanderschueren, S.Boonen		EFECTO DE 6 MESES DE ENTRENAMIENTO CON VIBRACION CORPORAL INTEGRAL EN LA DENSIDAD OSEA DE LA CADERA, FUERZA MUSCULAR Y CONTROL POSTURAL EN MUJERES POSMENOPAUSICAS: ESTUDIO PILOTO CONTROLADO Y RANDOMIZADO.
			Publicación: Journal of Bone and Mineral Research. (Vol.9, Nº3, 2004-03-23).
España	N.Palacios, O.Santaella, L.Sainz	Serv.Medicina Endocrinología Y nutrición. C.de Medicima del Deporte. CARICD.CSD.Madrid.	RELACION ENTRE LA MASA OSEA Y LA FUERZA MUSCULAR: UN NUEVO CAMPO EN LA APLICACIÓN DE LA VIBROESTIMULACION EN EL MUNDO DEL DEPORTE.
			Publicación: IX Congreso Nacional de la Federación Española de Medicina Deportiva - Noviembre 2001 (OVIEDO).
España, Portugal	N.Gusi, A.Raimundo-Mendoza, A.Leal	Univ.Extremadura F.C.Deporte – Hosp. Cáceres Traumatología (España) y Univ. Evora F.C.Deporte (Portugal)	EFECTOS DE UN PROGRAMA DE EJERCICIO VIBRATORIO A 25 Hz SOBRE LA MASA OSEA DE MUJERES POSTMENOPAUSICAS.
			Publicación: Rev. Española de Enfermedades Metabólicas Oseas – (Vol.3 Nº5)

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España, Portugal	N.Gusi, A.Leal	Univ.Extremadura–Caceres (España) y Univ. Evora (Portugal).	EFFECTS OF 8 MONTHS WHOLE BODY VIBRATION EXERCISE ON BMD IN POST-MENOPAUSAL WOMEN. Publicación: IX Intern. Conference Exercise and Healthy Aging (1-3 Oct-04 Oeiras- Portugal)
España, Portugal	N.Gusi, J.Parraca, A. Raimundo-Mendoza, A.Leal	Univ.Extremadura–Caceres (España), Hosp.Cáceres (España) y Univ. Evora (Portugal).	COMPARACION DE LA ACTIVIDAD ELECTROMIOGRAFICA Y ACELEROMETRIA TRIDIMENSIONAL EN DISTINTOS ANGULOS DEL TREN INFERIOR EN EL EJERCICIO VIBRATORIO. Publicación: XI Congreso de la Federación Española de Medicina del Deporte (Nov-2005 – Palma de Mallorca).
Australia	John A.Eisman	Inst.of Medical Research, Sydney, NSW 2010. Australia.	GOOD, GOOD, GOOD… GOOD VIBRATIONS: THE BEST OPTION FOR BETTER BONES? Publicación: The Lancet Publishing Group - Vol. 358 - Dec.8 (2001)
Japón	Y.Nishihira, T.Iwasaki, A.Hatta, T.Wasaka, T.Kaneda, K.Kuroiwa, S.Akiyama, T.Kida, K.S.Ryol	Inst.,Doctoral and Master Program of Health and Sport Sciences-Univ.Tsukuba – Japan.	EFFECT OF WHOLE BODY VIBRATION STIMULUS AND VOLUNTARY CONTRACTION ON MOTONEURON POOL Publicación: Japan Society of Exercise and Sports Fhysiology (1-1-1 Tennodai,Tsukuba 305 – 8574)
Japón	K.Miyamoto, S.Mori, S.Tsuji, S.Tanaka, M.Kawamoto, T.Mashiba, S.Komasubara, T.Akiyama, J:Kawanishi, H.Norimatsu.	Kagawa Med.Univ. Kagawa– Shirotori Hosp. – Kagawa Med. Univ.Hosp. Kagawa – Japan.	WHOLE-BODY VIBRATION EXERCISE IN THE ELDERLY PEOPLE. Publicación: IBMS Osaka 2003.
Alemania, U.S.A.	O.Bruyere, M.A.Wuidart, E.di Palma, M.Gourlay, O.Ethgen, F.Richy, J.Y,Reginster.	C.Public Health Aspects of Osteop.Disorders–Dpto. Epidermiology and Public Health–Bone and Carrilage Metabolism Unit–Univ.of Liège (Belgium) - Haute Ecole Andre Vesate–Liège (Belgium) and UNC-Chapel Hill, NC - USA	CONTROLLED WHOLE BODY VIBRATIONS TO DECREASE FALL RISK AND IMPROVE HEALTH RELATED QUALITY OF LIFE IN ELDERLY PATIENTS.
España, Portugal	N. Gusi, J.Parraca, P. Tomas-Carus, A. Leal, A. Raimundo	University of Extremadura, 10071 Cáceres, Spain- University of Evora, Portugal- Department of Traumathology, Cáceres Hospital, Spain	INFLUENCE OF THE GRADE OF KNEE FLEXION ON MECHANICAL AND ELECTROMYOGRAPHICAL IMPACT DURING WHOLE BODY VIBRATION EXERCISE

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España, Portugal	N. Gusi, A. Raimundo, A. Leal	University of Extremadura, 10071 Cáceres, Spain- University of Evora, Portugal- Department of Traumathology, Cáceres Hospital, Spain	WHOLE- BODY VIBRATORY EXERCISE REDUCES THE RISK OF BONE FRACTURE
España	E.García-Artero, Ortega Porcel FB, Ruiz Ruiz J., Carreño Gálvez F.	Universidad de Granada, Facultad de Medicina, Dpto. de Fisiología.	ENTRENAMIENTO VIBRATORIO. BASE FISIOLOGICA Y EFECTOS FUNCIONALES(VIBRATION TRAINING. PHYSIOLOGICAL BASIS AND EFFECTS.)
Austria	K. Kerschan-Schindl, S. Grampp, C.Henk, H. Resch, E. Preisinger,V. Fialka- Moser, H. Imhof.	Department of Physical Medicine and Rehabilitaion, University of Viena, Department of Radiology, Osteology, University of Viena, Department of Internal Medicine KH der Barnherzigen Schwestern.	WHOLE- BODY VIBRATION EXERCISE LEADS TO ALTERATIONS IN MUSCLE BLOOD VOLUME
España	Dr. Gerard Moras Feliu, Dr. Lisímaco Vallejo Cuellar	INEFC Centro de Barcelona	EFECTOS DE LAS VIBRACIONES MECANICAS OSCILATORIAS(Plataforma Galileo) SOBRE EN PACIENTES CON FOBROMIALGIA: Estudio de tres casos.
España	Dr. Gerard Moras Feliu, Dr. Lisímaco Vallejo Cuellar	INEFC- Institut de Educación Física de Catalunya- Barcelona, Laboratorios de Recerca en Fisiología del Ejercicio y Biomecánica.	PROGRAMA DE REHABILITACION MEDIANTE VIBRACIONES MECANICAS OSCILATORIAS (GALILEO) EN PACIENTE CON FASCITIS EOSINOFILICA: ESTUDIOS DE CASO.
España	Julio Tous Fajardo, Gerard Moras Ferliú	Univ. Ramón Llull, Barcelona; INEFC Barcelona	Entrenamiento por medio de vibraciones mecánicas; revisión de la litratura. Publicación: Revista Digital - Buenos Aires - Año 10, Nº 79- Diciembre 2004
U.S.A.	Andrew F. J. Abercromby, William E. Amonette, Charles S. Layne, Brian K. McFarling, Martha R. Hinmand and H. Paloski	Wyle Laboratories Inc., HOUSTON TX; Human Perfomance Laboratory; University of Houston-Clear Lake, HOUSTON, TX; Laboratory of Integrated Physiology, Univ. Of Houston, HOUSTON, TX; Department of Physical Therapy, Hardin-Simmons Univ., ABILENE, TX; and Human Adaptations and Countermeasures Division, National Aeronautics and Space Administration, HOUSTON, TX	VIBRATION EXPOSURE AND BIODYNAMIC RESPONSES DURING WHOLE-BODY VIBRATION TRAINING. (2007)

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PAIS	AUTOR	CENTRO	TÍTULO - PUBLICACIÓN
Holanda	S. F. E. Praet, H. Mulder, N. Snelder	Máxima Medical Center, VELDHOVEN; Osteosupport SMO, ROTTERDAM; TU Delft / RU, LEIDEN	Medical Therapy in Osteopenic patients with GALILEO 900/2000
Alemania		NOVOTEC MEDICAL	Response to "Whole Body Vibration" training in spots and rehabilitation; the scientifical status quo. (2008)
U.S.A.	Andrew F. J. Abercromby, William E. Amonette, Charles S. Layne, Brian K. McFarling, Martha R. Hinmand and H. Paloski	Wyle Laboratories Inc., HOUSTON TX; Human Perfomance Laboratory; University of Houston-Clear Lake, HOUSTON, TX; Laboratory of Integrated Physiology, Univ. Of Houston, HOUSTON, TX; Department of Physical Therapy, Hardin-Simmons Univ., ABILENE, TX; and Human Adaptations and Countermeasures Division, National Aeronautics and Space Administration, HOUSTON, TX	VARIATION IN NEUROMUSCULAR RESPONSES DURING ACUTE WHOLE-BODY VIBRATION EXERCISE
Alemania	O. Semler, O. Fricke, K. Verzyroglou, C. Stark, E. Schoenau.	Childrens's Hospital, University of Cologne, GERMANY	Preliminary Results on the mobility after whole body vibration in immobilized children and adolescents. - J MUSCULOSKELET NEURONAL INTERACT 2007.
Alemania	O. Semler, O. Fricke, K. Verzyroglou, C. Stark, Angelika Stabrey and E. Schoenau.	Childrens's Hospital, University of Cologne, GERMANY	Results of a prospective pilot trial on mobility ater WBV in children and adolescents with Osteogenesis Imperfecta. - CLINICAL REHABILITATION 2008
Canadá	F. Rauch	Genetics Unit, Shriners Hospital for Children, Montreal, Canada	Material matters: a mechanostat-based perspective on bone development in osteogenesis imperfecta and hypophosphatemic rickets
Alemania	D. Blottner, M. Salanova, B. Püttmann, G. Schiffl, D. Felsenberg, B. Buehring y J. Rittweger	Department of vegetative anatomy, Center of Space Medicine. Berlin, GERMANY	BRS: Human skeletal muscle structure and function preserved by vibration muscle exercise following 55 days of bed rest. - EUR. J. APP PHYSIOL 2006

INDICE DE TRABAJOS WBV - GALILEO

PAIS	AUTOR	CENTRO	TÍTULO - PUBLICACIÓN
Holanda	J.J.M. Pel, J.Bagheri, L.M. van Dam, H.J.G. van den Berg-Emons, H.L.D. Horemans, H.J. Stam, J. van der Steen.	Dept. of Neuroscience, Erasmus MC, & Dept. of Rehabilitation Medicine, Erasmus MC, Rotterdamm, The Netherlands.	Platform accelerations of three different whole-body vibration devices and the transmission of vertical vibrations to the lower limbs. - MEDICAL ENGINEERING AND PHYSICS (2009)

J Musculoskel Interact 2000; 1:54-58

Original Article

Balance training and exercise in geriatric patients

M. Runge, G. Rehfeld, E. Resnicek

Aerpah-Klinik Esslingen, Germany

Abstract

Objective measures of gait and balance which meet the criteria of reliability and validity are required as a basis for exercise regimens. We established reference values of clinically relevant locomotor and balance performances for geriatric patients. We are using these data for evaluating the effects of different therapeutic approaches to locomotor and balance disorders. *Reference values for chair rising.* We administered a battery of five tests concerning neuromuscular function, locomotion and balance to a sample of 212 participants without apparent locomotor deficits (139 women, 73 men, mean age 70,5 years, SD 6,78 , median 70 years, range 60 to 90 years, recruited by public announcements). The test battery comprised the "chair rising test" for measuring lower extremity neuromuscular function (five repetitions of rising from a chair as quickly as possible with arms crossed over the chest). The test has been proven reliable, valid, sensible and predictive for falls and future locomotor status and ADL-status[2]. Chair rising [sec/5x], Range: 5.4-19.4, Mean: 9.1 (women:9.2, men:9.0), SD: 1.97, Median: 8.9. *Training of balance and muscle power with Galileo 2000 - preliminary results.* Galileo is a device for whole body vibration/oscillatory muscle stimulation. The subject stands with bended knees and hips on a rocking platform with a sagittal axle, which thrusts alternatively the right and left leg 7-14 mm upwards with a frequency of 27 Hz, thereby lengthening the extensor muscles of the lower extremities. The reflexive reaction of the neuromuscular system is a chain of rapid muscle contractions. We conducted a randomized controlled trial, n=34 (age: mean 67y, range 61-85, 11 female), cross-over design, intervention group 2 months training program three times a week (each session 3x2 minutes), performance tests of all participants every two weeks). The first 19 subjects have finished the intervention period. They reached mean performance gains in chair rising of 18 %, strikingly different to the constant values of the controls! We interpret the findings as improvements in muscle power by the oscillative muscle stimulation.

Keywords: Elderly, Fall, Fracture, Balance, Muscle Power

New Insights about the Relationship between Bone Strength and Muscle Strength

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Abstract

According to the mechanostat theory, the mechanical loads on bones help to determine bone strength, and the largest loads come from muscle forces. Indeed, recent studies found that muscle strength and the bending strength of bone are highly correlated (r>0.93), and bone „mass" and muscle mass likewise (r>0.93). Two strain thresholds seem to help to control bone strength. If the mean voluntary loads on bone do not exceed the minimum threshold for remodeling (MESr), remodeling removes bone until this threshold is exceeded. Between 800 and 1600 uStrain bone is preserved. If mean loads on bone regularly exceed 1600 µtrain Strain (minimum threshold for modeling MESm) bone is added to make it stronger. This suggests that any physical training that does not exceed 1600 µtrain will not increase bone strength.

Growing muscle strength and body weight in children can cause bone strains that exceed the modeling threshold. This could help to explain the active bone modeling and increases in bone „mass" and strength that occur in growing children. Data in an Argentine absorptiometric study show that in children bone and muscle mass both increase linearly until puberty, but in girls at 12 years of age bone „mass" begins increasing faster than muscle mass. A similar but smaller increase occurs in boys at age 15. This suggests, estrogen may make girls store more bone than needed for strictly mechanical reasons, possibly to provide calcium stores during lactation after pregnancy.

WG05] Technical Devices.

Helmut W. Minne. Dept. of Internal Medicine and Endocrinology, Clinic "DER FURSTENHOF", Bad Pyrmont, Germany.

Saturday, October 2, 1999, 7:40 PM, Promenade A, Adam's Mark Hotel

Technical devices are of increasing importance in prevention and treatment of osteoporosis as well as musculoskeletal rehabilitation. There are three areas where technical devices promise to improve the patients` condition and quality of life: 1) Machines, which are developed to support muscle training and thus to stimulate bone formation (whole body vibrators). 2) Devices, which protect bones from overloading during falls. 3) Orthoses, which support the posture, that suffered deformation due to vertebral fractures of the spine.
Whole Body Vibration: Muscle contraction exerts pressure on bone tissue. This pressure represents a stimulus for osteoblasts to build bone. Muscle training has the capacity to reduce bone loss and to stimulate bone formation. Strain, as put on skeletal tissue by muscle contraction, has to exceed a threshold value of > 1500 µ Strain, because lower strain is not recognized as a stimulus for bone formation. An unknown proportion of our population prefers to rest and does not enjoy active athletic training. Newly developed vibrating platforms may overcome this problem: they exert mechanical loading on the lower appendicular and axial skeleton, and thereby produce strain on bone tissue. Regular use of such vibrating platforms stimulates muscular oxygen uptake. Postmenopausal women reduced bone loss in the course of a one year`s training with such a platform. Hip Protection: Helpless falling is a risk factor for hip fractures. Energy absorption is an important determinant of hip fractures, because high impact is put on the trochanteric region when hitting the ground. An external hip protector was designed to divert a direct impact away from the greater trochanter during falls. The hip protector consists of two shells (stiff polycarbonate with a rim of soft plastozote) fixed in special underwear. The use of this hip protector reduced the risk of hip fractures significantly (RR: 0.44).
Technical Assistance to Support the Posture of the Spine: Patients with vertebral fractures suffer deformation of the spine and reduction in height. This causes pain and disabilities and deterioration of lung function Orthoses are prescribed to improve the patients` condition in general. They are either difficult to put on or put pressure on the abdomen and restrict breathing. The patients` compliance is limited. Therefore, a reasonable proportion of these devices end up in the wardrobe. This led us to develop a new orthosis, trying to avoid the disadvantages of the existing ones. This back support is based on the backpack principle and straightens the spine by active muscle action (bio-feed back). Thoracic and abdominal breathing is not restricted. By wearing this orthosis patients gain a sense of security and can improve their level of performance because the orthosis prevents the origin of painful pressure and exhaustion states. Furthermore, patients appreciate the fact that the new orthosis is light and comfortable. It has a low profile, and is barely visible under normal clothing. The patients reported significant improvement during walking and increased mobility in general.

Working Group: Working Group on Musculoskeletal Rehabilitation in Patients with Osteoporosis (6:30 PM-10:00 PM)

Biological Reaction to Vibration - Implications for Sport

Joachim Mester, Peter Spitzenfell, Judith Schwarzer & Florian Seifriz
Institute for Theory and Practice of Training and Movement, German Sp
University, Cologne, Germany

Mester, J., Spitzenfell, P., Schwarzer, J., & Seifriz, F. (1999). Biological reaction to vit implications for sport. *Journal of Science and Medicine in Sport* 2 (3): 211-226.

In many situations of everyday life, vibration load occurs. Here whole body vibratio vehicles, such as boats, cars, helicopters and others as well as hand-transmi vibration (motor saws etc.) can be named. As vibration is assumed liable to cause var threats to human health, a great number of studies in work science focussed on d effect relations and concepts for prevention. Although in many sports remarkable ration load also occurs, there is very little research on the potential dangers and ben of vibration stimuli, e.g. on whole body vibration and the implications for musc activity and neuromuscular control in sport. In personal studies the damping behav and training effects under whole body vibration were investigated. Various rese areas have been studied in order to approach the relevant topics: neuromuscular posture control, energy metabolism in terms of oxygen uptake under whole b vibration and local concentration of phosphates by means of ^{31}P-MRS. Furthermore effects of a strength training under whole body vibration were analysed. The res underline that vibration is a neglected research topic in sport science from the preven point of view as well as from the one focussing on the improvement of sport performa

Introduction

For a very long time mechanical vibration has been considered to be of infl on human well-being. In the 17th century some attention was paid to the pain of coachmen that was attributed to the vibration of horse-coaches in days. In modern life with all its technical devices many sources of vibration (human body can be identified. These sources range from hand-held mac such as motor-saws which exert vibration stimuli on the hands and body, whole body vibration in certain transportation devices. Here a great numl different devices can be observed, for example cars, motor cycles, tractors, l trains, aircraft, helicopters and many more. As vibration input can be se detrimental to health, strict rules for the chronic vibration input at va workplaces have been elaborated by work science. These rules are put do International conventions as in those from the International Organizatic Standardization (ISO 2631).

In sport none of these rules exist, although in many sports remarkable vibi load occurs, such as in sailing, surfing, alpine skiing, inline-skating, off biking, horse-back riding. As the potential dangers of vibration must al taken into consideration in sports, it seems strange that this field has not in the focus of scientific interest so far. The amount or the intensity of vibi exposure is as unknown as the possible effects of training in these sports very long ago, however, the significance of mechanical vibration for equilit

Acute physiological effects of exhaustive whole-body vibration exercise in man

J. Rittweger[1,2], G. Beller[2] and D. Felsenberg[2]

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Summary

Vibration exercise (VE) is a new neuromuscular training method which is applied in athletes as well as in prevention and therapy of osteoporosis. The present study explored the physiological mechanisms of fatigue by VE in 37 young healthy subjects. Exercise and cardiovascular data were compared to progressive bicycle ergometry until exhaustion. VE was performed in two sessions, with a 26 Hz vibration on a ground plate, in combination with squatting plus additional load (40% of body weight). After VE, subjectively perceived exertion on Borg's scale was 18, and thus as high as after bicycle ergometry. Heart rate after VE increased to 128 min^{-1}, blood pressure to 132/52 mmHg, and lactate to 3·5 mM. Oxygen uptake in VE was 48·8% of $\dot{V}O_{2max}$ in bicycle ergometry. After VE, voluntary force in knee extension was reduced by 9·2%, jump height by 9·1%, and the decrease of EMG median frequency during maximal voluntary contraction was attenuated. The reproducibility in the two VE sessions was quite good: for heart rate, oxygen uptake and reduction in jump height, correlation coefficients of values from session 1 and from session 2 were between 0·67 and 0·7. Thus, VE can be well controlled in terms of these parameters. Surprisingly, an itching erythema was found in about half of the individuals, and an increase in cutaneous blood flow. It follows that exhaustive whole-body VE elicits a mild cardiovascular exertion, and that neural as well as muscular mechanisms of fatigue may play a role.

Keywords: energy turnover, exercise physiology, osteoporosis, sports, training.

RECOVERY EFFECTS OF GALILEO 2000

A New Device for Training-Interventions

Klinikum re. d. Isar - Technische Universität München - Germany

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Department of Preventive and Rehabilitative Sports Medicine

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Changes of the max torque from the first to the last measuring (%)

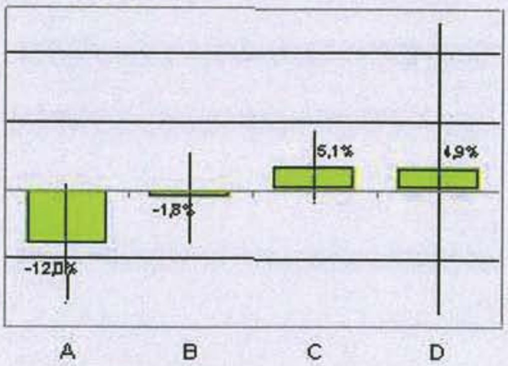

Fig.2

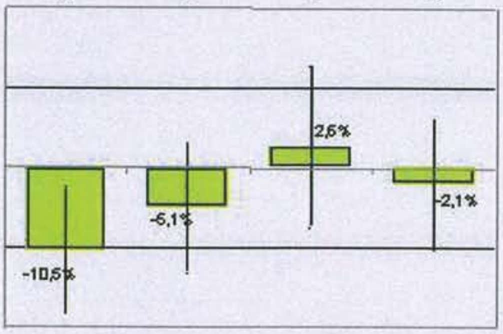

Fig.3

In this study, we investigated a new device for muscle training and recovery called Galileo 2000 (Novotec, Fig.5) which included exertion with superimposed vibratory stimulation *(VS)*.

32 healthy men and women were devided (randomized) into four groups. The experimental groups (B,C,D) received 2 min VS (25-30 Hz) either at the end of the first (B) or of the second break (C) or at the end of each of the two recovery breaks (D). The control group (A) received no VS.

All subjects performed 3 series of 3-5 maximal (isometric) voluntary contractions (MCV, torque) in the elbows (flection) and the knees (extension) using the SCHNELL multi-muscle-machine M3 (Fig.4). There was a rest of 15 minutes between each series.

The *results* (Fig.1-3) indicate that superimposed VS applied for short periods in recovery breaks allows to keep the MVC of flexion in the elbow and extension in the knee on a significantly higher level than without VS during the recovery breaks.

Fig.4

Fig.5

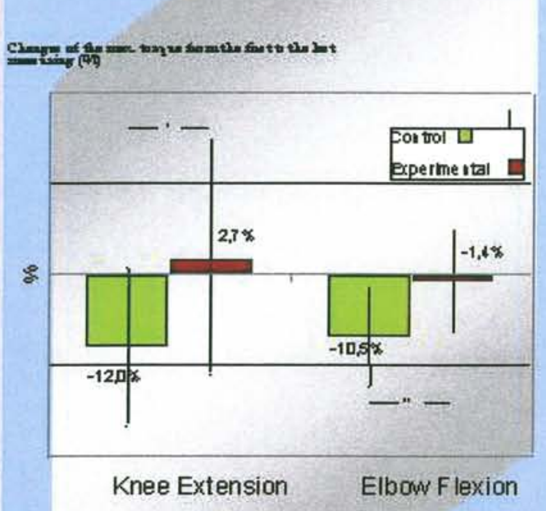

Fig. 1

Correlation of Strength Strain Index (SSI) and Torque in Upper Limbs

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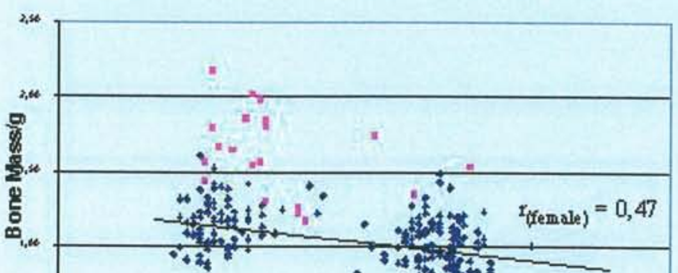
Technical Univ. Munich - Klinikum re. d. Isar - Germany
[1] Department of Preventive and Rehabilitative Sports Medicine [2] Department of Nuclear Medicine [3]STRATEC-Medizintechnik, Pforzheim - Germany

SSI-Torque of both Sexes

Age and Bone Mass of both Sexes



- A wildly spread and common method to asses the current status of the bone quality is to correlate age with bone mineral density. A serious problem of this method is that it gives no evidence about bone strength.
- The aim of this study was to find a technique that is able to predict bone strength.
- In a cross-sectional study of 342 healthy subjects of both sexes (19-82 years) the polar Strength Strain Index (SSI) was determined by pQCT-messurements, using the STRATEC XCT 2000. The messuring place was set on the right radius at 4% of the complete ulna lenght. Maximal muscle-force was messured isometrically at an angle of 90° at the right upper limb. The SCHNELL multi muscle machine M3 divided the individual outcomes with the length of the antebrachium to get the torque.
- Our results show a high correlation between the maximal muscle torque and the SSI ($r=0,82$, $p<0,01$) and therefore corroberate the hypothesis that muscle force is a leading variable that influences bone strenght.
- Furthermore these outcomes might be worthfull for predicting bone diseases.

Long term effects of Galileo 2000 - a new training device

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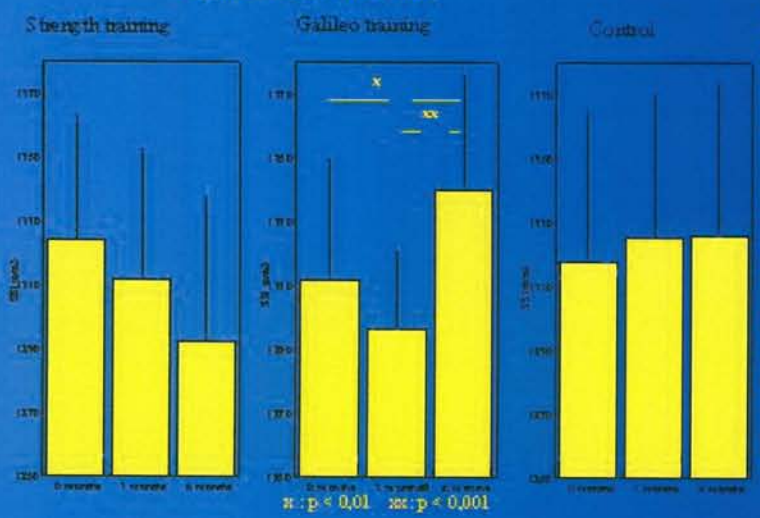
Polar SSI 14% of Tibia



Galileo 2000 is a new device for dynamic muscle training. The device evokes rhythmic (25-30Hz) muscle contractions.

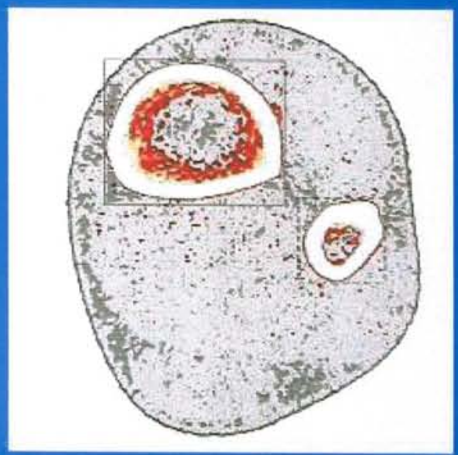
In this study a group of 44 untrained healthy postmenopausal women (50-65 y) were examined to evaluate long term effects (muscle force and bone-strength) under two forms of continually adapted dynamic strength training for the lower limbs. Women were randomized into 2 groups.

The first group (Strength) performed a conventional dynamic strength training, providing an intensity of about 70% of each person's one-repetition-maximum (1RM). The lower limbs were trained by the following movements and machines: abduction, adduction, anteversion and retroversion of the thigh (using a hip machine) and extension of the knees and hip (using the legpress).

The second group (Galileo) performed a strength training during an additional intervention of high frequency vibrations (25-30Hz, Galileo 2000). Practising knee bends with weights (4-5 seconds for one knee bend), optimum effectiveness was assumed when marked fatigue of the exercised group of muscles was observed within 180-240 seconds per set.

Both groups performed 2 sets a unit, twice a week over 6 months.

A third group (Control) of 21 persons served as a control.



$$SSI\ (mm^3) = \sum \frac{a_i \times d_i^2}{d_{max}} \times \frac{CD}{CD_{max}}$$

Bone strength:

The polar SSI at 14% (Stress-Strain-Index) which was measured by the pQCT (Stratec XCT-2003) was used as a method to determine the bone strength. The SSI was calculated from the cortical density/area and the radius of the bone.

Results indicate that strength training with Galileo 2000 leads to a slight decrease of bone strength after 3 months (p = 0,107) followed by a strong increase of bone strength after 6 months (p = 0,0005). In comparison with the baseline data a significant increase of stiffness of 2,15% is remarkable (p = 0,0054) after 6 months.

The group practising the conventional strength training showed a tendency towards an decrease of bone strength over the period of 6 months (p = 0,29).

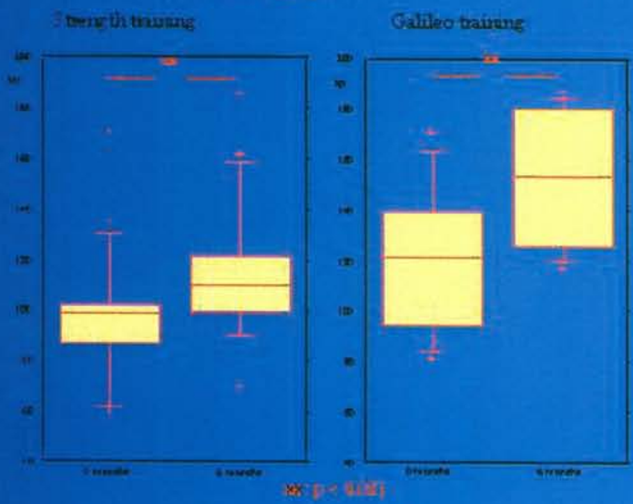
No changes could be observed in the control group.

Muscle force:

The 1RM at the legpress was used in order to explore the strength of each person. The training was also able to amplify each test person's 1RM (p = 0,0002). The Strength group had an increase of 19,4% and the Galileo group of 27,0%.

Based on these results, we conclude that Galileo 2000 may be a promising device for an effective, safe, reproducible and adaptable method of therapeutic strength training.

1RM on the legpress



MECANISMOS FISIOLOGICOS DEL EJERCICIO POR VIBRACIONES

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El ejercicio por vibraciones (EV) es un nuevo tipo de ejercicio diseñado para ser aplicado en ancianos y atletas. Está pensado para provocar contracciones musculares por medio de un estímulo oscilatorio.

Hemos investigado los parámetros de activación muscular del VE por medio de registros EMG y midiendo la inhalación de oxígeno. Además, hemos monitorizado la fatiga de los sistemas neuromuscular y cardiovascular durante EV intenso.

La toma de oxígeno aumenta según el EV. Este aumento depende de la amplitud y frecuencia de la vibración, y no depende de movimientos lentos voluntarios adicionales. Los registros EMG mostraron que la actividad tuvo lugar en los músculos exteriores de las piernas, pero inicialmente también en los flexores. A frecuencias inferiores, también se puede detectar una actividad EMG significativa en el músculo erector del tronco.
La toma de oxígeno durante el EV en cuclillas con sobrecarga de 20 Kg fue del 50 % de la toma máxima de oxígeno durante ejercicio intensivo con la bicicleta ergomética. En estas condiciones las pulsaciones alcanzan las 130 por minuto.

Algunos pacientes presentan una disminución significativa de la presión sanguínea diastólica después del EV intenso. Otros, sobre todo las mujeres, presentan picazón y erythema después del EV intenso, que desaparecen pronto por lo general con sesiones de entrenamiento adicionales.

STRENGTH TRAINING WITH WHOLE BODY VIBRATIONS – SINGLE CASE STUDIES AND TIME SERIES ANALYSES

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Vibration loads occur in many sports, such as alpine skiing, mountain biking, in-line skating, and others. It is known from work physiology that vibration load may lead to health hazards (Griffin 1994, Herterich and Schnauber 1992). That is why in ergonomics strict rules in the area of international norms (ISO 2631/1) have been established. Effects of vibration load in physical activity and sports are a focus of scientific interest. On the one hand adaptations in the field of motor control have been investigated, on the other hand studies on the effects of vibration stimuli on muscle strength ! been carried out. Some of these studies suggest that strength increases up to 50 %, whereas other results indicate that there is no significant improvement (Issurin et al. 1994, Künnemeyer and Schmidtbleicher 1997, Nazarov and Spivak 1985, Weber 1997). Furthermore in many sports it is necessary to absorb and damp vibrations in a given situation of vibration input. In alpine skiing e.g. vibrations occur with frequencies up to 30 Hz (measured at hip joint) (Nigg 1997). Vibration input leads to significant neurophysiological effects, such as the stimulation of the muscle spindles and the associated reflex mechanisms. So the main goal of this paper is to study the effects of vibration load in the context of strength training. Traditional cross-sectional studies are not able to produce information about the process of effects. Therefore this investigation was designed as a single-case-study with techniques of time series analyses in order to find out how vibration stimuli added to traditional strength training may influence strength and damping abilities.

Over various periods single athletes at different levels of performance carried out strength training with and without vibration input. Vibration stimuli were designed as a sinusoidal oscillation with an amplitude of 2.5 mm and 24 Hz. The training consisted of traditional exercises in strength training such as knee bends (one-legged), lunges (both with dumb-bell), astride jumps, ankle jumps, drop jumps, step ups, etc.. For diagnostic purposes the following tests were used: static leg press for isometric strength, drop jump and squat jump on force plate for reactive strength reps. speed strength. Additionally a "vibration step test" for analysing the regulative abilities under vibration load was carried out. The following parameters have been measured in the time-series-design: heart rate, lactate, EMG, creatine-kinase, urea, transmission factors and ground reaction force.

Results show a dramatic increase of creatine-kinase and urea during each vibration period indi-..ing the high strain with a remarkable eccentric load compared to the non-vibration period. Due to probable muscle damage, it was observed that the performance of strength in the static leg press first decreased at the beginning of the training and then increased at the end of the whole training by more than 40 % of the initial value in some cases. The analysis of speed-strength also shows an increase in the height of squat-jumps after 14 days of training up to 25 %. Extraordinary results of this kind only can be explained by the "Tonic Vibration Reflex" (Martin and Park 1997), such that under vibration even fatigued motor units can be re-recruited and thus contribute to the force-production.

It can be concluded that the combination of traditional strength training with vibration load may lead to a remarkable increase of strength, provided that a necessary level of stimuli is used. These loads, however, include the high risk of severe "muscle soreness" and muscle damage. This form of strength training, on the other hand, may cause extraordinary improvements in strength that can be achieved in traditional training only by means of very high external weight loads. Further studies will be carried out in order to detect individually optimised training concepts.

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International Continence Society 33rd Annual Meeting

Florence, Italy. 5th – 9th October 2003

Abstract Title:

EFFECT ON MUSCLES OF MECHANICAL VIBRATIONS PRODUCED BY THE GALILEO 2000 IN COMBINATION WITH PHYSICAL THERAPY IN TREATING FEMALE STRESS URINARY INCONTINENCE

S. von der Heide, R. Hilgers, G. Emons and V. Viereck

Department of Gynecology and Obstetrics, Georg-August-University Goettingen, Germany

Abstract Text:

Aims of Study

A prospective randomized study was performed to determine whether intensive vibration training (1-4) using the Galileo 2000 in combination with physical therapy improves the continence rate in women with urodynamically proven stress urinary incontinence. The influence on the pelvic floor muscles and the therapeutic effect on stress incontinence were investigated.

Patients and methods

The Galileo 2000 is a platform with a sagittal axle on which a teeterboard is tilted up and down (5 mm) at a variable frequency of 5 – 30 Hz. This movement produces mechanical oscillations with an average cycle length of about 40 msec, which is the time required to induce a natural monosynaptic stretching reflex in the respective muscle via the muscle spindle during one up and down movement. The neuromuscular system reacts to this stimulation by a chain of rapid muscle contractions which may result in entire-body vibration. Both forms of treatment aim at strengthening the muscles involved in closing the urethra, vibration therapy in a reactive way and physical therapy in an active way.

Twenty-nine patients were examined clinically and urodynamically (including perineal ultrasound and pelvimeter) and assigned to 3 treatment groups. Group A underwent combined physical therapy (PT) and vibration training with the Galileo (Gal) throughout the treatment period. Group B started with physical therapy and switched to vibration training after 12 weeks (PT > Gal), and Group C first had vibration training and then changed to physical therapy (Gal > PT). Weekly training comprised 2 training units with physical therapy of 30 min duration and vibration training of 2 x 4 min. The total length of training was 24 weeks and was followed by a 12-week follow-up period.

Results

The patients' median age at the time of treatment was 50 years (range 34 – 69 years). The objectively determined continence rate was 80% in Group A (combined treatment), 56% in Group B (PT > Gal), and 60% in Group C (Gal > PT). These results were in agreement with the subjective frequency of weekly urine loss. All three groups showed a considerable improvement of mean pelvic floor strength determined pelvimetrically (by 8 µV in Group A, 7 µV in Group B, and 6 µV in Group C). These findings were confirmed by palpation and ultrasound. At the end of the study the average grade of stress urinary incontinence decreased from 1.8 to 0.2 in Group A, from 1.7 to 0.2 in Group B, and from 1.8 to 0.3 in Group C. These results were also reflected by a subjective improvement of complaints in all patients ($p < 0{,}001$).

Conclusions

Muscle stimulation by vibration training improves the subjective and objective parameters of stress urinary incontinence. The combination of vibration training and physical therapy turned out to be highly effective and thus represents a genuine therapeutic option for patients with stress urinary incontinence.

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Tratamiento de Dolor Crónico de Espalda Baja con Extensiones Lumbares y Ejercicio de Vibración Corporal Integral. Ensayo Controlado y Randomizado.

Jörn Rittweger, MD,* Karsten Just, MD,† Katja Kautzsch, MsPsych,‡ Peter Reeg, MD,§ y Dieter Felsenberg, PhD ||

Diseño del Estudio: Un ensayo controlado y randomizado fue conducido por un periodo de 6 meses de seguimiento.
Objetivo: Para comparar ejercicios de extensiones lumbares y ejercicios de vibración corporal integral para el dolor crónico de espalda baja.
Antecedentes: El dolor crónico de espalda baja involucra los sistemas musculares también como conectivo y neurológico. Diferentes tipos de fisioterapia son aplicados para su tratamiento. La vibración industrial está señalada como un factor de riesgo. Recientemente, los ejercicios de vibración han sido desarrollados como un nuevo tipo de fisioterapia. Es pensado para activar los reflejos de las vías musculares.
Métodos: En este estudio, 60 pacientes con dolor de espalda baja crónico sin ninguna enfermedad específica de columna, quienes tenían un promedio de edad de 51.7 años e historia de dolor de 13.1 años, practicaron bien ejercicios de extensión lumbar isodinámica o ejercicios de vibración durante 3 meses. Las medidas que resultaron fueron extensión lumbar de torsión, sensación de dolor (escala análoga visual), y discapacidad relacionada con el dolor (índice de discapacidad por dolor).
Resultados: Una significativa y comparable reducción en la sensación de dolor y discapacidad relacionada con el dolor fue observada en ambos grupos, La extensión lumbar de torsión se incrementó significativamente en el grupo de ejercicios de vibración (30.1 Nm/kg), pero significativamente más en el grupo de ejerçicios de extensión lumbar (+59.2 Nm/kg; SEM 10.2; P<0.05). No hubo correlación entre ganancia en la torsión lumbar y alivio del dolor o discapacidad relacionada con el dolor (P>2).
Conclusiones: Los datos actuales indican que tener poca fuerza en el músculo lumbar probablemente no es la causa exclusiva de dolor de espalda baja crónico. Diferentes tipos de terapia de ejercicio tienden a arrojar resultados comparables. Interesantemente, la vibración bien controlada podría ser la cura del dolor de espalda baja, en vez que su causa.

Treatment of Chronic Lower Back Pain with Lumbar Extension and Whole-Body Vibration Exercise
SPINE Volume 27, Number 17, pp 1829-1834

Mechanical stimulation in neuromuscular diseases

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Introduction

The incidence of neurodegenerative progressive diseases (Parkinson's Disease (PD) Multiple Sclerosis (MS), Amyotrophic-Lateral-Sclerosis (ALS)) is characterized by an increasing development in the European countries. Whereas the neuropathological features and lesioned structures are different (cortical vs. spinal level) there are fundamental similarities in motor control abnormalities: ataxia, disturbed sensory function and disturbed reflex pattern. Since pharmacological treatment has been shown to be less effective we aimed at finding alternative treatment or training strategies to improve motor control in these patients. Based on the results of analyses in high performance sports we proved if whole-body-vibration (WBV) - that is strongly connected with sensory stimulation and reflex elicitation - could be an effective training device. This paper deals primarily with the results of analyses with PD patients.

Methods

Altogether more than 200 subjects with HOEHN and YAHR stage 1-4 participated to several types of analyses. Cross sectional studies were focused on spontaneous changes in motor control achieved by vibration treatment. Pre- and Post Tests consisted of complex biomechanical test batteries including gait analysis using a 3D high speed video system, manual coordination tests as well as isometric strength tests. With respect to usual clinical assessments, motor examination was done by UPDRS (United Parkinson's Disease Rating Scale). In order to control bias factors one study was organized in a blind design i.e. raters did not know about the status of treatment. All subjects were withdrawn from L-DOPA medication over night. Treatment is based on five series of WBV taking 60 seconds each. Vibration amplitude was 3 mm; frequency was set at 5 to 6Hz.

Results

Around 80% of analysed patients showed spontaneous improvements in several parameters of motor control. In gait analyses increased gait velocities and reduced ground contact times could be noticed. In strength tests subjects improved their maximum strength about 26 % on average. This increase was connected with a highly significant reduction of antagonists' iEMG. Data of manual coordination show all over better results which are connected with significantly reduced action tremor. In UPDRS motor score test a highly significant improvement of 5.5 points on average was found (Figure 1). Parameters that showed mostly affected were rigidity, balance and gait.

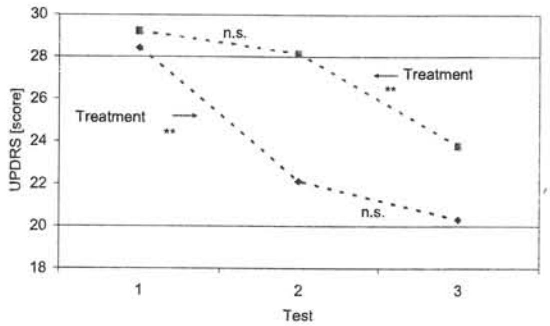

Fig. 1: UPDRS score of patients' pre and post treatment. One group was treated between Test 1 and 2, the other group between 2 and 3. Changes of the UPDRS score are after the treatment statistically highly significant.

Discussion/Conclusion

After a general consideration of all findings concerning motor effects of WBV it seems not possible to explain presented results by a single or simple function neither in PD nor in other neuromuscular diseases. In PD the extent of effects as well as the duration of response is characterized by a wide variety. Since some effects continued for several hours acute peripheral changes in sensory behaviour can not explain these results exclusively. It can be speculated that neurotransmitter concentrations e.g. dopamine are affected by the stimulation since the results of animal experiments indicate this kind of function of WBV (Ariizumi & Okada 1985, Yamaguchi 1985). A further model relates to a modification of pathologically changed activation of brain areas e.g. thalamus (Thommerdahl et al. 1999, Bonhomme et al. 2001).

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Tommerdahl, M., et al. (1999): J. Neurophysiol. 1999, 16-33
Yamaguchi, Y. (1985): Sangyo Igaku 1985, Abstract

USE OF A THERAPEUTIC RANGING/EXERCISE PROGRAM IN THE REHABILITATION OF A PERSON WITH PROGRESSIVE SUPRANUCLEAR PALSY

JG Gianutsos, PhD; LC Oakes, BA; N Prufer, BA; V Kramskii, BA; EF Richter III, MD (Department of Rehabilitation Medicine) and M Hutchinson, MD, PhD (Department of Neurology) New York University School of Medicine, New York, NY, USA.

A 73-year-old male diagnosed six years earlier with advanced Progressive Supranuclear Palsy (PSP), an atypical form of Parkinsonism, had deteriorated over several months despite attempts to adjust medication.

He was non-ambulatory, wheelchair-bound and dependent in activities of daily living (ADL). He presented with generalised rigidity and bradykinesia, severe speech impediment, stooped posture, gait freezing and postural instability. His most disabling symptoms were unresponsive to levodopa.

Computerised-testing over months of treatment documented change resulting from his participation in our therapeutic ranging/exercise program. During each weekly one-hour session, his legs were mechanically ranged on a linear displacement device for 15 minutes to increase joint range of motion. Then, he was supervised through an exercise regimen. Improvement in facial expression, speech volume, and tone were evident by month four.

At 9 months, he could jump, walk on a treadmill, and ambulated with a walker. By eleven months he stood unaided, walked 400 feet with assistance, and stepped adequately to permit computerised gait testing. Over the next 7 months his gait scores improved steadily from an original 40 range to a consistent 80 range.

THE EFFECTS OF WHOLE BODY VIBRATION ON REFLEX-INDUCED STANDING IN PERSONS WITH CHRONIC AND ACUTE SPINAL CORD INJURY

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The therapeutic benefits of Whole Body Vibration (WBV) have been recognised since Charcot and Tourette constructed vibrating devices to aid their patients. We employ WBV to determine the extent to which reflex standing can be induced in persons with spinal cord injury (SCI) who are otherwise unable to stand without the use of locked long-leg braces. The procedure activates segmental reflexes through rapid mechanically-delivered repetitive stretches to the lower extremities.

The program consists of weekly one-hour sessions during which WBV is delivered for 15-20 minutes with the person standing. The dependent variables are: duration of induced standing, sitting balance, trunk control, muscle tone, stamina, dermal condition, and mood.

To date, we have failed to induce reflex standing in a person with quadriplegia at the C7-level whose lower extremities were flaccid, and whom we tested at 4 months post-injury. Results obtained from al lest four other persons with SCI in whom we have successfully induced the effect will be presented. The 4 persons range in age from 22 to 52 years with time-since-injury ranging from 6 months to 17 years.

WBV represents an alternative to fitness effects gained through functional electrical stimulation (FES) and/or treadmill-induced walking with partial-weight support.

Bone Vol. 22, No. 1
January 1998:1–6

ELSEVIER

PERSPECTIVE

Estrogen and Bone-Muscle Strength and Mass Relationships

H. SCHIESSL,[1] H. M. FROST,[2] and W. S. S. JEE[3]

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The largest voluntary loads on bones come from muscles. To adapt bone strength and mass to them, special strain threshold ranges determine where modeling adds and strengthens bone, and where remodeling conserves or removes it, just as different thermostat settings control the heating and cooling systems in a house. If estrogen lowers the remodeling threshold, two things should occur. First, at puberty in girls, bone mass should begin to increase more than in boys with similar muscle strengths, owing to reduced remodeling-dependent bone losses, while gains from longitudinal bone growth and bone modeling continue normally. That increase in bone mass in girls should plateau when their muscle strength stops increasing, since their stronger bones could then reduce bone strains enough to turn modeling off, but could let remodeling keep conserving existing bone. Second, decreased estrogen secretion [or a related factor(s)], as during menopause, should raise the remodeling threshold and make remodeling begin removing that extra bone. That removal should also tend to plateau after the remaining and weaker bone lets bone strains rise to the higher threshold. Postmenopausal bone loss shows the second effects. Previously unremarked relationships in the data of a 1995 Argentine study showed the first effects. This supports the idea that estrogen can affect human bone strength and mass by lowering the remodeling threshold, and loss of estrogen would raise the threshold and help cause postmenopausal bone loss even if other factors help to do it. The Argentine study also suggested ways to study those things and the roles of muscle strength and other factors in controlling bone strength and mass in children and adult humans. Those factors include, in part, hormones, vitamins, calcium, diet, sex, race, age, medications, cytokines, genetic errors, gene expression patterns, and disease. (Bone 22:1–6; 1998) © 1998 by Elsevier Science Inc. All rights reserved.

Key Words: Estrogen; Bone mass; Muscle; Menopause; Osteoporosis; Absorptiometry; Biomechanics.

"... Between muscle and bone there can be no change in the one but it is correlated with changes in the other ..." (D'Arcy Thompson, 1917)

Address for correspondence and reprints: Dr. H. M. Frost, Department of Orthopaedic Surgery, Southern Colorado Clinic, 41 Montebello, Pueblo, CO 81001.

[F255] Brief Exposure to Low Level, High Frequency Mechanical Loading Reduces Postural Instability.

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Friday, October 1, 1999, 11:30 AM, Exhibit Halls 1 & 2

Postural instability represents a major risk factor in osteoportic fractures of the hip, as instability is a principal initiator of falls. Indeed, interventional strategies directed toward improving postural stability can be as effective in reducing fracture risk as increases in bone mineral density. While it is known that vibration applied to the achilles tendon can transiently influence postural stability, the long term effects of such mechanical stimuli have not been described. We investigated the long term influence of brief daily exposures to a vibrational stimulus by exposing a group of 15 women, aged 20-60 years, to 10 min/day of a 30 Hz loading regimen consisting of a vertical acceleration of 0.2 G. Treatment was continued for four weeks, with postural stability monitored daily through this period. Stability was quantified utilizing force plate recordings of postural sway over 60 seconds. The sway data was converted into the frequency domain, and spectral energy density at 10 Hz was used to characterize stability. Treatment dependent changes were evaluated by linear regression. Following completion of the four week treatment protocol, patients underwent two weeks of 10m/d sham exposure (simply standing on the platform), with stability measurements again made on a daily basis. Daily exposure to the mechanical stimulus resulted in a significant improvement in postural stability, with removal from the treatment causing remission. At the beginning of the study, average center of pressure (COP) motion at 10 Hz was 2.3μm, which dropped by 30% to 1.6μm over the one month treatment ($p<0.01$). With termination of daily treatment, a corresponding increase in COP at 10 Hz was observed. In the two weeks of sham treatment, COP motion returned to starting levels (2.6μm; $p<0.001$), suggesting that the neuromuscular system affected by this treatment is rapidly adaptable. Postural stability is associated with a fluid swaying motion, and instability with abrubt shifts in body position. The significant decline in abrubt postural motions following treatment are therefore indicative of improved stability. In a previous clinical trial, this low level, high frequency stimulus was shown to inhibit loss of bone density in a post-menopausal population. It appears, therefore, that this unique stimulus can both inhibit bone loss and improve postural stability, two of the three major risk factors in hip fractures. This noninvasive treatment may prove to be a simple, non-pharcologically based means to significantly reduce fracture risk in the elderly.

Poster Session I: Osteoporosis Epidemiology: Fracture I (11:30 AM-1:00 PM)

Transmisibilidad de vibraciones de 15-Hertz a 35 Hertz a la cadera humana y columna lumbar: Determinando la posibilidad fisiológica de proporcionar estímulos mecánicos anabólicos de bajo nivel a las regiones del esqueleto con un muy alto riesgo de fractura debido a la osteoporosis.

Clinton Rubin, PhD,* Malcom Pope, DrMedSci,† J.Chris Fritton, PhD, DSc, MS,*
Marianne Magnusson, DrMedSci, † Tommy Hansson, MD, PhD‡ and Kenneth McLeod, PhD¶

Diseño del Estudio: Varios experimentos fueron llevados a cabo para determinar el grado al cual altas frecuencias (15-35 Hz) a nivel de suelo, por vibración corporal integral son transmitidas al fémur y las vértebras lumbares más próximas de un ser humano de pie.

Objetivos: Para establecer si un estímulo mecánico de extremo bajo nivel (<1g, donde 1g = al campo gravitacional de la tierra, o 9.8 ms^{-2}) puede ser entregado eficientemente al esqueleto axial de un humano.

Antecedentes: La vibración es frecuentemente considerada un factor etiológico en el dolor de espalda baja tanto como otras diferentes complicaciones músculo esqueléticas y neurovestibulares, pero recientes experimentos in vivo en animales indican que signos mecánicos de extremadamente bajo nivel enviados a los huesos en un rango de frecuencia de 15 a 60 Hz puede ser fuertemente anabólicos. Si estos signos mecánicos pueden ser transmitidos efectivamente y no invasivamente al humano de pie para alcanzar esos sitios del esqueleto con más alto riesgo de osteoporosis, como la cadera y la columna lumbar, entonces la vibración podría ser usada como única y no farmacológica intervención para prevenir o reversar la pérdida de hueso.

Materiales y Métodos: Bajo condiciones estériles y anestesia local, pins transcutáneos fueron colocados en el proceso espinoso de L4 y el más grande trocánter del fémur de 6 voluntarios. Cada individuo se puso de pie en una plataforma oscilante y los datos fueron recogidos por acelerómetros fijados en los pies mientras la plataforma vibratoria facilitó carga sinusoidal a frecuencias discretas desde 15 a 35 Hz, con aceleración de más de $1g_{picopico}$

Resultados: Con los sujetos en posición erguida, la transmisibilidad de la cadera excedió 100% para las frecuencias de carga menos de 20 Hz, indicando una resonancia. Sin embargo, a frecuencias mayores de 25 Hz, la transmisibilidad disminuyó aproximadamente 80% en la cadera y la columna. En una posición relajada, la transmisibilidad disminuyó a 60%. Con 20 grados de flexión de rodilla, la transmisibilidad fue reducida aun más a aproximadamente 30%. En retraso de la fase alcanzó un nivel alto como 70 grados en los signos de la cadera y la columna.

Conclusiones: Estos datos indican que las aceleraciones mecánicas de extremadamente bajo nivel y alta-frecuencia son transmitidas al instante al apendicular más bajo y el esqueleto axial del individuo de pie. Considerando el potencial anabólico de exceder los signos mecánicos de bajo nivel en este rango de frecuencia, este estudio representa un paso clave en el desarrollo de un tratamiento basado en la biomecánica para la osteoporosis.

Transmissibility of 15-Hertz to 35-Hertz Vibrations to the Human Hip and Lumbar Spine: Determining the Physiologic Feasibility of Delivering Low-Level Anabolic Mechanical Stimuli to Skeletal Regions at Greatest Risk of Fracture Because of Osteoporosis
SPINE Volume 28, Number 23, pp 2621-2627

Prevención de Pérdida Ósea Posmenopáusica por Estímulos Mecánicos de Alta Frecuencia y Baja Magnitud: Ensayo Clínico Evaluando Cumplimiento, Eficacia y Seguridad.

Clinton Rubin,[1] Robert Recker,[2] Diane Cullen,[2] John Ryaby,[3] Joan McCabe,[3] y Kenneth McLeod[4]

ABSTRACT: Un ensayo anticipado, randomizado, double-blind y placebo-controlado de 1-año de 70 mujeres posmenopáusicas demostró que periodos cortos (<20 minutos) de vibración de bajo nivel (0.2g, 30Hz) aplicada durante su estancia de pie puede efectivamente inhibir la pérdida ósea en la columna y el fémur, con eficacia incrementando significativamente con un alto cumplimiento, particularmente en aquellos sujetos con inferior índice de masa corporal.

Introducción: Indicativo del potencial anabólico de los estímulos mecánicos, modelos animales han demostrado que periodos cortos (<30 minutos) de vibración de baja magnitud (<0.3g), aplicados a una relativa alta frecuencia (20-90 Hz), incrementará el número y grosor de los trabeculae, así como aumentará la rigidez y fuerza del hueso cancellous. Tenemos un ensayo clínico anticipado de 1-año, randomizado, double-blind y placebo controlado en 70 mujeres, 3-8 años pasada la menopausia, se examinó la habilidad de los signos mecánicos de alta-frecuencia y baja-magnitud para inhibir la pérdida ósea en humanos.
Materiales y Métodos: Cada día, una mitad de los sujetos fue expuesta a una corta duración (dos tratamientos de 10 minutos/día), baja magnitud (2.0 m/s^2 pico-pico), 30 Hz aceleraciones verticales (vibración), donde la otra mitad estuvo de pie por la misma duración en aparatos placebo. DXA fue usado para medir la densidad mineral del hueso (BMD) en la columna, cadera y radio distal al comienzo y 3, 6 y 12 meses. 56 mujeres completaron 1 año de tratamiento.
Resultados y Conclusiones: El umbral de detección del diseño del estudio falló en mostrar algún cambio en la densidad ósea usando un análisis de intención de tratamiento para ambos grupos placebo y tratamiento. Un análisis de regresión en el grupo de estudio a priori demostró un efecto significativo de cumplimiento en eficacia de la intervención, particularmente en la espina lumbar (p=0.004). La prueba Posthoc fue usada para ayudar a identificar varios subgrupos que se podrían haber beneficiado de esta modalidad de tratamiento. Evaluando aquellos en el más alto cuartil de cumplimiento (86%), los sujetos placebo perdieron 2.13% en el cuello femoral durante 1 año, donde el tratamiento fue asociado con una ganancia de 0.04%, reflejando un 2.17% de beneficio relativo de tratamiento (p=0.06). En la columna, el 1.6% de disminución se observó durante 1 año en el grupo placebo fue reducida a un 0.10% de pérdida en el grupo activo, indicando un 1.5%de beneficio relativo de tratamiento (p=0.09). Considerando la interdependencia de peso, la columna de mujeres livianas (<65 kg), quienes estuvieron en el más alto cuartil de cumplimiento, mostró un beneficio relativo de tratamiento activo de 3.35% mayor BMD a través d el año(p=0.009); para el grupo de cumplimiento medio, un 2.73% de beneficio relativo en BMD fue encontrado (p=0.02). Estos resultados preliminares indican el potencial para una intervención no invasiva y mecánicamente mediada para la osteoporosis. Este enfoque no farmacológico representa un medio fisiológico de inhibir la pérdida de BMD que sigue a la menopausia, quizás es mucho más efectivo en la columna de mujeres más livianas quienes están en mayor necesidad de intervención.

Prevention of Postmenopausal Bone Loss by a Low-Magnitude, High-Frequency Mechanical Stimuli: A Clinical Trial Assessing Compliance, Efficacy, and Safety.
JOURNAL OF BONE AND MINERAL RESEARCH
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0169-4194/99/2:423–433/$12.75

Invited Perspective

Perspectives on Bone Mechanical Properties and Adaptive Response to Mechanical Challenge

Yebin Jiang, MD, PHD,[1] Jenny Zhao, MD, MS,[1] Clifford Rosen, MD,[2] Piet Geusens, MD, PHD,[3] and Harry K. Genant, MD[1]

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Abstract

The bones of the human skeleton serve a mechanical function besides providing a reservoir for calcium and hematopoietic homeostasis. When mechanically challenged, they usually respond and adapt; failure to do so can result in fracture. The mechanical behavior of bone is determined by bone mass and its material properties and by its geometry and architecture. Therefore, in vivo noninvasive measurements of bone mass, geometry, and structure can predict bone strength and are usually employed as a useful—if not always reliable—way to estimate bone fragility, whereas direct bone biomechanical testing in vitro can provide detailed information about mechanical strength. Because bone strains are likely to be important regulators of bone mass and strength, exercise protocols designed to counteract the effects of osteoporosis should load the target bone with repeated high peak forces and high strain rates or high impacts on a long-term basis. Such a protocol creates varied strain distributions throughout the bone structure, producing short, repeated strains on the bone in directions to which it is unaccustomed. Exercise in this manner can maintain and perhaps increase bone mass and improve mechanical properties and neuromuscular competency, reducing skeletal fragility and the predisposition to falls.

Key Words: Bone biomechanics; bone mass and structure; mechanical usage; densitometry; physical exercise.

Nov 3, 2003

Vibration therapy improves walk, balance in elderly

Orlando, FL - Controlled whole-body vibrations (CWBV) improve quality of life, walk, balance, and motor capacity in elderly patients, according to a new study reported at the annual meeting of the **American College of Rheumatology** [1].

Dr Olivier Bruyere

"All older patients in nursing homes—except those with any contraindications—could benefit from CWBV," says study researcher **Dr Olivier Bruyere** (University of Liege, Liege, Belgium). The apparatus costs roughly €8000, and treatment requires just 10 minutes a day.

Precisely how CWBV works is unclear, he says, but it may somehow improve balance or help build bone similar to the way that exercise does, he speculates.

As previously reported by **rheuma*wire***, vibration therapy is being investigated as an approach to the prevention and treatment of osteoporosis.

Good vibrations

In the new study, 42 volunteers in a nursing home were randomized to a vibration group or a nontreatment group for 6 weeks. The treatment group underwent 6 weeks of CWBV (4 one-minute series 3 times a week) on a vertical vibrating platform (10 Hz in the first and third series and 27 Hz in the second and fourth ones). The machine used was the Galileo 900® (Orthometrix Inc, White Plains, NY).

After 6 weeks of therapy, patients in the vibrating group showed:

- 143% improvement in physical function.
- 41% improvement in pain.
- 60% increase in vitality.
- 23% improvement in general health.
- 57% improvement in quality of walking as assessed by the Tinetti test (compared with a 2% improvement in control subjects).
- 77% improvement in equilibrium (compared with 1% worsening in controls).
- 39% decrease in time required to get up and go (compared with an increase of 14% among controls).

While it was only a small study, "after just 3 weeks or 9 sessions, we saw a great improvement in get-up-and-go," Bruyere tells **rheuma*wire***. "Longer studies are needed," he adds. Patients in the new study also did about 10 minutes a day of classical physical exercise.

Denise Mann

Source

1. Bruyere O, Wuidart, MA, et al. Presentation: Controlled whole body vibrations improve health related quality of life in elderly patients. Orlando, FL: American College of Rheumatology: 2003 meeting; October 23-28, 2003:Abstract 1271.

CONTROLLED WHOLE BODY VIBRATIONS IMPROVE HEALTH RELATED QUALITY OF LIFE IN ELDERLY PATIENTS.

Olivier BRUYERE[1,2,3,4], Marc-Antoine WUIDART[3], Elio di PALMA[3], Jean-Yves REGINSTER[1,2,3]

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4. Haute Ecole André Vésale, Liège, Belgium

Objective: To investigate the effects of controlled whole body vibrations (CWBV) exercises on global health in elderly patients.

Methods: 42 volunteers patients, resident in a nursing home, were randomized to either a vibration group or control non-treated group. The vibration intervention consists of a 6-week CWBV training (4 x 1 minutes series, 3 times a week) employed by standing on a vertical vibrating (10 Hz in the first and the third series and 25 Hz in the second and fourth ones) platform (Galileo 900®). Different validated tests were performed, at the beginning and at the end of the study, in all patients. Quality of life was assessed by the 9 subscales of the SF-36 questionnaire: physical function (PF), social function (SF), role emotional (RE), role physical (RP), mental health (MH), vitality (V), pain (P), general health (GH) and health change (HC). Quality of walking, as well as the balance were assessed by the Tinetti test. The "get-up-and-go" test was used to assess the motor capacity.

Results: Baseline characteristics of the two groups (22 patients in the vibration group and 20 in the control group) was not statistically different except for age (84.5 (5.9) years in the treated group and 79.0 (6.9) years in the control group, p=0.008). After 6 weeks of treatment, 7 items (PF, SF, RE RP, V, P, GH) of the SF-36 improved significantly in the CWBV group compared to the control group, with, for example, 143% of improvement in PF (p=0.0002 between the two groups), 41% in P (p=0.004), 60% in V (p=0.0006), and 23% in GH (p=0.0002). Improvement of 57% in the quality of walking, assessed by the Tinetti test, was also observed in the treated group compared to only 2% in the control group (p=0.0003). For the equilibrium, improvement was 77% in the CWBV group and the worsening was 1% in the control group (p=0.001). Eventually, a decrease of 39% of the time to performed the get-up-and-go test was also observed, after 6 weeks, in the treated group, compared to an increase of 14% in the control group.

Conclusion: Fast and easy exercises, 3 times a week during 6 weeks, using a CWBV apparatus, could improve the quality of life, the walk, the balance and the motor capacity in elderly patients. Longer studies with more patients are needed to assess the impact of such benefits.

Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents.

Bruyere O, Wuidart MA, Di Palma E, Gourlay M, Ethgen O, Richy F, Reginster JY.

Abstract Bruyere O, Wuidart M-A, Di Palma E, Goulay M, Ethgen O, Richy F, Reginster J-Y. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. Objective To investigate the effects of whole body vibration in the elderly. Design Randomized controlled trial. Setting Nursing home. Participants Forty-two elderly volunteers. Interventions Six-week vibration intervention plus physical therapy (PT) (n=22) or PT alone (n=20). Main outcome measures We assessed gait and body balance using the Tinetti test (maximum scores of 12 for gait, 16 for body balance, 28 for global score), motor capacity using the Timed Up & Go (TUG) test, and health-related quality of life (HRQOL) using the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36). Results After 6 weeks, the vibration intervention group improved by a mean +/- standard deviation of 2.4+/-2.3 points on the gait score compared with no score change in the control group (P <.001). The intervention group improved by 3.5+/-2.1 points on the body balance score compared with a decrease of 0.3+/-1.2 points in the control group (P <.001). TUG test time decreased by 11.0+/-8.6 seconds in the treated group compared with an increase of 2.6+/-8.8 seconds in the control group (P <.001). The intervention group had significantly greater improvements from baseline on 8 of 9 items on the SF-36 compared with the control group. Conclusions Controlled whole body vibration can improve elements of fall risk and HRQOL in elderly patients.

The Galileo System
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The *Galileo System* consists of a vibrating platform for whole body exercise (*Mo 2000, 900 and XS*) and a vibrating dumbbell for the exercise of the upper limbs, forearm, arm and shoulders (*Model 100*).

The patented *Galileo System* has been developed to stimulate muscles in a manner t promotes the r rapid development while minimizing the need for conscious exertion a minimizing stress on the musculature, respiratory and cardiovascular systems. Becaus muscle's natural involuntary reflexive response time, or stretch time, is typically in er of 20 milliseconds, many successive activations can be performed in a relativ short period of time, thereby increasing the efficiency of muscle development. Whetl activation of the muscle is achieved by oscillatory motion of the body itself (vibrati platform – *Galileo Models 2000, 900 and XS*), or by superimposing oscillatory motic of an external mass on the body (vibrating dumbbell – *Galileo Model 100*), t frequency of activations is set at about 25 Hertz (or 25 activations per second) in order optimize the stimulation of the muscles' stretch reflexes. The desired amplitude of ea oscillation can be adjusted between 2mm and 10mm, depending on the level of exerti desired (the higher the amplitude, the "stronger" the exercise). Typical exercise time is minutes per week.

This unique system is stirring great interest in the health industry and medi community. Independent preliminary clinical investigations in Germany and Italy, us healthy volunteers, have centered on measuring the effects that short and long-te exposure to *Galileo System* have on bone strength and mass as well as on muscle fo a power. These studies demonstrate a significant increase in both bone and mus strength. The exciting outcome of this research suggests that *Galileo System* could be effective therapeutic modality in bone diseases, neuromuscular conditions and ot pathologies. It also has a demonstrated beneficial impact on muscle and bone stren among healthy individuals.

Leading scientists at New York University's School of Medicine and its renowned Ru Institute of Rehabilitative Medicine are currently conducting clinical studies on *Galileo 900*, the device that generates a dynamic whole-body stimulation, to gauge a determine the scope of its therapeutic applications.

The Galileo System may affect a host of physiologic mechanisms. It is well known t an important determinant of bone strength is the load that muscles apply on bones. T European studies offer convincing evidence that mechanical vibrations that the *Gali System* produces enhance the mechanical power of muscles in isometric conditio Moreover the same studies showed a large increase in neural activities during vibratic indicating stimulation of the neuromuscular system. However, more research is need to determine how long the physiologic effect lasts after the cessation of the vibr stimulus.

The "rat tail model" developed in laboratory research, provided new insight into repeated stressors elicit a time-dependent "sensitization". That is to say, it trigg bigger response upon repeated exposure to the same stressor. During this expo blood flow to the brain increased. The *Galileo System* may lead to a si "sensitization" and this calls for further investigation. The influence of vibr stimulation on the mechanical behavior of skeletal muscle may involve neural myogenic adaptation through a proprioceptive feedback mechanism via alpha m neuron spinal reflex loop and or a cortical reflex.

Although the physiologic mechanism the *Galileo System* impacts needs fu acterization, a series of anecdotal reports suggest that it has potential therap benefits for a growing number of medical conditions. Several spinal cord injury pati are currently receiving experimental treatment with the *Galileo System* at the I Institute of Rehabilitation Medicine at the New York University School of Medi These patients with demonstrated muscle potentials by EMG are experiencing incre muscle strength and improvement in residual functions. The device shows g promises in the treatment of stroke victims and trauma patients with neurolog damages.

Reportedly, patients with conditions such as degenerative osteoarthritis and osteopor have been successfully treated with the *Galileo System*. If confirmed, these rep indicate that the therapeutic approach to bone disease involves treating the bone-mu mechanical coupling.

During the first minutes on the *Galileo System – Models 2000, 900 and XS* – individ experience a drop in blood pressure with a return to baseline. This may be the resul pooling in the lower extremities but could also be, due to lowering of the periph vascular resistance (PVR). During exercise, PVR decreases with a simultaneous incre in cardiac output (CO) and blood flow in muscles. The observed increase in bl pressure (BP=COxPVR) is secondary to the increase in CO. The potential cardiovasc effects of *the Galileo System* on cardiac indices and PVR need further studies determine whether this device may be indicated in the treatment of hypertension.

If the *Galileo System* generates an increase in blood flow through an effect on peripheral vascular system, it would be of clear benefit to patients with periph vascular diseases, diabetic vasculopathy and neuropathy. A number of poten applications may also include the treatment of muscle spasm, low back pain, tens headache.

The *Galileo System* has convincingly shown a sustained benefit in muscle performa nd bone strength in normal healthy individuals and has proven to be of great value thletes. Exercise stimulates the sympathetic nervous system and this activat increases cardiac output and therefore provides the nutrients to meet the increa

metabolic demands. Vasodilatation occurs at the same time in the exercising mus counteracting the increase in blood pressure following the rise in cardiac output. *Galileo System*, by mechanically stimulating skeletal muscles increases t vascularization without an increase in blood pressure and probably has a smaller effec cardiac output than during exercise. The beneficial effect noted on muscle perform in athletes using the *System* needs further characterization.

Prior to considering potential applications of the *Galileo System* in disease condition comprehensive safety study will be carried out in healthy volunteers.

Contraindications to the use of the *Galileo System* include pregnancy, individuals w implants and prosthesis, epilepsy, bone tumors and fractures, stroke victims in the ac phase prior to recovery. This list is not exhaustive.

THE INFLUENCE OF WHOLE BODY VIBRATION ON THE MECHANICAL BEHAVIOUR OF SKELETAL MUSCLE

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Key Words: Vibration, muscle mechanics, muscle power

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ABSTRACT

The aim of this study was to investigate the effects of whole body vibrations on the mechanical behaviour of human skeletal muscles. For this purpose, fourteen physically active subjects were recruited and randomly assigned to an experimental (EG) and a control group (CG). The EG was treated fur ten days with 5 sets of vertical sinusoidal vibrations lasting up to two minutes each, for a total volume of ten minutes per day. The subjects of CG were asked to maintain their normal activity and avoid strength or jumping training. Subjects were tested at the beginning and at the end of the treatment with specific jumping tests performed on a resistive platform. Results showed remarkable and statistically significant enhancement in the EG of the height of the best jump (1.6 %, P<O.5), the mechanical power of the best jump (3.3 %, P<O.5) and the average jumping height during 5s Cj (12 %, P<0.01). In contrast, no statistically significant variations were noted in the CG. Consequently, it was suggested that the effect of WBV treatment elicit fast biological adaptation connected to neural potentiation.

Respuestas hormonales a la vibración corporal integral en los hombres

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Abstract. El propósito de este estudio era evaluar las respuestas agudas de concentraciones hormonales sanguíneas (blood hormone) y el rendimiento neuromuscular seguido de un tratamiento de vibración corporal integral, (WBV, whole-body vibration). 14 individuos hombres [media (SD) edad 25 (4.6) años] fueron expuestos a WBV vertical sinusoidal, 10 veces por 60 s, con 60 s de descanso entre series de vibración (un periodo de descanso de 6 minutos de duración fue permitido después de 5 sets de vibración). Las pruebas de rendimiento neuromuscular consistían en saltos counter-movement y prensa de pierna máxima en una máquina slide, ejecutado con una carga extra de 160% de la masa corporal del individuo, y con ambas piernas, fueron administrados antes e inmediatamente después de el tratamiento WBV. La velocidad promedio, aceleración, fuerza promedio y energía fueron calculados y la raíz media cuadrada electromiograma (EMGrms) fueron registradas de los músculos vastus lateral y rectus femoris simultáneamente durante la medición de prensa de pierna. Muestras de sangre fueron también recogidas y las concentraciones de plasma de testosterona (T), hormona de crecimiento (GH) y cortisol (C) fueron medidas. Los resultados mostraron un incremento significativo en la concentración de plasma de T y GH, donde los niveles de C disminuyeron. Un incremento en la energía mecánica de salida de los músculos extensores de la pierna fue observado junto con una reducción en la actividad EMGrms. La eficiencia neuromuscular mejoró, como esta indicado por la disminución en el ratio entre EMGrms y energía. El rendimiento de los saltos, que fue medido usando la prueba de salto counter-movement fue también mejorado. Por lo tanto, podría ser argumentado que el mecanismo biológico producido por vibraciones es similar al efecto producido por entrenamiento de energía explosiva (saltando y rebotando). La mejora de energía explosiva podría haber sido inducida por un incremento en la actividad de sincronización de las unidades motoras, y/o la coordinación mejorada de los músculos sinergísticos y la inhibición de los antagonistas. Estos resultados sugieren que el tratamiento WBV lleva a respuestas agudas de perfiles hormonales y rendimiento neuromuscular. Es por lo tanto probable que el efecto del tratamiento WBV condujo a una adaptación biológica que esta conectada a un efecto de potenciación neural, similar a aquel reportado que ocurre siguiendo un entrenamiento de resistencia y energía explosiva. En conclusión, es sugerido, que WBV mecanismos de retroalimentación proprioceptiva y componentes neurales específicos, que llevan a una mejora de rendimiento neuromuscular. Además, desde que las respuestas hormonales, caracterizadas por un incremento en las concentraciones de T y GH y una disminución en la concentración de C, y el incremento en efectividad neuromuscular fueron simultáneos pero independientes, es especulado que los dos fenómenos podrían tener mecanismos comunes.

Hormonal responses to whole-body vibration in men
Eur J Appl Physiol (2000) 81: 449-454

THE INFLUENCE OF VIBRATION ON ARM FLEXORS MECHANICAL POWER AND EMG ACTIVITY OF BICEPS BRACHII.

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KEY WORDS: Vibrations, Mechanical Power

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The influence of vibration on arm flexors mechanical power and EMG activity of biceps brachii.

ABSTRACT

The aim of this study was to evaluate the influence of vibrations on arm flexors mechanical properties and neural activity. For this scope, twelve international level boxers, all members of the Italian national team, voluntarily participated to the experiment undergoing to mechanical vibrations treatment. All of the subjects were engaged in their regular boxing training. At the beginning of the study they were tested when performing a forearm flexion with an extra load similar to 5% of subjects' body mass. Following this phase, one arm was assigned to the experimental treatment (E) (mechanical vibration) and the other to the control treatment (C) (no treatment). The E treatment consisted of five reps lasting one minute each of mechanical vibrations applied during arm flexion in isometric conditions with one minute rest between them. Post tests were performed five minutes right after the treatment on both limbs. Results showed statistically significant enhancement of the average power (AP) in the arm treated with vibrations. EMGrms did not change in following the treatment but, when divided for mechanical power, and used as an index of neural efficiency, it showed statistically significant increases. The conclusion was that mechanical vibrations can enhance mechanical power and neural efficiency in elite athletes. Moreover, the analysis of EMGrms recorded before the treatment and during the treatment itself have shown enormous increase of neural activity during vibrations up to more than twice the baseline values. This indicates that, this type of treatment, is able to stimulate the neuromuscular system more than other treatments utilised to improve neuromuscular properties.

The Effect of Whole Body Vibration on Mechanical Behaviour of Skeletal Muscle and Hormonal Profile

Carmelo Bosco, Roberto Colli, Marco Cardinale, Olga Tsarpela, Marco Bonifazi

SUMMARY

The aim of this work was to analyse the effects of a seven bouts lasting one minute each of whole body vibrations (WBV) on mechanical behaviour of human skeletal muscle and on hormonal responses.

For this scope, eight handball players underwent seven bouts of WBV lasting one minute each. The WBV treatment was administered while standing on a vibrating machine with the toes on the vibrations platform. The knee angle was pre-set at 90° flexion. The frequency of the vibrations used in this study was set at 26 Hz (displacement = 10mm ; acceleration = 54 m . s^{-2}). Jumping tests (Bosco protocol) were performed before and after the treatment. Blood samples were collected from the antecubital vein before and immediately after the administration of the seven bouts of 1 minute WBV treatment each. in all subjects examined. Serum total testosterone (T) and cortisol (C) were analysed. The results showed a decrease in the jumping height measured during CMJ ($P < 0.01$).

Following the WBV treatment, the mechanical power output of the leg extensor muscle and the average height. measured during 5s CJ, demonstrated also respectively a statistical significant reduction ($P< 0.01$ and $P <0.05$). A parallel statistical significant decrease of both serum T ($P<0.01$) and C ($P <0.005$) was also observed. It can be suggested that WBV treatment may act on the biological system in a similar manner to heavy resistance training determining both neuromuscular and hormonal responses specific to the stimulus applied.

High-Frequency Vibration Training Increases Muscle Power in Postmenopausal Women

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ABSTRACT. Russo CR, Lauretani F, Bandinelli S, Bartali B, Cavazzini C, Guralnik JM, Ferrucci L. High-frequency vibration training increases muscle power in postmenopausal women. Arch Phys Med Rehabil 2003;84:1854-7.

Objective: To test whether training on a high-frequency (28Hz) vibrating platform improves muscle power and bone characteristics in postmenopausal women.

Design: Randomized controlled trial with 6-month follow-up.

Setting: Outpatient clinic in a general hospital in Italy.

Participants: Twenty-nine postmenopausal women (intervention group, n=14; matched controls, n=15).

Intervention: Participants stood on a ground-based oscillating platform for three 2-minute sessions for a total of 6 minutes per training session, twice weekly for 6 months. The controls did not receive any training. Both groups were evaluated at baseline and after 6 months.

Main Outcome Measure: Muscle power, calculated from ground reaction forces produced by landing after jumping as high as possible on a forceplate, cortical bone density, and biomarkers of bone turnover.

Results: Over 6 months, muscle power improved by about 5% in women who received the intervention, and it remained unchanged in controls (P=.004). Muscle force remained stable in both the intervention and control groups. No significant changes were observed in bone characteristics.

Conclusion: Reflex muscular contractions induced by vibration training improve muscle power in postmenopausal women.

Key Words: Bone density; Exercise; Muscles; Postmenopause; Rehabilitation; Vibration; Women.

Estimulación Mecánica en la Forma de Vibración Previene Posmenopáusica Pérdida de Hueso en Ratas Ovariectomizadas

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Abstract. El ejercicio físico es recomendado para la prevención y tratamiento de la osteoporosis. Sin embargo, el papel que juega y la efectividad en la adultez no están claramente establecidos. Mientras el ejercicio vigoroso de larga duración mejora la densidad ósea, pocos individuos adultos cumplen con tales programas de entrenamiento. El presente estudio evalúa la influencia de la estimulación mecánica no-fisiológica. En la forma de vibraciones de baja densidad (frecuencia: 50 Hz. Aceleración: 2 g.30 min/día por 5 días / semana). En la prevención de pérdida ósea en un modelo animal de osteoporosis posmenopáusica. En los grupos ovariectomizados de ratas una disminución estadísticamente significativa ($p<0.05$) de densidad ósea (fémur y tibia) fue registrada a 5 semanas de postovariectomía. Este efecto fue mantenido por las 12 semanas de duración del estudio de vibración previno la pérdida ósea temprana después de la ovariectomía. Las ratas ovariectomizadas sometidas a la vibración mostraron valores BMD estadísticamente significativos más altos (p c 0.05) comparados con aquellos de los controles ovariectomizados a las 5 semanas. La vibración no influenció la densidad ósea de las ratas SHAM-operadas. Sin embargo, la vibración incrementó la fuerza (fractura de carga del fémur de la rata) en las ratas ovariectomizadas. Este hallazgo no fue estadísticamente significativo. Nuestros datos indican que este método de vibración segura y fácilmente aplicable en la forma de plataforma vibratoria es efectivo en prevenir la pérdida ósea en la postovariectomía temprana en un modelo animal.

Mechanical Stimulacion in the Form of Vibration Prevents Postmenopausal Bone Loss in Ovariectomized Rats
Calcio Tissue Int (1998) 63:510-5

OSCILLATING MECHANICAL INTERVENTIONS LEAD TO ALTERATIONS IN MUSCLE BLOOD VOLUME

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Running title: Oscillating mechanical interventions – alterations in muscle blood volume

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ABSTRACT

Objectives – Occupationally used high-frequency vibration is supposed to have negative effects on blood flow and muscle strength. Conversely, low-frequency vibration used as a training tool appears to increase muscle strength, but nothing is known about its effects on peripheral circulation. The aim of this investigation was to quantify alterations in muscle blood volume after exercising on the training device Galileo 2000 (Novotec GmbH, Pforzheim, Germany).

Methods - Twenty healthy adults performed a 9-minute standing test. They stood with both feet on a platform, producing oscillating mechanical vibrations of 26 Hz. Alterations in muscle blood volume of the quadriceps and gastrocnemius muscles were assessed with power Doppler sonography and arterial blood flow of the popliteal artery with a Doppler ultrasound machine. Measurements were performed before and immediately after exercising.

Results - Power Doppler indices indicative of muscular blood circulation in the calf and thigh significantly increased after exercise. The mean blood flow velocity in the popliteal artery increased from 6.5 to 13.0 cm/s and its resistive index was significantly reduced.

Conclusions – The results indicate that low-frequency vibration does not have the negative effects on peripheral circulation known from occupational high-frequency vibration. Therefore, stimulation with low-frequency vibration from an apparatus like the Galileo 2000 may be a safe method for increasing muscle strength.

Keywords: Vibration; muscle contraction; arterial blood flow; tissue blood flow

Zur streng vertraulichen Einsichtnahme

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Safety of Whole-Body Vibration Exercise for Heart Transplant Recipients

Sicherheit von Ganzkörpervibrationstraining bei herztransplantierten Patienten

Zusammenfassung

Fragestellung: Die positiven Wirkungen des Ganzkörpervibrationstrainings (WBV) werden bis dato in der Rehabilitation nach Herztransplantation nicht eingesetzt, obwohl gerade diese Patienten oft eine ausgeprägte Muskelschwäche und Osteoporose zeigen. Ziel dieser Studie war es, die Sicherheit eines WBV sowie die kardiovaskulären und metabolischen Reaktionen bei herztransplantierten Patienten zu untersuchen. **Material und Methode:** 14 männliche, klinisch stabile, herztransplantierte Patienten wurden in diese Studie eingeschlossen. Als Intervention führten die Patienten eine Einheit Ganzkörpervibrationstraining am Galileo 2000 durch. Die Herzfrequenz, systolischer und diastolischer Blutdruck, die Plasmalaktatkonzentration, sowie die BORG-Skala wurden zur Bestimmung der objektiven und subjektiven Belastung während WBV herangezogen. **Ergebnisse:** Abbruchgrund bei WBV war bei jedem Patienten die lokalisierte Muskelschwäche der Beinmuskulatur. Die durchschnittliche Versuchsdauer betrug 248 Sekunden (Range 51 – 607). Herzfrequenz, systolischer und diastolischer Blutdruck sowie die Plasmalaktatkonzentrationen erreichten während des WBV Werte wie bei aerobem Ausdauertraining. Es kam bei keinem Patienten zu unerwarteten Zwischenfällen. **Schlussfolgerung:** Die Ergebnisse dieser Pilotstudie weisen darauf hin, dass WBV bei herztransplantierten Patienten sicher durchführbar ist. Bei einer Ein-

Abstract

Purpose: The benefits of whole-body vibration exercise (WBV) have not yet been recognized in heart transplant recipients although these patients often show a severe loss in skeletal muscle strength and bone mineral density over time. At present, WBV is not generally recommended for rehabilitation of transplant patients. The purpose of this study was to document the safety, cardiovascular responses and metabolic changes to WBV in heart transplant patients. **Material and methods:** 14 male clinically stable heart transplant recipients were included in this study. The subjects were exposed to one set of whole-body vibration using the Galileo 2000 device. Heart rate, systolic and diastolic blood pressure, blood lactate concentration and the Borg scale were used to determine objective and subjective exertion during WBV. **Results:** In every patient WBV was terminated due to muscular fatigue. The mean duration of exercise was 248 seconds (range, 51 – 607 seconds). Heart rate, systolic and diastolic blood pressure, lactate concentrations and the Borg score increased during WBV to levels achieved during aerobic exercise. No patient experienced adverse events. **Conclusion:** The results of this pilot study indicate that WBV is feasible and safe in heart transplant recipients. The cardiovascular and metabolic response of an acute bout of WBV is similar to that of standard aerobic exercise.

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Los ejercicios de vibración corporal integral conducen a alteraciones en el volumen sanguíneo muscular

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Abstract

Es supuesto que la vibración de alta frecuencia usada ocupacional mente puede tener efectos negativos en el flujo sanguíneo y la fuerza muscular. Contrariamente, la vibración de baja frecuencia usada como herramienta de entrenamiento parece incrementar la fuerza muscular, pero nada se sabe sobre sus efectos en la circulación periférica. El propósito de esta investigación era cuantificar las alteraciones en el volumen muscular después de recibir vibración muscular integral – después de ejercitarse en el aparato de entrenamiento Galileo 2000 (Novotec GMBH, Pforzheim, Alemania). 20 adultos saludables se sometieron a un test de 9 minutos erguidos. Estuvieron parados con ambos pies sobre una plataforma que producía vibraciones mecánicas oscilatorias de 26 Hz. Alteraciones en el volumen sanguíneo del cuadriceps y del músculo gemelo fue valorada con sonografía de energía Doppler y flujo arterial sanguíneo de la arteria popliteal con una máquina de ultrasonido Doppler. Las mediciones fueron realizadas antes e inmediatamente después de los ejercicios. Los índices de energía Doppler indicativos de circulación sanguínea muscular en el gemelo y el muslo se incrementaron significativamente después del ejercicio. La media de velocidad del flujo sanguíneo en la arteria popliteal se incrementó de 6.5 a 13.0 cms^{-1} y su índice de resistividad fue significativamente reducido. Los resultados indican que las vibraciones de baja frecuencia no tienen los efectos negativos en la circulación periférica conocidos de la vibración ocupacional de alta frecuencia.

Whole-body vibration exercise leads to alterations in muscle blood volume
Clinical Physiology 21, 3, 377-382 •) 2001 Blackwell Science Ltd.

VIBRATORY STIMULATION TRAINING: A NEW APPROACH FOR DEVELOPING STRENGTH AND FLEXIBILITY IN ATHLETES

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INTRODUCTION

Exercises for strength abilities and flexibility are a main component of the training process in most sport discplines. They determine both the general and specific bases for skillful performance. Moreover, the types of exercises, the methods and the instruments used for strength training are the most popular areas of innovation in sport training. Elite sport strength training

has been the focus of special attention in the past in the following directions:

- isometric exercises (Hettinger, 1964)
- isokinetic exercises (Counsilman, et al., 1972)
- electrostimulatory contractions (Koc, 1971)
- the use of anabolic steroids as ergogenic stimulators (see Silber, 1992 for a review)

All these directions, with the exception of the last one, contributed to the progress of training methods. Another situation is observed in the area of flexibility training. The repertoire of stretching exercises was supplemented in the last four or five decades with the introduction of PNF (proprioceptive nervous facilitation) techniques only.

It is certain that contemporary athletic training requires methodological and technological innovations which may improve the physiological and biomechanical aspects of athletic training.

The vibratory stimulation (VS) method may be considered as a combination of these two aspects. Early investigations on VS were conducted by Hugharth and Eklund (1966) and Matthews (1966) from a neurophysiological point of view. The effects of VS stem from the fact that the muscle is stimulated during active contractions. The practical application of this method has also been used on physiotherapeutic grounds (Bishop, 1974). Only recently, VS was investigated regarding motor fitness training (Nazarov & Spivak, 1987; Issurin et al., 1988). While VS could potentially be applied to a large area of fitness exercises, the implementation of this approach has been limited until now. This is probably due to a lack of knowledge and experience, and a lack of appropriate devices.

The purpose of this work is to present some positive results using the VS method to develop strength and flexibility in athletes. Namely, the study was aimed at testing the VS training and defining the effect of the VS program compared to conventional methods.

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Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes

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Fourteen elite and 14 amateur athletes were subjected to vibratory stimulation during bilateral biceps curl exercises of explosive strength exertion. The athletes performed two separate series of three sets of exercises in random order. The second set of one series was administered with superimposed vibration of 44 Hz and an acceleration of about 30 $m \cdot s^{-2}$ transmitted through the two-arms handle to the arm muscles. The mechanical power of each repetition was measured by the 'Power Teach' instrument. The maximal and mean power values for each set were automatically recorded and shown on the screen. The acute effect was evaluated as the difference between the mean and peak power output in the second (with vibratory stimulation) and first (without vibratory stimulation) sets. Similarly, the residual effect was taken to be the difference between the power values of the third (after vibratory stimulation) and the first (before vibratory stimulation) sets. The results were subjected to a repeated-measures analysis of variance with group as a between-participants factor. The results showed that exercise mode (with *vs* without vibratory stimulation) resulted in a significant immediate effect for mean power and for maximal power. The factor group (elite *vs* amateurs) resulted in a significant effect for maximal power only. The increase in explosive strength exertion attributed to vibratory stimulation was 30.1 and 29.8 W (10.4% and 10.2%) for maximal and mean power respectively in the elite group, and 20.0 and 25.9 W (7.9% and 10.7%) respectively in the amateur athletes. Vibratory stimulation resulted in an insignificant residual effect.

Keywords: acute effect, amateur athletes, elite athletes, explosive strength, vibratory stimulation exercises.

TRAINING OF THE SKELETAL-MUSCLE APPARATUS OF SPORTSMEN THROUGH ELECTROVIBROSTIMULATION

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INTRODUCTION

It is often necessary to correct the functional state of the human skeleto-muscular apparatus (SMA) in order to increase the muscle contraction force and the joint mobility as in sports and ballet, for the ret :itation of invalids and in prolonged space flight to compensate for hypokinesy and hypodynamy. For sportsmen it is important to restore their condition after injuries in the shortest possible time. However, traditional methods require a long time to achieve a high functional condition of the SMA. Investigations of the last years showed that electrostimulation is an effective method for the increase of the muscle force and that through vibrostimulation a better joint mobility is achieved.

METHOD

Systematically repeated muscle contractions caused by electrical pulses increase the physiological muscle diameter which results in an increased muscle force. After 20 electrostimulation sessions the maximum of the isometric tension can increase with 40% - 50%. The electrostimulation induces the addressed muscles to deliver work, which resu in an hypertrophy of the myofibrils together with a relative decrease of the sarcoplasmic spaces. As the muscle fibres of the gross motor units are located more superficially than the deeper lying fibres of the fine motor units, at the onset of the electrostimulation treatment the gross motor units of the large movements are recruited first, even with a weak electrical stimulation. So those motor units, which are hard to train at will, but which are very important for the development of the muscle force, can be trained easily by the electrical training. The vibrational forces belong to the rhythmical mechanical stimulations, which summon a specific reaction of the neuromuscular apparatus and other systems of the body. With vibrostimulation, these mechanical impulses and oscillations can act as physiological stimuli. The vibrostimulation has a lasting effect on the nervous system, which can stay even during several days after the treatment. Already a short vibro-massage shortens the rehabilitation period of the muscular system of sportsmen. The efficiency to develop the muscle forces of the joint movements or to revalidate the motional functions after trauma and illness is at least ten times higher than in the traditional methods of sports and sportsmedicine.

The working hypothesis was applied as follows: during the exercises electro- and vibrostimulation were used simultaneously in order to perfect the active movement in the different joints. During a programmed sequence of motions by synergists and antagonists, the vibrostimulation was applied to the antagonists while the electrostimulation was applied to the agonists and synergists. The vibrostimulation elongates the antagonistic muscles, i.e. the zone of the passive insufficiency decreases, whereas the electrostimulation causes the force of the synergistic contraction to increase in the zone of the active insufficiency (fig. 1). As a result we observe an improvement in the active movement of the human skeletal-muscular apparatus. We assume, that the simultaneous stimulation of both synergists and antagonists helps to achieve an optimum pattern of the joint movement.

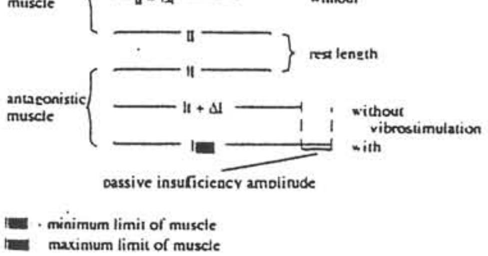


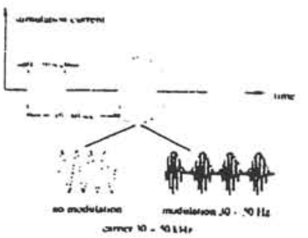
fig. 1: Effects of Muscular Electrovibrostimulation Training

We therefore developed a program-controlled device for the electrovibro-stimulation of the human skeleto-muscular apparatus for applications in medicine, ballet and sport. Separate electro - or vibrostimulators are available but devices for the combined electrovibrostimulation do not exist. The characteristics of the existing devices are not fit for professional use, as a.o. the existing electrostimulators lack a stabilization of the injected muscle current, the pulse frequency range is too limited, the only unipolar pulses cannot remove electric rest charges, and none can give pulse bursts or a modulated pulse sequence. Likewise the existing vibromassage units are not so well adapted to medical purposes, because they are not versatile in application and because the vibro characteristics can only be tuned in a very limited frequency range.

The Laboratory of Biocybernetics of the St.Petersburg State Technical University developed and tested a prototype of a muscle electrovibrostimulator, after the laboratory model had been ordered by the Central Scientific Research Institute of Prosthetics in Moscow.

The apparatus consists of three main parts: the electrostimulator, the vibrostimulator and the programmable control and driver unit. The electrostimulator consists of a generator for pulses or pulse trains of selectable frequency, duration, amplitude and shape, adaptable to the patient's condition. The pulse lenghth varies between 1 to 10 seconds with 10 to 60 second periods between consecutive bursts. The number of pulses for a single treatment can be chosen between 2 to 11. The pulse bursts consist of a continuous or amplitude modulated 30 - 50 kHz harmonic signal. In the modulated mode the modulation is a 30 - 50 Hz sine wave with 100% modulation depth. In this mode, each pulse train starts from zero amplitude, which makes the electrostimulation softer even for rather large (50 mA) stimulation currents. The output stage amplifier of the electrostimulation channel has a strong negative feedback which stabilizes the current to better than ±1% even under extreme values of the skin-muscle load resistance between the electrodes. (fig. 2).

The vibrostimulator is based on an electromotor, whose rotor revolutions are transformed into the linear oscillations of the vibrator. The design of the transformer mechanism allows a continuously variable vibrational amplitude of the vibrator probe of 3 - 6 mm in a frequency range of 15 - 30 Hz. Both parameters are electrically controlled so that they can be varied during the electrostimulation following a preset program. The device has different exchangeable massage probes which permit the massage of different parts of the patient's body with maximum effect.



ig. 2: Characteristics of the Electrostimulation Pulse

The module of the programmable driver unit allows manual selection of the parameters for electro- and vibrostimulation, and automatic control of the action of the electrovibrostimulator with given amplitude, frequency and duration. The electronic circuits of the electrovibrostimulator and the control unit use the IC technology in MSI, which is a fair compromise between a good reliability of the apparatus under field conditions and a reasonable price of the unit.

The broad adaptation range of the pulse parameters of the combined apparatus allows an optimum application in order to ensure for every patient the maximum efficiency of the medical and medico-profilactic measures.

RESULTS

In order to test the developed electrovibrostimulator two series of experiments were set up. In the first series the separate influence of vibrostimulation and electrostimulation on the improvement of the joint movement was measured during different exercises. By the second series the effect of the combined method of the muscular electrovibrostimulation in the physical training of athletes was experimentally determined. Therefore three experimental and three control groups were formed. In each experimental group one of the stimulation methods was tested: in the first group the electrostimulation, in the second the vibrostimulation, in the third the combined electrovibrostimulation. In total more than 100 top athletes took part in the experiments, among them 10 world qualification masters of sport and 20 masters of sport. The other athletes were candidates of master of sport and sportsmen of the 1st class. Also took part in our experiments the Honoured Masters of Sport A. Ditjatin and E. Davidova, two winners of golđ at the XXII Olympic Games in Moscow.

Each group had 25 training sessions. During these trainings the athletes did special exercises with electrostimulation, vibrostimulation or with combined electrovibrostimulation. During each training session we defined and registered the level of development of the movements of the trained joints. The stimulation treatment was applied once a day every second day, always in combination with the ordinary training. The whole experiment lasted for 6 weeks.

A neccessary condition of the experiment was the active participation of the sportsman. In an exercise the athlete performed rythmical movements during which he e.g. tried to lift his leg as high as possible, first without, then with vibrostimulation. With the vibrostimulation switched on, the leg moved higher than without. After several minutes the vibrostimulation was switched off and the athlete should then keep his leg in the up position as long as possible, at least several seconds. After this phase the vibro- and electrostimulation were applied simultaneously. As a result, the added electrovibrostimulation helped the testperson to lift the leg 6-10 cm higher than his normal height limit.

During all the time of the electrovibrostimulation we perceived a tendency to increase the amplitude of the movement. With clear statistical significance this increase of the active mobility at lifting the leg was observed for all sportsmen. A quite important observation is, that the electrovibrostimulation effect stays for a considerable time: from 1 month till 1,5 months. During this time the repetition of that specific exercise without the electrovibrostimulation proved the effectiveness of our method.
On the other hand, the passive mobility in the hip-joint also improved. Gymnasts who could do the splits before, experienced that it was easier for the: ɔ do the splits under electrovibrostimulation. Sportsmen unable to do the splits before, came already after a first electrovibrostimulation session 3-5 degrees nearer to the aim of this exercise. Sportsmen who had never done the splits before started to do it completely after 5-7 electrovibrostimulation trainings. Only three sportsmen from the experimental group could not perform the splits completely. However, the amplitude of their hip-joint motion in the frontal plane increased with not less than 8-10 degrees.

This shows that the improvement of active leg-lifting under the influence of electrovibrostimulation influences the ability to spread the legs passively as well. In anatomical terms, leg-lifting can be defined as anteversion or flexion of the hip-joint. It is generally known, that anteversion in itself facilitates both abduction (i.e. spreading) as well as rotation the hip-joint. This can be attributed a.o. to the de-spiralling of the iliofemoral ligament in hip-flexion. Possibly electrovibrostimulation has some influence on this phenomenon too.

The results of these experiments show that the combined electrovibrostimulation gives in a shorter time a better effect for the training of the active and the passive mobilities in the hip-joint and confirm the superiority of the electrovibrostimulation training in attaining the optimum joint mobility. We assume that vibrostimulation perfects the mobility by reducing the zone of the passsive muscle insufficiency, whereas electrovibrostimulation reduces both, the zone of the passive as well as the zone of the active insufficiency. Vibrostimulation elongates the antagonistic muscles, so that the range of the passive insufficiency decreases. Electrostimulation increases the contraction force of the agonistic-synergistic muscles in the zone of the active insufficiency, resulting in a better active mobility of the locomotor system. The simultaneous stimulation of synergists and antagonists creates the optimum mobility structure in the joint.

CONCLUSIONS

Research in our laboratory of Biocybernetics of the St.-Petersburg State Technical University showed that the results of the combined electro- and vibrostimulation are better than those obtained after a separate application of both. With a programmable device for the combined electrovibrostimulation we achieved an increase of the concentrical and eccentrical muscle contraction force, a substantial decrease of the zones of active and passive muscle insufficiency and an increase of the joint mobility. The experimental data show that after the electrovibrostimulation the increase of the active and the passive mobility in the joints goes practically parallel. This means that notwithstanding a considerable increase of the mobility because of the stretching of the antagonistic muscles, the joint maintains its function and stability because of the increase of the synergistic muscle force. The electrovibrostimulation training also had a positive influence on the rehabilitation of the joint mobility after trauma. In that case, the experiments confirmed the effectiveness of the electrovibrostimulation training for the redevelopment of the muscle force and joint mobility. So our research resulted in the development of a method which improves the functional condition of the human SMA in the zones of the active and passive insufficiencies, especially under extreme loads.

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Good Maintenance of High-Impact Activity-Induced Bone Gain by Voluntary, Unsupervised Exercises: An 8-Month Follow-up of a Randomized Controlled Trial

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ABSTRACT

The purpose of this study was to evaluate whether premenopausal women's voluntary unsupervised aerobic and step training could maintain the skeletal benefits obtained by an 18-month supervised high-impact training, and if so, to what extent. Thirty women of the original 39 study subjects (i.e., persons who completed the preceding H-month randomized training intervention and who volunteered to continue the training on their own for a further 8 months) and 19 women of the 45 original control subjects (i.e., persons who volunteered to continue as controls) were included. The study group trained an average of twice per week and the training consisted of regular aerobic and step classes provided by local fitness centers. Areal bone mineral density (BMD, g/cm^2) was measured from the lumbar spine, femoral neck, trochanter area of the femur, distal femur, patella, proximal tibia, calcaneus, and dominant distal radius at baseline and after 18 and 26 months. During the extended 8-month follow-up, the BMD of the study group increased more at the femoral neck (the intergroup change was +0.9% at 18 months and +2.8% at 26 months, $p = 0.004$ for the change between 18 and 26 months) and remained at the 18-month level at the distal femur, patella, proximal tibia, and calcaneus. In these sites, the statistically significant changes during the entire 26 months of training were 1.7–4.0% in the training groups compared with the changes of -0.9-1.5% in the control group. In the lumbar spine, BMD decreased from the 18-month level in both groups. In conclusion, the significant BMD increases that were obtained by supervised 18-month high-impact training were effectively maintained with subsequent unsupervised regular aerobic and step classes (twice per week). The finding emphasizes the effectiveness and feasibility of self-controlled aerobic and step exercises in the primary prevention of osteoporosis among healthy premenopausal women. (J Bone Miner Res 1999;14:125-128)

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Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study

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Keywords
body balance; electromyography; muscle performance; whole body vibration

Summary

This randomized cross-over study was designed to investigate the effects of a 4-min vibration bout on muscle performance and body balance in young, healthy subjects. Sixteen volunteers (eight men, eight women, age 24–33 years) underwent both the 4-min vibration- and sham-interventions in a randomized order on different days. Six performance tests (stability platform, grip strength, isometric extension strength of lower extremities, tandem-walk, vertical jump and shuttle run) were performed 10 min before (baseline), and 2 and 60 min after the intervention. The effect of vibration on the surface electromyography (EMG) of soleus, gastrocnemius and vastus lateralis muscles was also investigated. The vibration-loading, based on a tilting platform, induced a transient (significant at the 2-min test) 2·5% net benefit in the jump height ($P = 0{\cdot}019$), 3·2% benefit in the isometric extension strength of lower extremities ($P = 0{\cdot}020$) and 15·7% improvement in the body balance ($P = 0{\cdot}049$). In the other 2-min or in the 60-min tests, there were no statistically significant differences between the vibration- and sham-interventions. Decreased mean power frequency in EMG of all muscles during the vibration indicated evolving muscle fatigue, while the root mean square voltage of EMG signal increased in calf muscles. We have shown in this study that a single bout of whole body vibration transiently improves muscle performance of lower extremities and body balance in young healthy adults.

Effect of four-month vertical whole body vibration on performance and balance

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ABSTRACT

TORVINEN, S., P. KANNUS, H. SIEVÄNEN, T. A. JÄRVINEN, M. PASANEN, S. KONTULAINEN, T. L. JÄRVINEN, M. JÄRVINEN, P. OJA, and I. VUORI. Effect of four-month vertical whole body vibration on performance and balance. *Med. Sci. Sports Exerc.*, Vol. 34, No. 9, pp. 1523–1528, 2002. **Purpose:** This randomized controlled study was designed to investigate the effects of a 4-month whole body vibration-intervention on muscle performance and body balance in young, healthy, nonathletic adults. **Methods:** Fifty-six volunteers (21 men and 35 women, aged 19–38 yr) were randomized to either the vibration group or control group. The vibration-intervention consisted of a 4-month whole body vibration training (4 min·d^{-1}, 3–5 times a week) employed by standing on a vertically vibrating platform. Five performance tests (vertical jump, isometric extension strength of the lower extremities, grip strength, shuttle run, and postural sway on a stability platform) were performed initially and at 2 and 4 months. **Results:** Four-month vibration intervention induced an 8.5% (95% CI, 3.7–13.5%, $P = 0.001$) net improvement in the jump height. Lower-limb extension strength increased after the 2-month vibration-intervention resulting in a 3.7% (95% CI, 0.3–7.2%, $P = 0.034$) net benefit for the vibration. This benefit, however, diminished by the end of the 4-month intervention. In the grip strength, shuttle run, or balance tests, the vibration-intervention showed no effect. **Conclusion:** The 4-month whole body vibration-intervention enhanced jumping power in young adults, suggesting neuromuscular adaptation to the vibration stimulus. On the other hand, the vibration-intervention showed no effect on dynamic or static balance of the subjects. Future studies should focus on comparing the performance-enhancing effects of a whole body vibration to those of conventional resistance training and, as a broader objective, on investigating the possible effects of vibration on structure and strength of bones, and perhaps, incidence of falls of elderly people. **Key Words:** VERTICAL JUMP, LOWER LIMB EXTENSION STRENGTH, SHUTTLE RUN, POSTURAL SWAY, YOUNG ADULTS

Effect of Vibrostimulation on Athletes' Performance

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E. Kushnirenko

The traditional ways of improving the physical fitness of athletes through the use of training are widely known. However, in recent years the so-called nontraditional methods have become increasingly popular. These include electrostimulation, acupuncture, acupressure, vibrostimulation of active points, and so forth. The purpose of this paper is to study the effect of single vibrostimulation of biologically active points on the improvement of athletic performance. As a criterion of efficiency of vibroaction a PWC_{170} test was used; spectral characteristics of the tremor of upper extremities were studied, and the time shown by the athletes on the 100-m swimming distance was recorded.

Efecto de 6 meses de entrenamiento con vibración corporal integral en la densidad ósea de la cadera, fuerza muscular y control postural en mujeres posmenopáusicas: Estudio piloto controlado y randomizado.

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Dirk Vanderschueren,[3] y Steven Boonen[4]

ABSTRACT: una tensión mecánica de alta frecuencia parece estimular la fuerza ósea en animales. En este ensayo controlado y randomizado, la densidad mineral de los huesos (BMD, bone mineral density) fue medida en mujeres posmenopáusicas después de 24 semanas de seguir un programa de entrenamiento con vibración corporal integral (WBV, whole body vibration). El entrenamiento con vibraciones incrementó significativamente la BMD de la cadera. Estos hallazgos sugieren que el entrenamiento con WBV podría ser muy útil en la prevención de la osteoporosis.

Introducción: Tensión mecánica de alta frecuencia ha mostrado que ayuda a estimular la fuerza de los huesos en diferentes tipos de animales. Sin embargo, los efectos del ejercicio de vibración en el esqueleto humano han sido estudiados raras veces. Particularmente en mujeres posmenopáusicas, quienes son las de mayor riesgo de contraer osteoporosis, se seleccionaron al azar y se controlaron los datos para hallar la seguridad y eficacia de la vibración con o sin carga. El propósito de este ensayo fue valorar los efectos músculo-esqueleticos de cargar con alta frecuencia por medio de vibraciones en el cuerpo entero (WBV) en mujeres posmenopáusicas.

Materiales y Métodos: Setenta voluntarias (edades, 58-74 años) fueron asignadas al azar a un grupo de entrenamiento con vibración corporal integral (WBV, n=25), un grupo de entrenamiento de resistencia (RES, n=22), o un grupo de control (CON, n=23). El grupo WBV y el grupo RES entrenaron tres veces a la semana por 24 semanas. El grupo WBV desarrollo ejercicios de extensión de rodilla estáticos y dinámicos en plataforma vibratoria (35-40 Hz, 2.28-5.09g), los cuales cargaron mecánicamente el hueso y provocaron contracciones reflejas del músculo. El grupo RES entrenó los extensores de la rodilla con prensa de pierna dinámica y ejercicios de extensión de pierna, incrementando resistencia desde un bajo (20 RM) a un alto (8 RM). El grupo CON no participó en ningún entrenamiento. La densidad del hueso de la cadera fue medida usando DXA al inicio del estudio y después de 6 meses de intervención. Las fuerzas isométrica y dinámica fueron medidas por medio de un dinamómetro dirigido a motor. Los datos fueron analizados por medio de mediciones repetitivas ANOVA.

Resultados: No fueron observados efectos secundarios relacionados con la vibración. El entrenamiento con vibración mejoró la fuerza isométrica y dinámica del músculo (+15% y +16%, respectivamente; $p<0.01$) y también incrementó significativamente BMD de la cadera (+0.93%, $p<0.05$). No fueron observados cambios en BMD de la cadera en las mujeres que participaron en entrenamiento de resistencia o los controles de edad comparable (-0.60% y -0.62%, respectivamente; no significativos). Los marcadores de suero de recambio óseo (turnover) no cambiaron en ninguno de los grupos.

Conclusión: Estas hallazgos sugieren que el entrenamiento WBV podría ser una manera factible y efectiva de modificar factores de riesgo bien-reconocidos por caídas y fracturas en mujeres mayores y justificar la necesidad para estudios humanos adicionales.

Effect of 6-Month Whole Body Vibration Training on Hip Density, Muscle Strength, and Postural Control in Postmenopausal Women: A Randomized Controlled Pilot Study.
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RELACION ENTRE LA MASA OSEA Y LA FUERZA MUSCULAR : UN NUEVO CAMPO EN LA APLICACIÓN DE LA VIBROESTIMULACION EN EL MUNDO DEL DEPORTE.

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La formación y desarrollo del tejido esquelético es un proceso continuo y dinámico, que implica la participación de factores genéticos, raciales, hormonales (endocrinos y autocrinos), nutricionales y mecánicos.

El tejido óseo, a diferencia de otros tejidos, posee una serie de mecanismos enzimáticos que permiten la mineralización de su matriz extracelular, convirtiéndolo en una estructura dura y adecuada para su función de soporte del organismo.

Junto a estas funciones mecánicas, el tejido óseo desempeña también una importante función metabólica en la regulación y homeostasis del calcio plasmático y de otros elementos inorgánicos, además de albergar en su interior el tejido progenitor de los elementos formes de la sangre, la médula ósea.

El desempeño y mantenimiento de las funciones del hueso requiere una adecuada interacción entre sus diferentes tipos celulares en el proceso de neoformación y posterior mineralización de la matriz, que esta sometida a un constante remodelamiento gracias al equilibrio entre la aposición y la resorción ósea.

El resultado de este equilibrio es la cantidad de mineral óseo depositado en la matriz extracelular.

El estrés mecánico y la presión han demostrado una importancia fundamental en el mantenimiento de la homeostasis mineral y esquelética. De hecho factores piezoeléctricos y físicos son fundamentales tanto en el crecimiento y configuración como en la conservación del capital mineral del hueso en la edad adulta.

La capacidad del hueso para responder al estrés físico está en concordancia con la ley de Wolff descrita por este médico alemán hace cien años: "cada cambio en el ambiente se sigue de un cambio en la arquitectura interna" o dicho con otras palabras "la forma sigue a la función". De acuerdo con esta ley, la estructura ósea presenta idéntica orientación que las correspondientes trayectorias de carga, adaptándose el hueso en su estructura trabecular y cortical.

El tejido óseo reacciona a la tensión mecánica desarrollando potenciales en respuesta a las fuerzas impuestas por la actividad muscular y la gravedad. La tensión sobre el hueso desarrolla electropositividad, que activa a las células osteocíticas que producen reabsorción ósea, mientras que la compresión produce electronegatividad y activa las células osteoblásticas formadoras de hueso. Por todo esto, cualquier hueso sujeto a estrés aumenta la densidad a lo largo de las líneas de fuerza, siendo evidente tanto en el grosor de la cortical, como en el patrón trabecular del hueso. (Carbon 1992). Durante la fase de remodelado óseo la resorción osteocítica precede a la formación del nuevo hueso y el estímulo excesivo y repetido hace que la resorción exceda a la formación, pudiendo dar como resultado las fracturas de estrés.

• Estructura del hueso

La estructura del esqueleto óseo no es homogénea; en él se pueden distinguir dos componentes bien diferenciados: el hueso cortical, más compacto, que representa el 80% de la masa ósea total y el hueso trabecular o esponjoso, que representa el 20%

restante. El hueso trabecular se localiza preferentemente en el esqueleto axial, el turnover óseo en él es más rápido y en consecuencia es más sensible a los cambios en contenido mineral que el hueso cortical. Esta es la razón por la cual los estudios de contenido mineral óseo se centran fundamentalmente en huesos ricos en componente trabecular, tal como los cuerpos vertebrales, lugares del esqueleto en los cuales son más frecuentes las fracturas osteoporóticas.

Ambos tipos de hueso, trabecular y cortical, difieren no sólo en la porosidad y en la superficie sino también en la proximidad a la médula ósea, a la corriente sanguínea, en la rapidez del remodelamiento y en la magnitud y pérdida de hueso con la edad, influyendo también sobre el riesgo de fracturas. La resistencia del hueso frente a la ruptura está relacionada linealmente con su contenido mineral.

Las técnicas actuales de densitometría ósea han demostrado ser herramientas sensibles, fiables, seguras y eficaces en la evaluación del contenido mineral óseo. Su principio físico común se basa en la capacidad de atenuación (absorción) que posee el tejido óseo a la exposición de una fuente de radiación ionizante. Existe una relación exponencial entre la masa ósea y esta capacidad de atenuación. A mayor contenido de hueso presente, mayor es la capacidad de absorción de la radiación ionizante, detectándose menor radiación en un sistema de detección próximo.

• Evolución de la masa ósea

La normalidad de la arquitectura esquelética, el pico de masa ósea o la masa en un momento concreto, no son estados genéticamente determinados sino, más bien reflejos de una historia de modelamiento y remodelamiento profundamente influenciada por la sobrecarga mecánica.

La masa ósea aumenta durante la infancia, la adolescencia y el comienzo de la vida adulta, hasta un momento no bien definido, probablemente situado en la tercera década, en que dicho aumento se detiene. Se alcanza así su valor máximo, que permanece estable hasta el comienzo de la década de los 40, cuando ya empieza a disminuir. El patrón de pérdida ósea no está definido con precisión. Tal vez sea constante, tal vez sea rápido al principio y lento al final, o tal vez sea irregular, con fases de mayor celeridad de pérdida que otras. En cualquier caso podemos aceptar que en conjunto la pérdida es más o menos uniforme (alrededor de 0,5-1,0% anual). En las mujeres se añade una clara aceleración tras la menopausia, de unos 5-10 años de duración, más intensa al principio, en que puede llegar a perderse un 5-8% anual.

La pérdida ósea no afecta por igual a los dos tipos de hueso, sino que se sabe que el hueso trabecular empieza a perderse antes que el cortical, y que el incremento postmenopáusico en las pérdidas se deja también sentir más en él. Se calcula que a lo largo de su vida la mujer pierde un 50% de su masa ósea trabecular, y un 35% de la cortical. El hombre pierde alrededor de dos tercios de estas cifras.

• Actividad física y masa ósea

Dentro de los factores determinantes del máximo de masa ósea se encuentra el ejercicio físico. En los últimos años se han acumulado multitud de evidencias que parecen indicar que la actividad física y el deporte aumentan el contenido mineral óseo y/o disminuyen su pérdida. Según Aloia (1978) existen tres posibles mecanismos que expliquen este fenómeno: a) influencia nerviosa directa; b) cambios vasculares y en el flujo sanguíneo asociados al ejercicio; c) tensión mecánica y muscular producidas al mantener peso.

La capacidad del hueso para soportar cargas refleja tanto su propiedad material (densidad y modulación), como la distribución espacial del tejido óseo. Estos signos de fuerza del hueso están desarrollados y mantenidos en parte por las fuerzas que se aplican sobre él durante la actividad diaria y el ejercicio.

Las cargas funcionales que se producen durante la actividad física ejercen una influencia positiva sobre la masa ósea. El grado de esta influencia y el tipo de programa que induce el estímulo osteogénico más eficaz todavía no se conocen con profundidad. Mientras que se sabe con certeza que una disminución en la actividad física, tal como el reposo en cama, produce una gran pérdida de la masa ósea, el aumento de la misma por un incremento en la actividad es menos concluyente. Los resultados varían según la edad, el estado hormonal, la nutrición y el tipo de ejercicio.

Se puede deducir una relación dosis- respuesta entre la carga mecánica y el hueso por el hecho de que la respuesta del mismo es proporcional a la fuerza aplicada tanto en células como en cultivos de órganos y modelos animales, donde se ha empleado una carga conocida a una magnitud y frecuencia determinadas (Smith y Gilligan, 1991). Las respuestas proporcionales se han observado en el segundo mensajero, factores de crecimiento, matriz y fuerza ósea. Rubin y Lanyon (1987) en estudios experimentales han sido capaces de establecer que, en situación de desuso, la exposición a períodos extremadamente cortos de tensión dinámica, no solo previene la reabsorción que normalmente acompaña a la disminución de sobrecarga, sino que incluso origina un incremento de formación ósea proporcional al pico de tensión. En el modelo humano, sin embargo, la determinación de la relación dosis-respuesta es más difícil de definir por la ausencia de una tecnología apropiada para evaluar directamente la carga mecánica y la aptitud del esqueleto.

En la literatura revisada se comenta que la actividad física aumenta la capacidad del esqueleto para resistir las fracturas a través del mantenimiento y mejora de la densidad mineral ósea (DMO) y la capacidad neuromuscular, produciendose una disminución de la fragilidad del hueso y de la predisposición a las caídas.

Lanyon (1989) sugiere que los osteoblastos, las células de revestimiento óseo, y los osteocitos, debido a su número y conexiones físicas, pueden estar morfológicamente bien situados para percibir los cambios de las cargas mecánicas en los huesos. Mundy (1990) señala que los osteoblastos, los osteocitos y las células de revestimiento están conectadas y responden a la tensión mecánica a través de la activación de la vía del segundo mensajero. La iniciación de esta vía se produce cerca o dentro de la membrana celular, por la transformación de un estímulo extracelular, ya mecánico o químico, en un mensaje intracelular. El estímulo mecánico inicia una cascada de hechos que producen tres mensajeros intracelulares : inositol 1-4,5-trifosfato (IP3), diacilglicerol (DAG), y adenosina ciclica 3´, 5´-monofosfato (C-AMP). Todavía está por describir sí los factores mecánicos, tal como la actividad física, pueden ser empleados para maximizar el pico de masa ósea o para contrarrestar la osteopenia. Algunos investigadores han desarrollado modelos para predecir la respuesta del hueso a los cambios de las cargas mecánicas (Frost 1987, Whalen 1988).

En algunos trabajos (Gutin 1992, Smith 1991, Snow-Harter y Marcus 1991) se sugiere una relación positiva entre la actividad física y la adaptación ósea del lugar ejercitado.

Nilsson y Westlin (1971) encontraron que 64 atletas tenían mayor densidad ósea en el fémur distal que 39 casos controles sedentarios.

Pirnay et al (1987) estudiaron 10 tenistas profesionales (edad media 20 años) y los comparan con un grupo control de similares características, observando que la densidad mineral era mucho mayor en los tenistas. Incluso en el brazo no dominante la DMO del radio fue un 15% superior que en el grupo control. Estas diferencias se demostraron tanto en el hueso cortical como en el trabecular. Los autores sugieren una influencia favorable del ejercicio muscular sobre la mineralización ósea mediante la formación de corrientes eléctricas.

Gutin y Kasper (1992) en una revisión realizada sobre el tema concluyen que la actividad física, tanto aeróbica como de fuerza, se correlaciona con la densidad mineral. Las personas jóvenes que utilizan una parte específica de su cuerpo en un ejercicio determinado presentan un aumento de la densidad ósea en ese lugar, pero no necesariamente en otra región del esqueleto.

La mayoría de los estudios sobre la influencia del ejercicio en el hueso adulto señalan marcadas diferencias de la DMO en diferentes regiones entre los deportistas y el grupo control en un amplio rango de actividades deportivas.

Prives (1960) fue de los primeros que investigó la relación entre estructura ósea y actividad física, para lo que estudió 3.000 personas en un periodo de 10 años. Mediante radiografías observó los huesos en diferentes trabajos físicos y deportes. Encontró que los jornaleros, por ejemplo, tenían huesos más grandes que los oficinistas y advirtió que los hueso variaban cuando se cambiaba de ocupación.

Existen numerosos trabajos que han encontrado diferencias entre la DMO de personas sedentarias y que realizan distintas actividades físicas en general (Zylstra 1989, Aloia 1988, Halioua 1989, Jonsson 1992, Stillman 1986). Estas diferencias están en un rango del 6'5 al 9% de aumento de la DMO en las personas activas en el radio, 10% en la columna lumbar, 8% en diafisis femoral, 11% en pelvis y más de un 16% en trocantes mayor y cuello femoral. También se ha observado de forma repetida diferencias entre mujeres activas y sedentarias, tanto premenopausicas (Wolman 1991, Davee 1990, Johsson 1992, Kanders 1988, Stillman 1986), como perimenopausicas (Zhang 1992) o postmenopausicas (Lane 1986, Johsson 1992, Cheng 1991).

Según todos estos estudios transversales, se demuestra que las personas con historia de haber realizado actividad física tienen mayor masa ósea que sus equivalentes sedentarios. La magnitud de estos cambios es variable y depende del tipo e intensidad del ejercicio, la zona medida, el sexo y el estado fisiológico de la persona, pero oscila en un rango aproximado de un 6-20%. Entre todos los estudios citados, el hueso cortical parece tener menos cambios que el trabecular. Desgraciadamente, en este tipo de estudios no se puede demostrar la hipótesis de que el ejercicio añade hueso al esqueleto adulto, ya que no se conoce la masa ósea de los sujetos antes de iniciar la actividad deportiva y podría pensarse que existe la probabilidad de una selección natural (debido a la complexión física por ejemplo) para realizar una actividad determinada, y esto podría influir en la comparación de la masa ósea entre los grupos; Además no se recoge la actividad deportiva durante la infancia y adolescencia, factor este que puede afectar la masa ósea.

Williams et al (1984), midieron el contenido mineral óseo mediante densitometria en el calcáneo en un grupo de 20 corredores varones al principio y al final de un periodo de entrenamiento de 9 meses. Los deportistas tenían una edad que oscilaba entre 38 y 68 años y nunca habían corrido hasta este estudio. Los individuos que corrieron constantemente más de 16 Km cada mes, durante los 9 meses, tuvieron un aumento significativo de la DMO. En los que no corrieron de forma continua no se observó dicho aumento. Los autores del estudio sugieren que la carrera realizada de forma constante aumentando gradualmente la distancia y manteniéndola a un cierto nivel, es efectiva en incrementar el contenido mineral óseo del hueso trabecular, mientras que el entrenamiento esporádico y variable tiene poca influencia.

Relación entre fuerza osea y aumento de la fuerza muscular mediante vibroestimulación. Aplicación en el deporte.

Unos músculos fuertes y que funcionen bien es la condición inicial para conseguir unas articulaciones sanas, huesos estables, prevenir la osteoporosis y adquirir una correcta coordinación de movimiento, incluso a avanzada edad.

♦*Relación de la Densidad ósea con la masa muscular.*

Los efectos del ejercicio sobre el músculo están bien documentados. A través del entrenamiento se produce una adaptación funcional que capacita al sistema muscular para funcionar a un nivel superior. Sin embargo, la especificidad del entrenamiento es crítica para conseguir los resultados esperados. Mediante el entrenamiento con pesas, donde se aplica una carga creciente, la adaptación produce hipertrofia y una función neuromuscular aumentada, lo que conduce a un incremento de la fuerza únicamente de los músculos que fueron sobrecargados. En el entrenamiento de tipo aeróbico aunque se ha observado aumento en la fuerza de algunos grupos musculares, no se no alcanza la magnitud del producido por el entrenamiento con pesas.

Ya que el esqueleto es un tejido dinámico asociado con el sistema muscular, no es sorprendente que se hayan observado cambios en el mismo en respuesta a la especificidad del ejercicio de entrenamiento. En 46 autopsias rutinarias, Doyle et al (1970) encontraron una correlación significativa entre el peso de las cenizas vertebrales y el peso del músculo psoas. En un análisis de regresión múltiple, el peso del psoas fue el que mejor predijo el peso de las cenizas vertebrales.

Pocos estudios han examinado la relación entre la fuerza muscular y la densidad ósea. Sinaki y Offord (1988) encontraron una correlación positiva entre la densidad ósea de la espina dorsal y la fuerza del dorsal largo (extensor de la espalda) en 68 mujeres postmenopáusicas sanas. Esta correlación fue constante incluso cuando la densidad se corrigió según la edad. En un estudio similar, Sinaki et al (1986) realizaron una encuesta a un grupo de mujeres para valorar su nivel de actividad física. Los resultados revelaron que las mujeres con actividad física elevada tenían mayor fuerza isométrica en la espalda y mayor densidad ósea en la columna que las mujeres con un nivel menor de actividad. Aunque los resultados son preliminares, sugieren la existencia de una relación entre la fuerza de un grupo específico de músculos y el hueso correspondiente. En un estudio de Bevier et al (1989) se encontró una correlación positiva entre la fuerza del apretón de manos y la densidad del antebrazo en 87 hombres y mujeres de edad avanzada. Los hombres presentaron igualmente una relación significativa entre la fuerza de la espalda y la densidad de la espina dorsal determinada por absociometría fotónica dual.

♦*Aumento de la fuerza muscular mediante vibroestimulación*

El músculo es capaz de realizar varios procesos de contracción y relajación por segundo si se le somete a una adecuada estimulación mecánica (vibroestimulación). La frecuencia que es más eficiente para el desarrollo muscular es de 28-30 Hz. Esto significa que 14-15 impulsos por segundo, aplicados durante varios minutos, son suficientes para reforzar y mejorar la capacidad de coordinación. Después de 2-3 días los músculos respectivos o cadenas de músculos completas habrán recibido cientos de estimulaciones adecuadas para su desarrollo que producen un incremento del metabolismo, circulación sanguínea y de la temperatura.

La fuerza muscular regional es importante para determinar la fuerza del esqueleto completo, de forma independiente a otras variables (sexo, edad..).

Las grandes cargas aplicadas a los huesos durante las actividades cotidianas provienen de los músculos. Los cambios en la fuerza muscular pueden variar las cargas en el hueso (por ejemplo, la fuerza longitudinal que desarrolla sobre el fémur un futbolista durante un partido puede exceder 5 veces el peso total del cuerpo). Se ha visto que tanto la fuerza muscular como la masa libre de grasa se asocian de forma positiva con la masa ósea de cualquier zona del organismo, aunque de manera más específica lo hacen con el segmento del esqueleto adyacente.

La vibración aplicada al músculo induce una contracción muscular refleja. Issurin et al (1999) aplicaron este método para estudiar el desarrollo de fuerza y flexibilidad en 28 deportistas, observando que el entrenamiento con vibroestimulación producía un incremento lineal de la fuerza isotónica durante el periodo en el que se aplicó.

En 1995 Zanchetta et al publicaron un estudio en el que median la masa ósea total y la masa magra total mediante densitometría ósea en 778 niños y adolescentes entre 2 a 20 años. Se vió muy claro que existía una correlación lineal muy positiva (r= 0.997) entre ambas medidas, que secundariamente reflejan la relación entre la fuerza ósea y muscular.

Las investigaciones de los últimos 15 años han encontrado que la DMO vertebral en las deportistas amenorreicas es baja. Algunos investigadores han observado que las deportistas amenorreicas presentan una DMO vertebral significativamente menor que la

de las mujeres eumenorreicas, lo cual indica la existencia de osteopenia (masa ósea inferior a la normal) en las mujeres que han perdido la menstruación (Cann et al,1984;Drinkwater et al,1984). En los primeros estudios se especuló que el porcentaje de grasa corporal era el principal factor causante de la pérdida de los ciclos menstruales.

Marcus et al (1985) compararon la masa ósea de la columna lumbar y del radio entre deportistas de fondo amenorreicas y eumenorreicas equiparadas en función de su capacidad aeróbica, porcentaje de grasa corporal, intensidad del ejercicio y edad de la menarquia. Estos autores encontraron que la DMO vertebral en las mujeres amenorreicas era un 20% menor que en las que tenían ciclos normales y un 10% menor que en las mujeres eumenorreicas no deportistas de edad similar. La DMO del radio (cortical) no mostraba diferencias significativas entre los grupos de deportistas o entre las amenorreicas y los controles eumenorreicos. Este estudio deja claro que la amenorrea es un problema multifactorial y no el resultado estricto de una grasa corporal escasa.

Las fracturas de estrés fueron más frecuentes en las mujeres amenorreicas. Los autores concluyen diciendo que el ejercicio intenso puede reducir el impacto que la amenorrea produce sobre la DMO, aunque las corredoras amenorreicas continúan. teniendo alto riesgo de fracturas relacionadas con el ejercicio.

Algunos investigadores han intentado utilizar esta relación estructura-función, demostrada entre el ejercicio y la morfología ósea, para prevenir la osteopenia en la menopausia. Aloia et al (1978) estudiaron 18 mujeres postmenopausicas, de las cuales 9 realizaban ejercicio 1 hora tres veces a la semana. Se midió la masa ósea antes y después de un año de ejercicio, observándose que aumentaba en el grupo que realizaba ejercicio, y disminuía en el sedentario, concluyendo que el ejercicio podía modificar la pérdida ósea que ocurre con la edad.

Flieger et al (1998) evaluaron la influencia de la vibroestimulación para prevenir la perdida ósea postmenopausica. Para ello utilizaron dos grupos de ratas ovariectomizadas, a uno se le aplicó el estímulo durante 12 semanas (grupo 1) y el otro fue utilizado como control (grupo 2). El grupo 1 tuvo unos valores de densidad mineral ósea significativamente superiores frente al grupo 2.

Lanyon (1990) con respecto al proceso funcional de adaptación ósea con el ejercicio físico se hace una serie de preguntas:

- **¿ Hasta que extremo puede un ejercicio apropiado proporcionar un estímulo conservador u osteogénico suficiente para prevenir la pérdida ósea?**
- **¿ Que regímenes de ejercicio deberían utilizarse?**
- **¿ Hasta que punto se puede obtener beneficio del ejercicio sin ejercicio?**

Las evidencias actuales apoyan el hecho de que el ejercicio apropiado modula la estructura ósea, ya que el hueso responde de una forma dinámica a las demandas funcionales. Sin embargo, aún no se conoce el régimen de ejercicio más positivo en cada localización, aunque en el momento presente parece que son más efectivos períodos cortos de actividad con sobrecarga de peso, que largos de cargas repetidas.

Todos estos trabajos abren un nuevo campo de investigación en el estudio de la influencia que la estimulación de la potencia muscular, mediante una plataforma vibratoria, puede tener en la formación de hueso nuevo o en la prevención de la perdida del mismo, con una aplicación práctica no solo en el mundo del deporte en las personas con riesgo de padecer osteopenia, sino como método para facilitar la potenciación muscular tan importante en el deportista.

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Efectos de un programa de ejercicio vibratorio a 25 Hz sobre la masa ósea de mujeres postmenopáusicas

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INTRODUCCIÓN Y OBJETIVO

Dos factores principales de las fracturas óseas son las caídas (fuerza de los miembros inferiores y equilibrio) y la cantidad de masa mineral ósea que está muy influenciada por el régimen de estímulos mecánicos recibidos por el hueso (Parsons et al., 1996). Así se ha recomendado el uso del ejercicio vibratorio para optimizar la fuerza y el equilibrio, en cambio ha sido poco estudiada su influencia en la masa ósea hasta la fecha. El ejercicio vibratorio de media-alta frecuencia ha sido altamente efectivo para el incremento de la masa ósea en modelos animales (Tanaka el al, 2003; Oxlund et al., 2003) pero su efecto en humanos es desconocido y controvertido empleando frecuencias medias-altas (30-50Hz) (Verschueren y col, 2004; Torvinen y col., 2003).

El propósito fue evaluar el efecto de un programa de ejercicio vibratorio en frecuencias medio-bajas (25Hz) de 8 meses sobre la densidad mineral ósea (DMO) en mujeres postmenopáusicas.

MATERIAL Y MÉTODOS

Participantes

Veinticuatro mujeres postmenopáusicas, sanas y no entrenadas físicamente, fueron estudiadas en dos grupos: entrenamiento (GE, n=12) y control (GC, n=12).

Los criterios de inclusión fueron:

a) Más de 3 años desde la última menstruación
b) Sin patología/medicación que afecte el metabolismo óseo o fuerza
c) Estado nutricional adecuado
d) No fumar ni ingerir más de 4 bebidas alcohólicas semanales.
e) Capacidad física para efectuar el protocolo (sin hernias, ni patologías traumatológicas o cardíacas).

Tabla 1. Características iniciales de la muestra

Grupo	Ejercicio	Control
N	12	12
Edad (año)	56 (7)	58 (6)
Edad tras última menstruación (año)	7 (6)	9 (4)
Peso	70 (12)	70 (7)
Altura	156 (4)	156 (4)

Valores expresados en media (d.e.); pLevene >.05

Figura 1. Evolución de la muestra

Métodos

El entrenamiento consistió en 3 sesiones semanales de 20 minutos que incluían calentamiento, 10 minutos de movilidad del miembro inferior y 6 series de 1 minuto de vibración corporal a 25 Hz y 3 cm de oscilación vertical a partir de los pies mediante un vibrador (Galileo 2000, Novotec, GMBH, Pforzheim, Alemania) recuperando 1 minuto entre series. La persona se mantenía en pie con el tronco erecto verticalmente y una flexión de 60º en la rodilla.

La DMO (gr/cm2) fue medida en la columna lumbar y la zona de la cadera mediante técnica DXA (Norland Excell Plus).

Se efectuaron análisis de la varianza ajustado por el peso.

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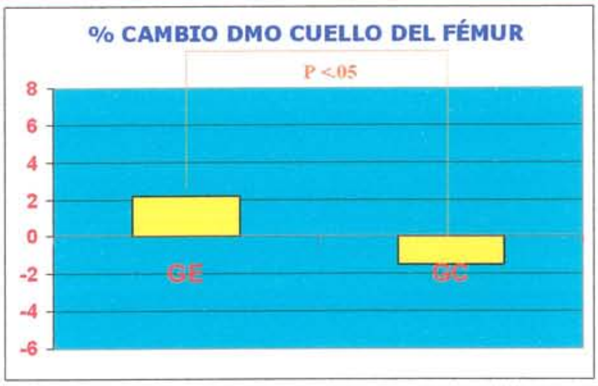
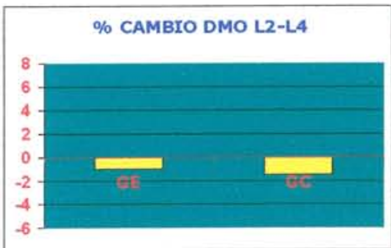
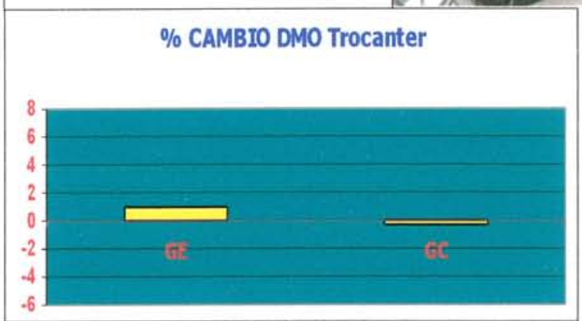
Verschueren SMP, Roelants M, Delecluse C, et al. J Bone Miner Res 2004 19(3):352-359.

RESULTADOS







DISCUSIÓN Y CONCLUSIONES

Se observaron cambios significativos en la DMO intragrupos en el cuello del fémur que es la región corporal de las estudiadas que más impacto biomecánico recibe debido a la posición corporal empleada. En cambio, no se registraron cambios significativos en el resto de sitios mostrando la especificidad de la postura adoptada. Estos resultados son coherentes con los registrados en otros grupos de investigación (Torvinen et al., 2003 y Verschueren, 2004). Así gran parte del impacto que pudiera recibir la columna fue amortiguado por la flexión de las rodillas y la cadera, amortiguación requerida para prevenir lesiones nerviosas o pinzamientos. La falta de significatividad estadística de los efectos positivos en el trocánter y t. de Ward puede atribuirse parcialmente a la postura del esfuerzo, pequeño tamaño de la muestra y período de entrenamiento. También debe resaltarse que el ejercicio vibratorio no mostró efectos adversos como la desmineralización.

En conclusión, el programa de ejercicio vibratorio a 25Hz fue efectivo para aumentar la masa ósea en el cuello del fémur. Este tipo de entrenamiento precisa de muy poco espacio y tiempo del paciente. Este programa es aplicable como coadyudante a otros tratamientos (otros ejercicios, farmacológicos, nutricionales, etc.).

Agradecimientos a la Consejería de Educación, Ciencia y Tecnología de la Junta de Extremadura Plan Regional de Investigación (2PR02B017)

EFFECTS OF 8 MONTHS WHOLE BODY VIBRATION EXERCISE ON BMD IN POST-MENOPAUSAL WOMEN

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While vibratory exercise has been highly effective in the increase of bone mineral mass on animals, the use of this technique in humans has shown non conclusive results. The purpose of this study is to evaluate the effects of whole body vibration training on the bone mineral density (BMD) in post-menopausal women. 28 healthy but non-trained post-menopausal women were divided randomly in two groups (control G1 and experimental G2) of 14 subjects. Training consisted in 3 weekly sessions during a time span of 8 months. Exercise sessions were subdivided in (a) 10 min of worm up cyclo-ergometric activity at 50 Wmin-1and (b) 6 series of 1 min whole body vibratory exercise with 1 min interval between each series. Vibratory exercise consisted in a frequency of 25 Hz and 3 cm of amplitude using a Galileo 2000 (Novotec, GNBH, Pforzheim, Germany). Vibratory exercise was performed in erect position with a knee flexion of 60º. Hip and lumbar BMD (gcm-2) was measured using DXA (Norland Excell Plus). Statistical analysis consisted in a two way analysis of variance for repeated measurements of the BMD adjusted in function of body weight. Femur neck BMD increased by 2% in G2 while BMD of G1 decreased during the same time span with 1.6%. Inter-groups variation is significant ($p=0.02$). At level of the trochanter G2 increased BMD with 1% and G1 decreased with 1.2%. Inter-group variation is non significant ($p=0.09$). BMD at lumbar level, even as at level of the Ward triangle are non significant in both G1 and G2. This non-significance at lumbar level can be attributed to the partial knee flexion during the vibratory exercise reducing the effects of the mechanical impact. Conclusion: An 8 month exercise programme of whole body vibration with a frequency of 25 Hz induced an effective BMD change at level of femur neck in post-menopausal women.

COMPARACIÓN DE LA ACTIVIDAD ELECTROMIOGRAFICA Y ACELEROMETRIA TRIDIMENSIONAL EN DISTINTOS ÁNGULOS DEL TREN INFERIOR EN EL EJERCICIO VIBRATORIO

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INTRODUCCIÓN Y OBJETIVO

Dos factores principales de las fracturas óseas son las caídas (fuerza de los miembros inferiores y equilíbrio) y la cantidad de masa mineral ósea que está muy influenciada por el régimen de estímulos mecánicos recibidos por el hueso (Parsons et al., 1996). Se ha recomendado el uso del ejercicio vibratorio para prevenir dichos factores a pesar del déficit de conocimiento sobre la magnitud del estímulo mecánico transmitido al cuerpo en diferentes posturas sobre la plataforma vibratoria. Además, el escaso conocimiento se ha analizado fundamentalmente en plataformas con vibración vertical, pero se desconoce en gran medida el impacto en plataformas que oscilan sobre un eje como es el caso de uno de los aparatos más usados en la práctica clínica (Galileo o Vibraflex) en diferentes grados de flexión de las articulaciones del tren inferior que pueden producir amortiguaciones o transmisibilidades reducidas del estímulo mecánico de la plataforma. El propósito de este estudio es:

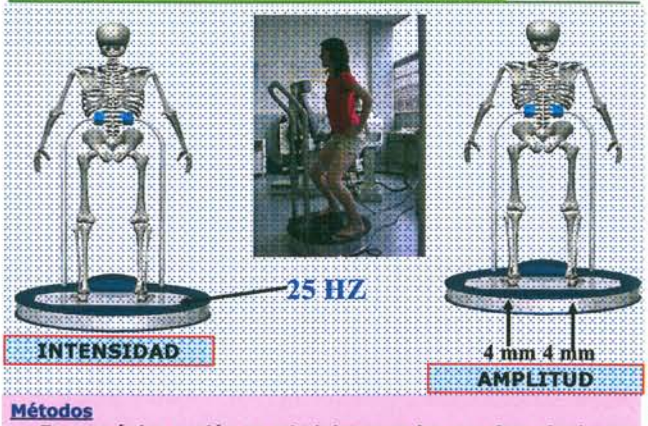
1. Comparar la aceleración registrada a nível lumbar en distintos ángulos de flexión de las rodillas
2. Comparar la activación eléctrica (EMG) de los músculos seleccionados en ángulos distintos de flexión de rodillas.

MATERIAL Y MÉTODOS

Participantes

Se estudiaron treinta mujeres sanas (sin consumo regular de tabaco y alcohol) y entrenadas físicamente tras firmar un informe de consentimiento.

Grupo	
N	30
Edad (años)	21.77 (1.65)
Peso (Kg)	59.30 (5.67)
Altura (m)	1.64 (5.40)
Índice de Masa Corporal (kg/m^2)	22.03 (1.99)



Métodos

En una única sesión se administraron las pruebas siguientes tras un breve calentamiento: contracción voluntária máxima dorsal y abdominal con el Test Shirado-Ito (Ito S et al. 1996), flexión y extension de la rodilla mediante acción Isometrica (Dinamómetro Isocinético, System 3, Biodex, USA) y 3 series de 20 s de vibración corporal a 25 Hz y 4 cm de oscilación vertical a partir de los pies mediante un vibrador (Galileo 2000, Novotec, GMBH, Pforzheim, Alemania) recuperando 1 minuto entre series. La persona se mantuvo en pie con el tronco erecto verticalmente pero varió de forma aleatoria (tabla randomizada) el grado de flexión de la rodilla empleado en cada serie entre los 15º, 45º y 90º en la rodilla.

El impacto mecanico (g) fue medida en la columna lumbar (L3) (TSD109F,Tri-Axial Accelerometer 5G, Biopac Systems, USA).

Se efectuaron análisis de la varianza ajustado por el peso.

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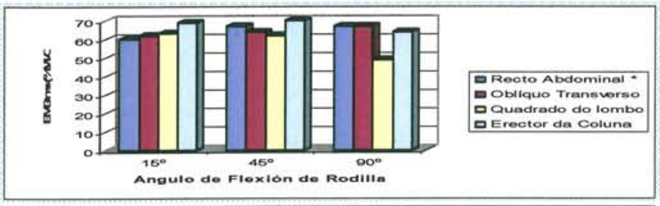
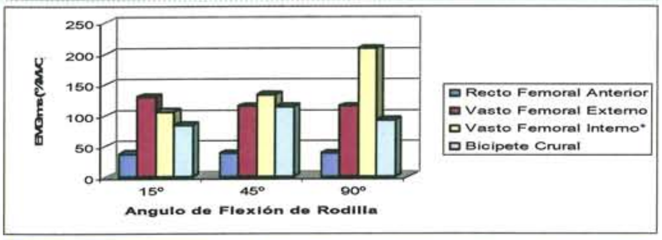
Torvinen S, Kannus P, Sievanen H, et al. J Bone Miner Res 2003 18(5): 876-884

Verschueren SMP, Roelants M, Delecluse C, et al. J Bone Miner Res 2004 19(3):352-359.

RESULTADOS

	Max.	p15º vs 45º	p15º vs 90º	p45º vs 90º	Med.	p15º vs 45º	p15º vs 90º	P45º vs 90º
EJE X		0.008	0.024	0.483		<0.001	<0.001	0.015
15º	13.4 (6.8)				4.5 (1.7)			
45º	11.4 (6.4)				3.5 (1.3)			
90º	11.8 (7.5)				3.0 (1.3)			
EJE Y		0.030	0.001	0.020		<0.001	<0.001	0.006
15º	7.4 (4.6)				1.1 (0.6)			
45º	6.6 (4.6)				0.8 (0.5)			
90º	6.2 (4.6)				0.6 (0.4)			
EJE Z		0.094	0.092	0.953		0.088	0.002	0.005
15º	5.0 (3.7)				0.5 (0.2)			
45º	4.6 (3.7)				0.4 (0.2)			
90º	4.6 (3.8)				0.3 (0.2)			





DISCUSIÓN Y CONCLUSIONES

La magnitud de las aceleraciones observadas (> 3 g en el eje lateral y 0,6 g en el eje vertical) superaron el umbral anabólico y osteogénico indicado por Rubin et al (2002).

Se verificó que la aceleración a nivel lumbar disminuye con el aumento del ángulo de flexión de las rodillas. Estos resultados son coherentes con los registrados en otros grupos de investigación (Rubin et al. 2003, Torvinen et al., 2003 y Verschueren, 2004). Así gran parte del impacto que pudiera recibir la columna fue amortiguado por la flexión de las rodillas y la cadera. El estudio verificó un mayor percentaje de EMGrms en el vasto interno y externo que en el recto femoral anterior. El WBV ha estimulado los músculos del tronco a 60 – 70% y la respuesta del músculo recto abdominal aumentó con el incremento de la flexión de las rodillas.

Concluyendo, el protocolo utilizado para el WBV en este estudio ha mostrado intensidades, referenciadas por estudios previos, suficientes para impedir la pérdida de masa ósea bien, ejercitar los músculos de los miembros inferiores y de la espalda baja. Una menor flexión de rodillas trasmite un mayor estímulo mecánico a nível lumbar. Este programa es aplicable como coadyudante a otros tratamientos (otros ejercicios, farmacológicos, nutricionales,etc.).

Agradecimientos a la Consejeria de Sanidad y Consumo de la Junta de Extremadura. Proyecto de Investigación Sócio-Sanitária (SCSS0466)

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Good, good, good . . . good vibrations: the best option for better bones?

There are many reports about the effects of exercise on bone but, overall, the data are not very encouraging. Some of the poor results may be attributed to difficulties with compliance. However, even among studies with positive results, the size of the effect, generally an increase of 1–2% in bone density, is disappointing. Not surprisingly, several meta-analyses have found the effect of impact or low-impact exercise on proximal femoral and forearm sites to be minimal or absent.[1-5] None of the studies on exercise has had enough power to assess fracture risk.

In a recent brief communication, Clinton Rubin and colleagues[6] reported that having adult ewes stand on a platform with high-frequency vibration for 20 min each day for 5 days a week over 1 year increased femoral trabecular bone density by 32%. Bone trabeculae were also shown to have closer spacing, which is consistent with stronger bone. Histomorphometric studies of bone turnover suggest that this effect may be due to the increased (more than two-fold, but not statistically significant) bone formation and mineralisation. However, there were no changes in cortical bone. One remarkable feature is that the load applied to bone from this vibration is about 5 microstrain, which is considerably less than the load sustained during roaming of the pasture, which the animals (treated and controls) did the rest of the time. This study follows a shorter-term study in mature female rats, in which a similar high-frequency, very-low-amplitude vibrations (0·25 *g* equivalent to <10 microstrain at 90 Hz vibration for 10 min, 5 days per week) was able to completely block the adverse effects on hind-limb bone density induced by tail suspension, whereas a similar period of normal load bearing did not.[7] These data suggest a specific effect of the high frequency of these remarkably small loads. Could these animal studies be relevant to osteoporosis in human beings?

At the recent meeting of the American Society for Bone and Mineral Research, Ward and colleagues[8] reported results of a small randomised, placebo-controlled study among 20 children with cerebral palsy who used a similar, commercially available vibrating platform for 10 min per day, 5 days per week for 6 months. They observed a significant increase in tibial, but not lumbar-spine bone density in the treated group. Despite the simplicity and short duration of the "vibration" and the young age of the children, compliance was low—less than 50% completed the study. Such poor compliance is particularly disappointing if use of the vibration platform is seen as an alternative to "exercise", which is generally not widely taken up. However, sex-hormone status may be another factor that could partly account for the difference in results between Ward and colleagues study and those from Rubin and colleagues. The animals in Rubin and colleagues' studies were mature eugonadal animals. Extrapolated to human beings, perhaps vibration on a platform might be useful only in eugonadal individuals—ie, postpubertal, premenopausal, or on hormone-replacement therapy.

Current preventive approaches to osteoporosis include lifestyle recommendations, including exercise and appropriate intake of calcium and vitamin D, the use of hormone replacement or similar therapy to reduce bone loss and, in later stages, antiresorptive agents, such as selective oestrogen-receptor modulators and biphosphonates. These antiresorptive agents are generally used after a fracture; they may reduce fracture risk by about 50% but do not return it to prefracture values. All these existing therapies have modest effects on measured bone density, of the order of a 5–10% increase over several years. Only parathyroid hormone (given subcutaneously) seems to have a true "anabolic" effect and has been reported to increase bone density to the extent seen in Rubin and colleagues' study.[9] Thus, the striking effects of a non-invasive "good vibrations" approach, if shown to be generally applicable and comparably effective in human beings, would be of considerable potential benefit.

In human beings, bone density, the best predictor of fracture risk, is strongly associated with bodyweight. Bodyweight is the strongest and often only "environmental" determinant of bone density in cross-sectional studies. Various investigators have suggested that this relation is due to the increased fat mass (and thus to humoral factors derived from it) or increased muscle mass (and thus to the muscular pull exerted on the skeleton). The studies from Rubin and colleagues suggest that the load associated with normal activities amplified by bodyweight may have a role in maintaining the integrity of bone structure. Could it be that the rapid corrections of muscle pulls during normal activities are amplified by the extra instability associated with moving a larger body bulk and may induce rapid high-frequency oscillations? Could this effect relate to neuromuscular function and neural or even paracrine effects on the adjacent bone? These findings are also consistent with the suggestion that horizontal forces during normal walking are needed for optimum skeletal loading.[10] Similarly it is recognised that the anabolic response of bone to skeletal loading, both of animals and human beings, is most effective when the rates are rapid but of short duration and "unusual" in direction.[11–13]

There is however, a potentially narrow gap between benefits and adverse effects of load bearing. Spinal density has been shown to decrease in young women who exercise too heavily[14] and application of a static load to rat ulna for 10 min per day slowed growth and decreased bone apposition, whereas a similar but dynamic strain (2 Hz, about 3500 microstrain) increased bone apposition.[15] Another aspect of physical loading studies is that there seems to be important interindividual and interstrain differences in load responses,[16–18] and there have been differences in effects by site (lower leg *vs* lumbar spine) and type of bone (trabecular *vs* cortical). Since bone strength is due to a composite of trabecular and cortical bone as well as complex aspects of bone geometry, it is not clear that the changes observed would necessarily translate into clinically relevant or sustained effects on overall bone strength.[19]

Thus, despite some uncertainties, the work of Rubin and his colleagues indicates the clinically relevant potential of non-invasive, short-duration, mechanical stimulation that could have an impact on osteoporosis risk. These studies of high-frequency vibrations on bone have raised many questions that can be answered only by careful randomised appropriately blinded, long-term studies. As with all other valid osteoporosis research, surrogate markers such as bone density and changes in bone turnover may identify the optimum dose for the important phase III studies that have clinically relevant endpoints, such as fracture risk.

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Effect of Whole Body Vibration Stimulus and Voluntary Contraction on Motoneuron Pool

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Abstract

NISHIHIRA, Y., IWASAKI, T., HATTA, A., WASAK, T., KANADA, T., KUROIWA, K., AKIYAMA, S., KIDA, T. and RYOL, K.S ., Effect of Whole Body Vibration Stimulus and Voluntary Contraction on Motoneuron Pool., Adv. Exerc. Sports Physiol., Vol.8, No.4 pp.83-86, 2002. We investigated the influence of transient whole body vibration and voluntary contraction on the motorneuron pool. Electromyographic recordings were obtained from the soleus muscle of 17 healthy subjects using surface electrodes placed bilaterally. Whole body vibration was applied in three sets of 3 minutes each using a training device, Galileo 2000 (Novotec Gmbh, Gemany). The H-reflex was elicited by electrically stimulating the right posterior tibial nerve, as subjects sat in a chair in a relaxed position. The H/M ratio was significantly increased after vibration compared to before vibration. This suggests an increase in the excitability of the alpha motoneuron pool. In this study, it may be considered that the H/M ratio increased as a result of the integration of influences from both whole body vibration and voluntary contraction.

Keywords: whole body vibration, voluntary contraction, motoneuron pool.

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WHOLE-BODY VIBRATION EXERCISE IN THE ELDERLY PEOPLE

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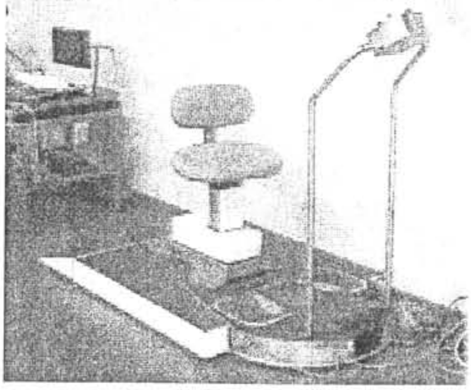
IBMS Osaka 2003

Most of femoral neck fractures in the elderly are caused by fall. Although exercise is considered to prevent fall by maintaining muscle power and balance and functional fitness, many old subjects are unable to exercise effectively. The aim of this study is to investigate the effects of the Whole body vibrations (WBV) in the elderly people. Twenty-one people aged 72.6 years old attending health program in local community were included in this study. Eleven carried out the exercise (Ex.) by low frequency oscillation loading device (Galileo 900, Novotec Pforzheim Germany, Fig.1) and the other ten did not (Cnt.). Ex. was exposed to a bout of the 20-30Hz vibrations standing on the platform 3 times a week. Calcaneal bone mineral density was measured using QUS (AOS-100, Aloka Japan), statical and dynamic balance test, functional fitness tests was performed before and after 6 months exercise program. Calcaneal bone mineral density did not differ between 1st and 2nd measurement, but balance-function improved significantly after 6 months exercise in Ex. These results suggest that WBV possibly prevents fall and femoral neck fracture by improving standing balance in elderly subjects.

Fig.1 Low frequency oscillation loading device (Galileo 900, Novotec Pforzheim Germany)



Controlled Whole body vibrations to decrease fall risk and improve health related quality of life in elderly patients.

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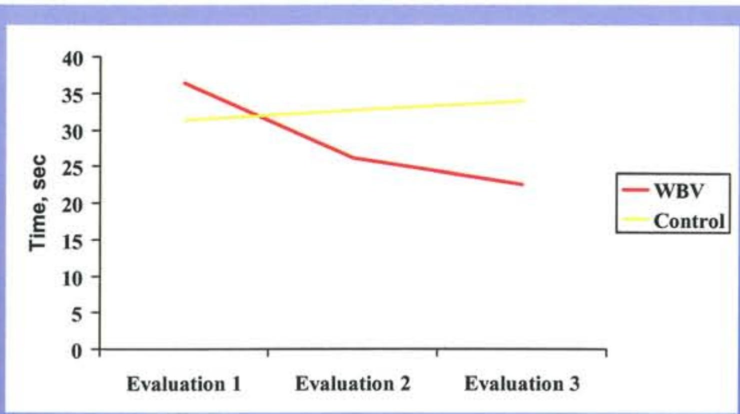
Objective: To investigate the effects of controlled whole body vibrations (CWBV) exercises on global health in elderly patients.

Methods: 42 volunteers patients, resident in a nursing home, were randomized to either a vibration group or control non-treated group. The vibration intervention consists of a 6-week CWBV training (4 x 1 minutes series, 3 times a week) employed by standing on a vertical vibrating (10 Hz in the first and the third series and 27 Hz in the second and fourth ones) platform (Galileo 900®). Different validated tests were performed, at the beginning and at the end of the study, in all patients. Quality of life was assessed by the 9 subscales of the SF-36 questionnaire: physical function (PF), social function (SF), role emotional (RE), role physical (RP), mental health (MH), vitality (V), pain (P), general health (GH) and health change (HC). Quality of walking, as well as the balance were assessed by the Tinetti test. The "get-up-and-go" test was used to assess the motor capacity.

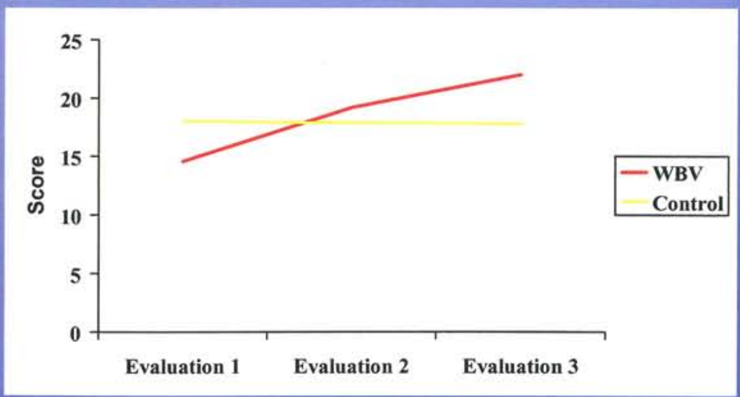
Results: Baseline characteristics of the two groups (22 patients in the vibration group and 20 in the control group) was not statistically different except for age (84.5 (5.9) years in the treated group and 79.0 (6.9) years in the control group, p=0.008). After 6 weeks of treatment, 7 items (PF, SF, RE RP, V, P, GH) of the SF-36 improved significantly in the CWBV group compared to the control group, with, for example, 143% of improvement in PF (p=0.0002 between the two groups), 41% in P (p=0.004), 60% in V (p=0.0006), and 23% in GH (p=0.0002). Improvement of 57% in the quality of walking, assessed by the Tinetti test, was also observed in the treated group compared to only 2% in the control group (p=0.0003). For the equilibrium, improvement was 77% in the CWBV group and the worsening was 1% in the control group (p=0.001). Eventually, a decrease of 39% of the time to performed the get-up-and-go test was also observed, after 6 weeks, in the treated group, compared to an increase of 14% in the control group.

Conclusion: Fast and easy exercises, 3 times a week during 6 weeks, using a CWBV apparatus, could improve the quality of life, the walk, the balance and the motor capacity in elderly patients. Longer studies with more patients are needed to assess the impact of such benefits.

Evolution of the Get up and go

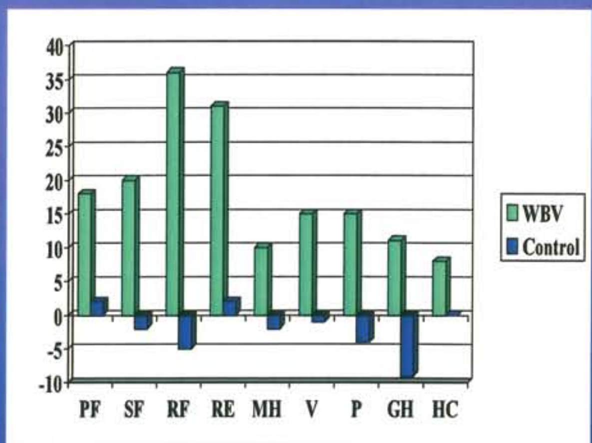


Evolution of the Tinetti global score



Galileo 900 Apparatus

SF-36 changes after 18 sessions (Absolute value)



Influence of the grade of knee flexion on mechanical and electromyographical impact during whole body vibration exercise

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Introduction: The magnitude of acceleration produced by Whole Body Vibration Exercise (WBV) with small vertical oscillations could be osteogenic but one of the most used WBV device by clinics produces oscillations by means of the rocking of a platform on an axle, pointing out a foot of each side of the axle (WBVa). The body posture is a major determinant of the mechanical impact transmitted from vibrating platform throughout body. The purpose was to compare the received three-dimensional acceleration in the lumbar zone and the electric activation of the muscles selected during a WBVa in three 3 different angles of flexion of the knees.

Methods: Thirty women (mean age 22, SD 2) performed 3 repetitions of WBVa (Galileo 900, Novotec, Germany) at 25 Hz and 4 mm of amplitude oscillatory during 30 seconds within 5 minutes of rest between them. The repetitions were performed with 15, 45 and 90° of flexion of knees. The acceleration was recorded by a tri-axial accelerometer (Biopac, USA) attached on the skin at L3 level and the EMG was registered by surface active electrodes (Biopac, USA) on the extensors and flexors of knee and low-trunk. The EMG recorded was expressed as the percentage of these obtained during maximal isometric knee flexo-extension at 45° (Biodex, USA) and trunk flexo-extension during Ito-Shirado Test. It was proceeded the analysis of the variance for repeated measures.

Results: The median of lateral acceleration was 3 times superior ($p < 0.001$) to the vertical line one in the 3 angles of measured flexion, and the vertical line was the double ($p < 0.001$) of the anterior-posterior line. The maximum accelerations: lateral (11–13 g) and vertical line (6–7 g) had increased when reducing the angles of flexion of the knees, such as the median of the accelerations at the lumbar level. The muscles of the trunk had been stimulated 60–70% and the Internal Vast muscle increases significantly its electric activity as knee flexion increased.

Discussion: Both, lateral and vertical accelerations were clearly superior to the osteogenic threshold previously described by Rubin et al. [1].

Conclusion: The machine used in WBVa transmitted higher mechanical lateral impacts than vertical ones. However, an osteogenic stimulus could be expected in both axes. The machine was especially useful to stimulate internal vastus and low back muscles.

Reference

[1] C. Rubin et al., *Spine 28* (2003), 2621–2627.

Whole-body vibratory exercise reduces the risk of bone fracture

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Introduction: While vibratory exercise has been highly effective in the increase of bone mineral mass on animals, the use of this technique in humans has shown non-conclusive results. The purpose of this study was to evaluate the effects of Whole-Body Vibration Training (WBV) on the bone mineral density (BMD) and on balance in post-menopausal women.

Methods: Twenty-eight healthy but non-trained post-menopausal women were divided randomly in two groups (experimental G_1 and control G_2) of 14 subjects. Training consisted in 3 weekly sessions during a time span of 8 months. Each session consisted of (a) 10 min of warming up on a cycle-ergometer, (b) 5 minutes of stretching and (c) 6 series of 1 min WBV within 1 min interval between series. WBV was performed at 25 Hz of frequency and 3 cm of vertical amplitude in erect position with a knee flexion of 60°. Hip and lumbar BMD ($g{\cdot}cm^{-2}$) was measured using DXA technique. Balance was measured by blind famingo test. Data was examined by analyses of variance for repeated measurements being adjusted by body weight for BMD data.

Results: The femoral neck BMD increased by 2.3% in G_1 while this of the G_2 decreased by 2.0% during the same time span. Inter-groups variation was significant (p =0.016). At level of the trochanter, G_1 increased BMD with 1.05% and G_2 decreased with 1.2% showing non-significant inter-group variation (p =0.07). At level of the Ward's triangle BMD, G_1 record a non-significant increase of 7.8% while G_2 did not change. At lumbar level, the decrease in both G_1 and G_2, was non-significant (0.9% vs 1.0% respectively). WBV group increases significantly ($p = 0.033$) balance comparing with W (−28.7% of falls vs +4.4% respectively).

Discussion: This non-significance at lumbar level could be partially attributed to: (a) the partial knee flexion during the vibratory exercise reducing the transmissibility of the mechanical stimulation of the platform and (b) the WBV produced by the device we used produced a 3 times greater acceleration on X-axis than Y-axis.

Conclusion: The eight-month exercise programme of whole-body vibration with a frequency of 25 Hz reduced the risk of fracture by increasing the BMD at level of femoral neck and increasing the balance in post-menopausal women.

Fisiología del Ejercicio

Entrenamiento vibratorio. Base fisiológica y efectos funcionales

E. García-Artero, F. B. Ortega Porcel, J. R. Ruiz, F. Carreño Gálvez

Vibration training. Physiological basis and effects

Resumen

El uso de las plataformas vibratorias como estrategia de entrenamiento es cada vez mayor entre deportistas de todos los niveles. Las vibraciones emitidas actúan sobre las estructuras neurológicas del organismo. Receptores musculares principalmente, pero también vías medulares e incluso estructuras corticales, sufren la acción del estímulo vibratorio. La activación muscular que se produce permite desarrollar mayores niveles de fuerza y potencia muscular. Al transmitirse por las estructuras blandas del organismo, el estímulo vibratorio origina adaptaciones cardiorrespiratorias. El sistema endocrino también responde, aunque sobre esto los resultados son aún contradictorios. Conocer la base fisiológica de su mecanismo de acción será fundamental para diseñar programas eficaces de entrenamiento vibratorio. La frecuencia vibratoria, la amplitud, el tiempo de estimulación, la posición adoptada, etc, deberán ser correctamente escogidos para obtener resultados positivos.

Selección, 2006; 15 (2):78-86

Palabras clave: Entrenamiento vibratorio. Activación neuromuscular. Rendimiento.

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Summary

The use of vibrating platforms as a training method is widely used in sport training. The vibration stimulates the neurological structures of the body, therefore, both muscle receptors and cortical and medulla structures are activated. The vibration stimulus is known to induce force and power gains, as well as cardiorespiratory adaptations. Endocrine adaptations also seem to occur after a vibration training period, but the results are contradictory. Knowing the physiological effects of that unusual but effective stimulus is of interest for designing successful vibration training-based programs. Frequency, amplitude, application time, body position, etc, are important variables to take into account in order to achieve optimal results.

Key words: Vibration training. Neuromuscular activation. Performance.

Introducción

Desde la segunda mitad de los años 80 hasta la actualidad se ha desarrollado una forma de entrenamiento basada en la utilización de estímulos vibratorios. Empleada por primera vez por entrenadores rusos (1), se trata de una modificación del *reflejo tónico vibratorio*, una contracción muscular refleja originada al estimular localmente un músculo o tendón mediante vibraciones (2).

Inicialmente se emplearon sistemas que transmitían vibraciones a los músculos, mediante cables o fijados

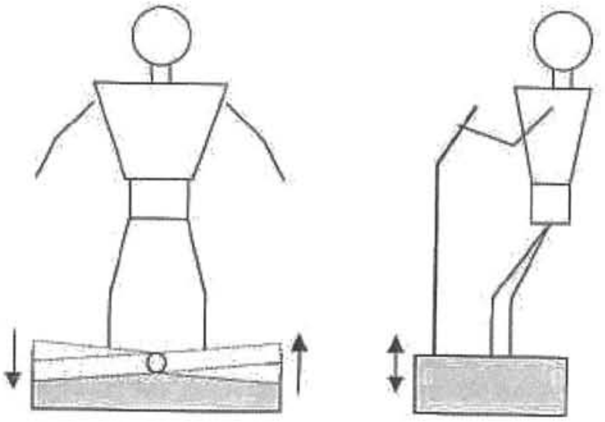

Figura 1. Plataforma vibratoria. La base de la plataforma, sobre la cual se colocan los pies, vibra alrededor de su eje central. La amplitud del movimiento oscilatorio aumenta cuanto mayor es la distancia respecto al centro.

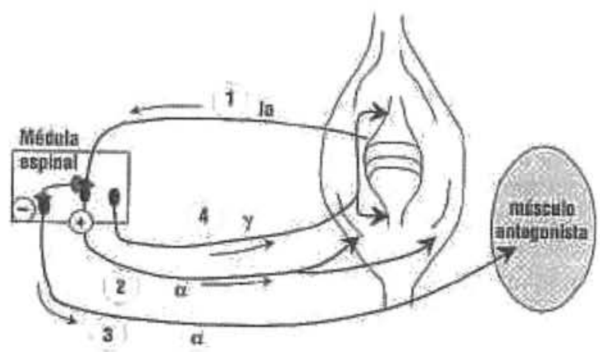

Figura 2. Reflejo miotático. 1) Señal aferente (sensitiva) procedente de la fibra muscular intrafusal. 2) Señal eferente (motora) dirigida hacia las fibras musculares extrafusales. 3) Señal eferente (motora) inhibitoria dirigida al músculo antagonista. 4) Señal eferente (motora) hacia los extremos de las fibras musculares intrafusales, para mantener elongada la parte central del huso.

directamente a la piel. En la actualidad existen máquinas que provocan una vibración del cuerpo entero. Se trata de plataformas que vibran en sentido vertical con una frecuencia (número de ciclos vibratorios por segundo, Hz) y amplitud de desplazamiento (distancia recorrida por la vibración en cada ciclo, mm) determinadas. La utilización de estas plataformas vibratorias orientada al desarrollo de las propiedades contráctiles del músculo ha dado lugar al entrenamiento vibratorio (EV) (Fig. 1).

El creciente número de trabajos publicados sobre esta forma de entrenamiento, y su uso cada vez más extendido entre deportistas de todos los niveles, hacen necesario el esfuerzo de recopilar los resultados y conclusiones de mayor rigor, con el fin de establecer los principios básicos que deben regir esta nueva metodología de entrenamiento.

Base fisiológica

Para conocer el proceso en profundidad, la mayoría de los estudios dedicados a la fundamentación fisiológica del EV se han llevado a cabo mediante estimulación específica local de un músculo aislado o grupo muscular. En este sentido, la aplicación de movimientos oscilatorios sinusoidales sobre los músculos o sobre los tendones provoca pequeños y rápidos cambios en la longitud de la unidad músculo-tendinosa. Estos rápidos cambios de longitud son detectados por los propioceptores, principalmente los husos neuromusculares (3). Recordemos que el huso neuromuscular es responsable de detectar de manera inconsciente el grado de elongación del músculo y mantenerlo constante mediante una contracción muscular refleja cuando ese músculo es elongado externamente. Es lo que se conoce como reflejo miotático (Fig. 2). Como consecuencia de la detección de las vibraciones por parte de los husos neuromusculares, se produce una mayor ratio de descarga de estas estructuras (3) y ello se traduce en un aumento de los potenciales motores evocados en los músculos sometidos a vibración (4, 5). También se ha sugerido la intervención de los corpúsculos tendinosos de Golgi (3) e incluso de los receptores cutáneos (6). Todo ello supone, tal y como se ha constatado, una activación de los circuitos medulares en los que se basa el reflejo miotático (7), lo que provoca una mayor sincronización de unidades motrices a través de sus motoneuronas α (8).

Por otra parte, también resultan estimuladas las motoneuronas γ (8) que mantienen elongada la parte central de los husos neuromusculares, haciendo que éstos sean más sensibles. Ello mejora la eficiencia del sistema neuromuscular una vez que el estímulo ha cesado. Los músculos antagonistas a los estimulados también resultan afectados, mediante un descenso de sus potenciales motores (5). Ello podría hacer que la co-contracción fuera menor, aliviando las fuerzas de frenado en los movimientos explosivos (8). El hecho de que este efecto inhibitorio de la vibración sobre los músculos antagonistas se haya observado también en el miembro contralateral al estimulado, indica cierta influencia de las señales aferentes sobre la coordinación interhemisférica (mediante las fibras transcallosas), lo cual podría a su vez modular las señales eferentes evocadas por la corteza motora (5).

Todo ello señala que el efecto de la estimulación vibratoria parece no limitarse a las estructuras medulares que dirigen el nivel reflejo de los movimientos. El aumento de los potenciales motores (4, 5), junto con el aumento de la frecuencia de la señal electromiográfica tras exposición prolongadada (7, 9), sugieren un estado de notable excitabilidad de la corteza motora. Ello provocaría un reclutamiento predominante de fibras musculares tipo II, quizá debido a un descenso del umbral de descarga de estas unidades motrices grandes, en comparación con el umbral elevado que suelen presentar en la activación voluntaria (10).

La consecuencia de todo ello es que la aplicación del estímulo vibratorio produce un estado de mayor eficiencia neuromuscular (11, 12) que permite aumentar el rendimiento en los movimientos voluntarios. Sin embargo, aún no se ha explicado el porqué de esta activación muscular. La clave parece radicar en un proceso de adaptación de los músculos a lo que supone el estímulo vibratorio. Esta activación muscular les confiere una mayor rigidez que les permite absorber más energía vibratoria, lo que ayudaría a atenuar los posibles efectos adversos (13, 14). Se trata, en definitiva, de una respuesta defensiva del organismo ante los estímulos que recibe.

Efectos del entrenamiento vibratorio

Efectos durante el estímulo vibratorio

Se trata de aquellos efectos que se producen mientras los músculos están siendo sometidos a la vibración. En estas circunstancias, y mediante estimulación local aislada de ún músculo, se ha constatado un aumento de los potenciales motores (efecto facilitador) en el músculo estimulado y un descenso de esos mismos potenciales (efecto inhibidor) en el músculo antagonista (4, 5). También se ha observado un aumento de la actividad electromiográfica (11, 15, 16, 17), aumento de la máxima contracción voluntaria isométrica (18) y concéntrica (19) y aumento de la potencia muscular (20).

La estructura muscular no es la única afectada. También se producen adaptaciones agudas por parte del sistema cardiorrespiratorio. Mantenerse en pie sobre una plataforma vibratoria durante 3 minutos supone un aumento considerable del consumo de oxígeno, hasta un nivel comparable al necesario para caminar a velocidad moderada (21). Por ello se puede decir que se trata de una forma de ejercicio, y no de una simple activación muscular pasiva (Tabla I).

TABLA I

Efectos durante el estímulo vibratorio

Sistema	*Efecto*
Neuromuscular	↑ potenciales motores músculos sometidos a vibración
	↓ potenciales motores músculos antagonistas
	↑ EMG
	↑ MCVI
	↑ MCVC
	↑ P
Cardiorrespiratorio	↑ VO_2

EMG: actividad electromiográfica; MCVC: máxima contracción voluntaria concéntrica; MCVI: máxima contracción voluntaria isométrica; P: potencia muscular; VO_2: consumo de O_2; ↑ : aumento; ↓ : descenso.

Efectos a corto plazo

Son aquéllos que tienen lugar inmediatamente después de la aplicación del estímulo vibratorio. Se ha observado una mayor potencia muscular (11, 12, 22) con una menor actividad electromiográfica, lo cual indica un estado de alta eficiencia neuromuscular (11, 12). Se han registrado mejoras en la capacidad de máxima contracción voluntaria concéntrica (22) e isométrica (23), una mayor altura de salto en contramovimiento (12, 23) y una mejora del equilibrio estático (23).

El aumento de la carga gravitatoria que ha de soportar el sistema neuromuscular provoca adaptaciones endocrinas. Se han registrado aumentos en las concentraciones plasmáticas de hormona de crecimiento (12, 24) y testosterona (12), junto con un descenso del cortisol (12), lo que origina un perfil hormonal eminentemente anabólico. Sin embargo, los resultados en este campo son aún contradictorios. Di Loreto y colaboradores (25) encontraron tan solo un descenso de la glucemia junto con un aumento de la concentración plasmática de noradrenalina, sin cambios en las concentraciones de hormona de crecimiento, IGF 1(*insulin-like growth factor 1*) ni testosterona (libre y total).

En algunos trabajos la aplicación de la estimulación vibratoria ha sido extenuante, para poder estudiar el tipo de fatiga provocada por esta forma de entrenamiento. En estas circunstancias se han registrado descensos en la altura del salto (9), en la capacidad de máxima contracción voluntaria (9, 26, 27, 28), en el pico de fuerza isométrica ante cargas submáximas (7), un descenso del tiempo que se puede mantener una contracción submáxima (7, 29) e incluso un deterioro en la producción de fuerza por unidad de tiempo (26).

Se trata, por tanto, de una fatiga manifestada principalmente a nivel muscular, causada por un estado de notable activación neurológica cuyo origen no está aún del todo esclarecido (9). Dilucidar a qué nivel neurológico nace esta fatiga será vital para poder determinar cuál es el origen de la activación muscular provocada por la estimulación vibratoria, y si este origen es único o una combinación de varios. Por los trabajos realizados hasta la fecha, parece ser el origen multifactorial la posibilidad con más argumentos a favor. Se ha observado un descenso en la capacidad voluntaria de activación muscular tras estimulación vibratoria, lo cual situaría el origen de la fatiga a nivel cortical. Sin embargo, en el mismo estudio se observó también un descenso en la capacidad total del músculo de generar fuerza mediante estimulación eléctrica, lo que situaría el origen de la fatiga a nivel periférico (30).

Debido a que las vibraciones pueden transmitirse por los tejidos blandos, éstas se convierten en un estímulo general sobre todo en el EV con plataformas. Además de la función neuromuscular, se ponen en marcha sistemas y funciones fisiológicas de mayor alcance. Tras una sesión de EV combinado con squat y llevado hasta la fatiga, se han registrado valores de 128 lpm como frecuencia cardíaca media, una tensión arterial de 132/52 mmHg, una concentración de lactato de 3.5 mmol/L, un consumo de oxígeno del 48,8% del máximo y un cociente respiratorio de 0,90 (9).

En estudios llevados a cabo en nuestro laboratorio (EFFECTS: **E**valuación **F**uncional y **F**isiología del **E**jercicio. **C**iencia y **T**ecnología para la **S**alud), mediante plataforma vibratoria (*Galileo 900®*, Novotec, Germany), se obtuvieron resultados que concuerdan con los de anteriores trabajos (9, 21). Estímulos vibratorios (25 Hz y 4 mm) aplicados sobre brazos y piernas por separado, en series de un minuto, provocaron un aumento de la frecuencia cardiaca, un aumento de la tensión arterial sistólica al aplicarse sobre las piernas, así como un descenso de la tensión arterial diastólica cuando las vibraciones fueron aplicadas sobre los brazos, todos ellos cambios estadísticamente significativos ($p<0,05$). Aunque estos resultados aún no han sido publicados, los procesos fisiológicos hacia los que apuntan estarían en consonancia con el aumento del flujo sanguíneo obtenido por otros autores (9, 31, 32), y añadirían (sobre todo el descenso de la TA diastólica) la posibilidad de un proceso de vasodilatación. Algún autor concreta algo más y habla de ensanchamiento de capilares (31). De un modo u otro, este argumento explicaría los eritemas que suelen aparecer en las sesiones de EV (9) y los aumentos que hemos registrado en los perímetros musculares de bíceps relajado, bíceps contraído y muslo. En resumen, el proceso global consistiría en que un elevado flujo sanguíneo en la zona origina un edema temporal de los miembros, debido a una notable extravasación del pasma desde los capilres al espacio intersticial, lo que en el campo del entrenamiento deportivo se conoce como hipertrofia transitoria.

TABLA II

Efectos inmediatos o a corto plazo

Sistema	*Modificación*
Neuromuscular	↑ P, ↓ EMG } ↑ eficacia neuromuscular
	↑ EMG (estimulaciones extenuantes)
	↑ MCVI, ↑ MCVC
	↑ CMJ
	↑ equilibrio estático
	↑ perímetros musculares
Cardiorrespiratorio	↑ FC, ↑ TA sistólica, ↓ TA diastólica
	↑ [lact], ↑ QR
	↑ flujo sanguíneo, vasodilatación, eritemas
Endocrino	↑ GH, ↑ T, ↓ C ¿?

C: cortisol; CMJ: salto en contramovimiento; EMG: actividad electromiográfica; FC: frecuencia cardíaca; GH: hormona del crecimiento; MCVC: máxima contracción voluntaria concéntrica; MCVI: máxima contracción voluntaria isométrica; P: potencia muscular; QR: cociente de intercambio respiratorio (VCO_2/VO_2); T: testosterona; TA: tensión arterial; [lact]: concentración sanguínea de lactato; ↑ : aumento; ↓ : descenso; ¿?: existencia de resultados contradictorios.

Especial atención merecen los cambios observados en la actividad electromiográfica una vez finalizada la aplicación del estímulo vibratorio. Tras series de 1 minuto, la señal electromiográfica desciende pero se alcanza un alto rendimiento neuromuscular (11, 12) de origen probablemente periférico. Sin embargo, cuando el estímulo se aplica hasta la fatiga en series de hasta 5 ó 6 minutos, ocurre todo lo contrario. El rendimiento muscular desciende pero la señal electromiográfica aumenta (7, 9), sugiriendo una alta excitabilidad cortical que conllevaría el reclutamiento de grandes unidades motrices. Sin olvidar nunca la importancia de parámetros como la frecuencia, la amplitud y la realización o no de movimientos voluntarios sobre la plataforma, estos resultados sugieren que el tiempo de aplicación de la estimulación vibratoria podría determinar qué tipo de estructuras neurológicas se ven afectadas (Tabla II).

Efectos a largo plazo

Son aquéllos que surgen tras un programa estructurado de EV (Tabla III). La duración de estos programas ha variado de unos trabajos a otros, por lo que éste será un factor a tener en cuenta a la hora de analizar los resultados.

TABLA III

Efectos a largo plazo

Sistema	*Modificación*
Neuromuscular	↑ MCVI, ↑ 1 RM ↑ CMJ ↑ capacidad de salto (saltos repetidos 5 s) ↑ equilibrio estático

CMJ: salto en contramovimiento; MCVI: máxima contracción voluntaria isométrica; 1 RM: 1 repetición máxima; s: segundos; ↑ : aumento; ↑ : descenso.

Tras 10 días de EV con un volumen aproximado de 10 minutos al día, Bosco y colaboradores (33) observaron mejoras significativas en un test de saltos repetidos de 5 segundos. En el test de salto en contramovimiento no hubo mejora alguna. Los autores argumentaron que en este tipo de salto la fase de elongamiento de los músculos no es lo suficientemente rápida como para activar el reflejo miotático o de estiramiento (base fisiológica del EV), cosa que sí ocurre en el test de saltos repetidos. Como explicación a las adaptaciones producidas, se sugirió una posible elevación del umbral de descarga de los órganos tendinosos de Golgi. Ello permitiría que el complejo músculo-tendón pudiera soportar mayores tensiones y, por tanto, un mayor número de unidades motrices fueran reclutadas durante la fase excéntrica.

Un estudio posterior (34) empleó exactamente el mismo protocolo de EV que Bosco (33), confirmando la ausencia de mejoras en el salto en contramovimiento y extendiéndola al salto desde parado y a diferentes tests de velocidad y agilidad. Los efectos que hasta ahora ha demostrado tener el EV y la base fisiológica en que se sustentan estos, sugieren que quizá las capacidades de velocidad y (sobre todo) agilidad no sean las más susceptibles de ser mejoradas con esta metodología. Además, en el caso concreto de la agilidad, se trata de una cualidad física que incluye numerosos factores tales como coordinación, fuerza explosiva, velocidad, entre otros.

Estudios aún no publicados de nuestro grupo de investigación (EFFECTS) mostraron que la aplicación de un programa de 4 semanas de EV en plataforma (25 Hz, 4 mm, 3 sesiones / semana, 10 minutos / sesión) sobre estudiantes de Educación Física (n=12; edad 24,2 ± 1,2 años; peso 70,8 ± 10,7 kg; talla 172,6 ± 11,1 cm) no produjo mejora alguna en el test de salto en contramovimiento. En este trabajo se evaluaron también otras variables relacionadas con la función neuromuscular y con el perfil antropométrico, destacando aumentos del 6.2% en la potencia máxima desarrollada en press banca y del 4% en el test de 1 repetición máxima de sentadilla (en ambos p>0,05). La capacidad de equilibrio estático, evaluada mediante *flamingo balance test*, mejoró notablemente, reduciéndose en un 51% el número de desequilibrios cometidos en un minuto de apoyo monopodal (p = 0,06).

De Ruiter (30), en un estudio de características similares al desarrollado por nosotros pero con una duración de 2 semanas, tampoco observó mejora alguna en la máxima contracción voluntaria isométrica ni en la fuerza por unidad de tiempo. En ambos trabajos el poco tiempo de estimulación (5 series de 1 minuto) y el tipo de muestra empleada pueden ser causa de los resultados. La corta duración de los programas de entrenamiento también puede ser en parte responsable. En un estudio muy reciente (35) se ha comprobado que 5 semanas de EV no han supuesto ningún aumento adicional en el rendimiento de atletas de velocidad respecto a su entrenamiento convencional.

Investigadores belgas (17) registraron, tras 12 semanas de EV en plataforma, mejoras significativas en la máxima contracción voluntaria isométrica y en la fuerza isocinética concéntrica de los extensores de rodilla. Dichas mejoras fueron similares a las obtenidas por otro grupo que entrenó fuerza convencionalmente, con igual duración total y misma frecuencia semanal. El grupo de EV obtuvo un incremento significativo en la altura del salto en contramovimiento que no se produjo en el otro grupo. No obstante hay que destacar que el entrenamiento convencional de fuerza, con 2 series por ejercicio y 10-20 repeticiones máximas en cada serie, no era el más apropiado para la mejora de la fuerza explosiva. La presencia de un grupo placebo (mismo programa de EV pero con una amplitud inapreciable) en el que no se produjo ningún tipo de mejora, permitió a los autores afirmar que las mejoras producidas en el grupo EV fueron debidas a la estimulación vibratoria y no a los ejercicios voluntarios realizados durante la misma.

Ampliar la duración de los programas de EV no siempre asegura resultados positivos. Tras dos meses de entrenamiento vibratorio en plataforma se obtuvo una mejora en la altura del salto en contramovimiento del 10,2%, mientras que a los 4 meses dicha mejora bajó hasta el 8,5% (36). En el mismo estudio, un aumento de la máxima contracción voluntaria isométrica fue observado sólo a los 2 meses. No se registraron cambios ni en la capacidad de equilibrio estático ni en la velocidad-agilidad. Los resultados llevaron a los autores a sugerir que las adaptaciones producidas por el EV son similares a las ocurridas durante las primeras semanas de un programa de entrenamiento de fuerza, adaptaciones de tipo neuromuscular.

Los efectos del EV mencionados hasta ahora, principalmente las adaptaciones endocrinas, sugieren la posibilidad de algún cambio en la composición corporal tras un programa de entrenamiento en plataforma. Aunque se trata de un aspecto aún por clarificar, debido a la existencia de resultados contradictorios (12, 24, 25), un estudio de Roelants y colaboradores (37) obtuvo resultados que apuntan en esta dirección. Tras 24 semanas de EV se registró un aumento significativo de la masa libre de grasa en mujeres jóvenes no entrenadas, junto con mejoras notables en la máxima contracción isométrica e isocinética concéntrica.

Entrenamiento vibratorio asociado a entrenamiento convencional

Entre las estrategias a largo plazo de esta metodología de entrenamiento, la combinación del EV con el entrenamiento tradicional de fuerza ha dado resultados muy prometedores. En tan sólo 3 semanas de entrenamiento realizando curl de bíceps combinado con vibración, al 80-100% de 1 repetición máxima, se registraron mejoras del 49,8% en el test de 1 repetición máxima, frente a mejoras del 16% obtenidas al realizar sólo entrenamiento tradicional (38). En la misma línea, 5 semanas realizando sentadillas a una intensidad de 6-10 repeticiones máximas sobre plataforma vibratoria produjeron mejoras significativas en el test de 1 repetición máxima (32,4%) y en la altura del salto en contramovimiento (9,1%), frente a un aumento también significativo pero menor de 1 repetición máxima (24,2%) y ningún cambio en el salto en contramovimiento en otro grupo que entrenó exactamente igual pero sin estímulo vibratorio (39). La combinación de ambas formas de entrenamiento, tradicional y vibratoria, puede ser la estrategia ideal para el desarrollo de la fuerza y la potencia muscular.

Percepción subjetiva ante la estimulación vibratoria en plataforma

Al tratarse de una forma novedosa de estimulación, resulta conveniente conocer las sensaciones que experimentan los deportistas, algo sobre lo que no muchos autores han trabajado. Los sujetos de nuestros estudios expresaron una sensación de cosquilleo en los músculos más cercanos a la plataforma, sensación que iba atenuándose progresivamente en zonas más alejadas. La fatiga provocada fue, según ellos mismos, muy localizada e intensa aunque de pronta recuperación. Tras series de 1 minuto de estimulación vibratoria, los valores promedio de RPE (*rating of perceived exertion*) fueron de 13 para brazos y 10,5 para piernas en la escala de Borg 6 a 20 (40). Deportistas de otro estudio (17) calificaron las sesiones de EV mediante plataforma como divertidas y fatigantes, en ningún caso como trabajo duro.

Como en todo tipo de entrenamiento, en el EV también se produce una adaptación progresiva a las cargas de entrenamiento. Cochrane (34) indicó que la primera sesión de EV causó en sus sujetos un nivel de incomodidad significativamente mayor que el resto. En nuestros estudios (EFFECTS-262) se observó un descenso significativo de la RPE de un 25 % al progresar dentro de un programa de 4 semanas.

Factores determinantes en el entrenamiento vibratorio

Existe una gran variedad de protocolos de estudio respecto al EV. No obstante, estos pueden ser agrupados en los siguientes parámetros fundamentales (Tabla IV).

TABLA IV

Entrenamiento vibratorio mediante plataformas orientado al desarrollo de la fuerza y la potencia muscular. Factores influyentes

Factor		*Valor idóneo*
Frecuencia	(Hz)	25 - 45
Amplitud	(mm)	4 - 6
Tiempo	serie total sesión	hasta 1 - 1,5 min hasta 20 - 25 min
Protocolo de ejercicios		dinámicos variados angulación específica con sobrecarga externa (en estado avanzado)
Tipo de atletas		mayores efectos cuanto mayor nivel de entrenamiento

Hz: hercios; min: minutos; mm: milímetros.

Forma de aplicación

El estímulo vibratorio puede ser aplicado de dos formas. De forma directa sobre el vientre muscular o sobre el tendón, mediante cables que transmiten la vibración de forma localizada o mediante instrumentos vibratorios fijados a la piel. O bien de forma indirecta, mediante plataforma vibratoria. Ésta última forma es la más empleada en la actualidad, y se conoce como *whole body vibration*. Se sabe que las estructuras blandas absorben parte de la vibración en su recorrido hasta el músculo objeto del entrenamiento. Por esto los músculos más cercanos a la plataforma vibratoria resultan activados en mayor medida que aquellos situados más lejos (17, 23). La forma directa no sufre esta atenuación, pues se aplica sobre el músculo o tendón que se pretende estimular. Sin embargo, la forma indirecta presenta la ventaja de activar un mayor número de músculos.

Frecuencia vibratoria

Ciclos por segundo que presenta la vibración (Hz). Una frecuencia de 50 Hz resultó más efectiva que 137 (15), al igual que 80 frente a 120 y 160 Hz (4) y 30 Hz frente a 120 (26). Al emplear plataformas vibratorias, frecuencias de 30, 40 y 50 Hz han resultado efectivas para aumentar la señal electromiográfica, aunque de forma significativamente mayor los 30 y los 40 Hz (16). Aumentar la frecuencia empleada en plataforma vibratoria en un rango de 18 a 34 Hz supone un aumento proporcional del consumo de oxígeno, lo cual indica que, al menos en ese rango, a mayor frecuencia mayor actividad metabólica muscular (41). En general, en el empleo de plataformas vibratorias las frecuencias se mantienen por debajo de los 50 Hz, pudiendo situar el rango más efectivo entre 25 y 45 Hz. Es recomendable comenzar con una frecuencia algo más baja e ir aumentando poco a poco conforme avanza el entrenamiento. En todo caso, se recomienda evitar frecuencias por debajo de 20 Hz debido al fenómeno de resonancia o desplazamiento entre los órganos y la estructura esquelética.

Amplitud de la vibración

Distancia recorrida por la vibración en cada ciclo (mm). Algunos autores lo expresan como la distancia total (*peak-to-peak*), pero lo habitual en plataformas vibratorias es indicarlo como la mitad del recorrido, es decir, la distancia desde la posición horizontal de la plataforma hasta uno de los extremos, ya sea el superior o el inferior. De esta segunda forma nos referiremos nosotros a la amplitud para explicar ahora su importancia en los efectos del EV. Dos estudios realizados por los mismos investigadores, idénticos en todo salvo en la amplitud de la vibración, obtuvieron resultados muy diferentes. Uno de ellos (42) empleó 1 mm de amplitud, sin producir cambio alguno en el rendimiento neuromuscular. El otro (23) utilizó 4 mm, obteniendo un aumento en la máxima contracción voluntaria isométrica y en la altura del salto en contramovimiento.

El aumento de la amplitud vibratoria en un rango de 2,5 a 7,5 mm, mientras el resto de parámetros permanecen constantes, supone un aumento del consumo de oxígeno, siendo estos aumentos significativamente mayores con las amplitudes más altas (41). Los estudios revisados parecen indicar que amplitudes de 4 a 6 mm garantizan la activación muscular pretendida con el uso de plataformas vibratorias.

Tiempo de aplicación del estímulo

Tras series vibratorias de 1 minuto se han obtenido aumentos de la potencia muscular (11, 12, 22), mientras que exposiciones excesivamente cortas de 6-7 segundos no han producido dichas mejoras (20). Cuando el estímulo se prolonga en exceso llegando a exposiciones ininterrumpidas de 5-6 minutos o incluso más, lo que se obtiene es todo lo contrario, un descenso del rendimiento neuromuscular (7, 9, 26, 27, 28, 29).

Dos estudios longitudinales de similares características obtuvieron resultados contrarios, radicando la principal diferencia en el tiempo de estimulación empleado en las sesiones. El estudio en el que sí se registraron mejoras en el rendimiento (17) empleó sesiones que incrementaron su duración desde 3 minutos al comienzo hasta 20 en las sesiones finales. Sin embargo, en aquél en el que no se obtuvo ninguna mejora (43) las sesiones progresaron sólo desde 5 hasta 8 minutos. Torvinen (36), a pesar de emplear un programa de EV de 4 meses, apenas registró mejoras en el rendimiento neuromuscular, quizá debido a que la estimulación vibratoria en cada sesión tenía un volumen total de tan sólo 4 minutos. Se recomienda aumentar sesión tras sesión el tiempo de estimulación vibratoria, hasta llegar a exposiciones ininterrumpidas (series) de 1-1,5 minutos y un volumen total de 20-25 minutos por sesión.

Protocolo de ejercicio

El tipo de ejercicio que el sujeto realiza mientras recibe el estímulo vibratorio puede influir notablemente. Los ejercicios dinámicos parecen ser los más adecuados para provocar mejoras en la fuerza y potencia musculares (44). Se suelen emplear, entre otros, movimientos de squat, squat profundo, squat con una pierna, extensiones de tobillo y apoyos sobre los talones. Algunos protocolos de EV han añadido sobrecarga externa (38, 39). La eficacia que han demostrado ha sido notablemente alta, obteniendo las ganancias crónicas más altas en lo que a parámetros neuromusculares dinámicos se refiere (test de 1 repetición máxima y salto en contramovimiento) y además en períodos de aplicación relativamente cortos, de entre 3 y 5 semanas.

El ángulo de flexión adoptado por las articulaciones (principalmente la rodilla) al realizar los ejercicios también debe ser tenido en cuenta. Este factor provocará una alta especificidad en los resultados, de modo similar a como ocurre en el entrenamiento isométrico. La relación directamente proporcional establecida entre la eficacia del estímulo vibratorio y el grado de estiramiento del músculo apoyaría esta teoría (16).

Nivel de entrenamiento

Tan sólo dos estudios se han ocupado de investigar los efectos de un mismo protocolo de EV sobre deportistas con diferentes niveles de entrenamiento. Dichos trabajos analizaron los efectos agudos y sus resultados pusieron de manifiesto que la vibración es más eficaz cuanto más entrenados están los sujetos. Se obtuvieron mejoras significativamente mayores en deportistas de elite respecto a amateurs (20) y en atletas olímpicos respecto a nacionales, juniors y amateurs (19). La mayor sensibilidad de los receptores musculares y del sistema nervioso central de los deportistas de elite hacia la estimulación adicional, puede ser la causa de este fenómeno (20[illegible]

Conclusiones

El EV se presenta como una novedosa estrategia en el campo de la actividad física y el deporte, cuyo uso se encuentra en expansión dentro del mundo deportivo. Los estudios realizados hasta la fecha, junto con revisiones como ésta, nos muestran cómo deben ser empleadas las plataformas para obtener importantes beneficios en el rendimiento deportivo. Series de hasta 1,5 minutos con frecuencias de 25-45 Hz, amplitudes de 4-6 mm, ejercicios dinámicos, variados y con sobrecarga cuando se tiene un nivel considerable, pueden ser las consignas más importantes de cara al desarrollo de la potencia muscular, la fuerza máxima isométrica y concéntrica y la fuerza explosiva.

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Whole-body vibration exercise leads to alterations in muscle blood volume

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Summary

Occupationally used high-frequency vibration is supposed to have negative effects on blood flow and muscle strength. Conversely, low-frequency vibration used as a training tool appears to increase muscle strength, but nothing is known about its effects on peripheral circulation. The aim of this investigation was to quantify alterations in muscle blood volume after whole muscle vibration – after exercising on the training device Galileo 2000 (Novotec GmbH, Pforzheim, Germany). Twenty healthy adults performed a 9-min standing test. They stood with both feet on a platform, producing oscillating mechanical vibrations of 26 Hz. Alterations in muscle blood volume of the quadriceps and gastrocnemius muscles were assessed with power Doppler sonography and arterial blood flow of the popliteal artery with a Doppler ultrasound machine. Measurements were performed before and immediately after exercising. Power Doppler indices indicative of muscular blood circulation in the calf and thigh significantly increased after exercise. The mean blood flow velocity in the popliteal artery increased from 6·5 to 13·0 cm s^{-1} and its resistive index was significantly reduced. The results indicate that low-frequency vibration does not have the negative effects on peripheral circulation known from occupational high-frequency vibration.

Keywords: arterial blood flow, muscle contraction, tissue blood flow, vibration.

EFECTOS DE LAS VIBRACIONES MECÁNICAS OSCILATORIAS (Plataforma Galileo) SOBRE EN PACIENTES CON FIBROMIALGIA: Estudio de tres casos

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El objetivo de este estudio ha sido analizar si ocho semanas de exposición a un programa de vibración mecánica sobre una plataforma oscilatoria "Galileo" en mujeres diagnosticadas de fibromialgia (FM). Participaron 3 mujeres (edad media de 52.3 ± 3.7 años, peso, 55.9 ± 4,7 Kg, talla 154,3 ± 5.0 cm. y IMC 22.0 ± 3,1). El programa consistió en una exposición a vibración mecánica una ves por semana. En cada sesión se realizaron diferentes ejercicios a intensidades entre 18 y 30Hz, una duración de 1 min. y un descanso mínimo entre ejercicios de 3min.Se encontró una disminución también significativa de la puntuación total en el test *Fibromyalgia impact questionnaire* (FIQ). Por lo que respecta al parámetro dolor de la puntuación del test *Visual Analogic Scale* (VAS) se aprecia una leve mejora . Estos resultados sugieren que 8 semanas de exposición a un programa de vibración mecánica oscilatoria se puede alcanzar una disminución del dolor. Es importante a determinar la frecuencia óptima de vibración ya que esta se debe aplicar de forma individualizada

Key words: Vibración mecánica oscilatoria, fibromialgia, FIQ i VAS.

Programa de rehabilitación mediante vibraciones mecánicas oscilatorias (Galileo) en paciente con fascitis eosinofílica: Estudio de caso

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La fascitis eosinofílica (FE)se caracteriza por la inflamación aguda o subaguda de la fascia profunda. El proceso inflamatorio precoz es seguido por un marcado engrosamiento de la fascia y del tejido conectivo adyacente, manifestándose clínicamente con inflamación, eritema y engrosamiento del área afectada, usualmente las extremidades[1]. El paciente en estudio presenta un diagnóstico compatible con fascitis eosinofílica y microscopia. La fascia muestra engrosamiento y severo infiltrado inflamatorio de predominio crónico, con células mononucleares y con algunos eusinófilos. El fragmento que incluyo músculo y fascia mostró también engrosamiento de la fascia con inflamación crónica i eusinófilos con afectación focal del músculo. El paciente además del tratamiento medicamentoso específico, se sometió a un programa de rehabilitación mediante actividad física y vibraciones mecánicas (plataforma oscilatoria Galileo) durante un periodo de tres meses, dos veces por semana, con sesiones de una hora. El paciente mostró una tendencia de mejora considerable, el análisis de sangre revelo una estabilización y disminución de los eusinófilos, como también una mejora de la movilidad articular de los miembros superiores e inferiores y de la cadera. El tratamiento de la FE generalmente incluye una combinación de fisioterapia, al igual que técnicas de protección de las articulaciones y la piel. Consideramos que en este caso las vibraciones mecánicas oscilatorias (Galileo) y la actividad física controlada puede ayudar a mejorar los rangos de movimiento, como también la tonificación y mejora del aparato músculo-tendinoso.

El programa de rehabilitación estuvo constituido por las siguientes fases: 1.actividad fisica y 2. vibraciones

1. Actividad física: frecuencia: de dos días a la semana, con una duración de una hora y media, la Intensidad de trabajo fue baja, media dentro de los rangos aeróbicos. Los contenidos desarrollados se tenían los estiramientos y flexibilidad en general, trabajos de fuerza y juegos con pelota.

2. Vibraciones: las vibraciones se realizaron sobre una plataforma vibratoria Galileo Fitness con amplitud que varía entre 0-6,6 mm (medial a distal) y con una frecuencia variable entre 5 y 30 Hz. Consta de 4 programas fijos de entrenamiento desde P1 hasta P4, como también existe la posibilidad de aplicar el programa de entrenamiento que uno considere necesario. El programa utilizado fue el P2 que correspondía con frecuencias de vibraciones de 18Hz, con un periodo total de 1minuto, 30s oscilatorio a 18hz y balanceos a 5Hz durante 30 s. La posición de los pies y para cada una de las partes corporales implicadas iniciaba en 0 hasta llevarlas al máximo que era en la posición cuatro. La plataforma con los deslizamientos ascendente y descendente provocan contracciones musculares naturales reflejas de los músculos flexores y extensores.

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Entrenamiento por medio de vibraciones mecánicas: revisión de la literatura

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Resumen

La exposición a vibraciones ha sido considerada tradicionalmente como perjudicial para el organismo humano. Sus efectos han sido estudiados de manera pormenorizada en medicina del trabajo habiéndose establecido incluso normativas ISO para evitar al máximo su aparición en los puestos de trabajo. Estas vibraciones suelen caracterizarse por su baja o muy alta frecuencia, su alta amplitud y la larga duración de su exposición al ser humano. Sin embargo, existen otras vibraciones que parecen provocar efectos beneficiosos en el organismo. En este caso, las frecuencias son moderadas (25-40 Hz), las amplitudes pequeñas (2-10 mm) y la duración de la exposición corta (inferior a los 30 minutos con intermitencias). En el presente texto se recogen fundamentalmente las aplicaciones de este método en campos como el entrenamiento deportivo, el fitness, la rehabilitación y la geriatría. De este modo, se incluye una revisión crítica de los estudios más relevantes así como la presentación de diferentes experiencias realizadas por los autores en los últimos cinco años.

Palabras clave: Vibraciones. Entrenamiento deportivo. Fitness.

Abstract

Exposure to vibrations has been traditionally considered as harmful for the human biological system. Extensive research has been done in occupational medicine and even ISO normative has been established to avoid vibrations in workplaces. These vibrations are usually of low or very high frequency, high amplitude and long term chronic exposure. However, there are other vibrations that may provoke beneficial effects on human biological system. In this case, we usually have moderate frequencies (25-40 Hz), low amplitudes (2-10) and short term exposure (less than 30 intermittent minutes). This text mainly includes applications for different fields such as sports training, fitness, rehabilitation and geriatrics. Thus, a critical review of most relevant studies is included among different practical experiences performed by the authors during the last five years.

Keywords: Vibrations. Sports training. Fitness.

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1. Introducción

Desde hace unos años se ha introducido en el mercado una serie de dispositivos capaces de, mediante movimientos oscilatorios sinusoidales, provocar un estímulo mecánico. Este estímulo se transmite por todo el cuerpo consiguiendo aumentar la carga gravitatoria a la que es sometido el sistema neuromuscular. Aparece así lo que se conoce como vibraciones de cuerpo completo[1] (*Whole-body vibration*; WBV) que han de diferenciarse de las vibraciones aplicadas localmente. Las primeras ocurren cuando todo el cuerpo es sometido a movimiento y el efecto no es localizado. Las segundas ocurren cuando una parte determinada del cuerpo es sometida a movimiento (por ejemplo, aplicación directa al bíceps braquial)(Cardinale & Pope, 2003; de Oliveira *et al.*, 2001).

Las vibraciones son muy habituales en la vida diaria. Fuentes de vibración se encuentran en medios de transporte como: coches (Troup, 1978; Chen *et al.*, 2003), motos, trenes, helicópteros (de Oliveira *et al.*, 2001), aviones, embarcaciones, etc...; o de trabajo: tractores

(Kumar *et al.*, 1999), camiones (Kumar, 2004) y multitud de tipos de maquinaria y herramientas (Cederlund *et al.*, 2001; Randall *et al.*, 1997). También en la actividad física y el deporte pueden encontrarse ejemplos evidentes como el patinaje en línea (Thompson & Belanger, 2002), el surf, el ski, la equitación, la vela, el mountain-bike. Todo material conocido por el hombre tiene una frecuencia natural a la que vibra (Warman *et al.*, 2002) y los tejidos biológicos como el músculo también vibran a frecuencias específicas tanto en reposo como en activación (Barry & Cole, 1988).

La forma más habitual de aplicar vibraciones con el objeto de mejorar el rendimiento físico es mediante plataformas, que consiguen el efecto "por todo el cuerpo", aunque también se han aplicado de manera localizada empleando mancuernas (Bosco *et al.*, 1999) o cables (Lieberman & Issurin, 1997; Issurin & Tenenbaum, 1999; Issurin *et al.*, 1994; McBride *et al.*, 2003).

Figura 1. Izquierda: ejemplo de ejercicio sobre plataforma vibratoria donde se combina el estímulo vibratorio con una acción muscular excéntrica. Derecha: ejemplo de ejercicio para el tren superior donde predomina la solicitación sobre el deltoides anterior y el pectoral mayor.

Las investigaciones sobre los efectos de las vibraciones en el ser humano tienen ya una larga tradición. Sus resultados van desde muy perjudiciales -perspectiva tradicional de la medicina del trabajo- a muy beneficiosos -perspectiva más actual del campo de la actividad física y el deporte así como la rehabilitación-. La explicación a estas grandes divergencias podría residir en los diferentes parámetros de vibración empleados. Si anteriormente distinguíamos la localización o no de las vibraciones, también se ha de tener muy en cuenta su frecuencia, amplitud, dirección y duración, ya que el cuerpo humano ha demostrado responder de manera altamente específica a la variación de estos parámetros (Cardinale & Pope, 2003). La aplicación de vibraciones al cuerpo humano puede ser descrita como placentera o molesta, puede influir en el rendimiento en ciertas tareas y provocar lesiones o enfermedades (Griffin, 1997) pero también provocar efectos positivos como el alivio del dolor crónico (Roy *et al.*, 2003; Lundeberg, 1984).

En la presente revisión se analizarán los efectos agudos y crónicos de la aplicación de vibraciones mecánicas sobre el cuerpo humano desde la perspectiva del rendimiento físico. Sin embargo, en el caso de no disponer de evidencias científicas al respecto, en algunas ocasiones se recurrirá a investigaciones en animales o en tejidos in vitro o a trabajos donde el objetivo no era observar la influencia sobre el rendimiento físico.

2. Variables que afectan a las vibraciones

Existen numerosas variables o parámetros que pueden afectar a los movimientos oscilatorios sobre el cuerpo humano, aunque pueden ser divididas en dos grandes categorías: variables extrínsecas (que ocurren fuera del cuerpo humano) y variables intrínsecas (aquellas que ocurren dentro del cuerpo o entre diferentes personas).

2.1. Variables extrínsecas

2.1.1. Magnitud: la magnitud de una vibración suele expresarse por razones prácticas en unidades de aceleración (m/s^2), empleándose para ello acelerómetros. En los aparatos que se emplean para la mejora del rendimiento físico no se ofrece información sobre este parámetro pero puede obtenerse a partir de la frecuencia (f) y el desplazamiento (d), mediante la ecuación (Griffin, 1997): $a=(2\ f)^2d$. Esto quiere decir que un movimiento oscilatorio sinusoidal con una frecuencia de 30 Hz y 4 mm de desplazamiento resultará en una aceleración de 14,48 g.

2.1.2. Frecuencia: es el número de ciclos de movimiento sinusoidal realizado en un segundo expresado mediante la unidad hertzio (Hz). El rango de frecuencias de vibración empleadas en los estudios de entrenamiento está entre 23 y 44 Hz.

2.1.3. Amplitud: es el desplazamiento que se realiza en cada ciclo de movimiento sinusoidal expresado por lo general en mm. El rango de amplitud empleado en los estudios se sitúa entre 2 y 10 mm, aunque el valor más empleado son 4 mm.

2.1.4. Dirección: las tres principales direcciones de la vibraciones aparecen en los ejes antero-posterior (x), lateral (y) y vertical (z) (Griffin, 1997). En el mercado existen plataformas vibratorias donde predomina la dirección vertical y otras donde existe además un marcado componente lateral (por ejemplo, las plataformas Galileo™).

2.1.5. Duración: algunas respuestas del cuerpo humano dependen fundamentalmente de la duración de la vibración a la que es expuesto. La normativa ISO 2631 establece los límites de tiempo de exposición basándose en los valores de la dosis de vibración. En los estudios orientados a la mejora del rendimiento la exposición total va desde 4 min hasta un máximo de 20.

2.2. Variables intrínsecas

2.2.1. Intrasujeto

- Postura corporal, posición y orientación del cuerpo (sentado, de pie, recostado, etc...).

2.2.2. Intersujeto

- Tamaño y peso corporal, respuesta biodinámica corporal, edad, sexo, experiencia, expectativas, actitud, personalidad y nivel de forma física.

Por otro lado, un concepto físico que conviene aclarar es la frecuencia a la cual un cuerpo entra en resonancia. Se dice que un cuerpo resuena cuando vibra al recibir impulsos de frecuencia igual a la suya o múltiplo de ella. En el momento en el que todo el cuerpo humano entra en resonancia se produce el máximo desplazamiento entre los órganos y la estructura esquelética, siendo esta una frecuencia de vibración a evitar para minimizar el impacto que sufren los tejidos implicados. Esta frecuencia parece ser independiente del peso corporal y la estatura (Randall *et al.*, 1997) aunque podría estar influenciada por la tensión muscular, presentando la mayoría de sujetos una mayor frecuencia cuando están tensos(Fairley & Griffin, 1989). Randall et al encontraron un rango de frecuencias resonantes en todo el cuerpo entre 9 y 16 Hz (promedio de 12,3 Hz). Sin embargo, otros autores defienden una frecuencia principal de 5Hz y una secundaria de 8Hz (Kitazaki & Griffin, 1998) así como una respuesta no-lineal (Mansfield & Griffin, 2000). Por otro lado, algunos efectos provocados por las vibraciones pueden alcanzar su máximo a una frecuencia algo superior a la de resonancia. Por esta razón, se recomienda emplear frecuencias superiores a los 20 Hz en los dispositivos habitualmente empleados para el entrenamiento de la fuerza (Yue & Mester, 2004).

3. Efectos de la aplicación de vibraciones mecánicas

Cuando el cuerpo humano es sometido a vibraciones responde de una manera bastante compleja que afecta a los diferentes sistemas que regulan sus funciones (Randall *et al.*, 1997; Lundström *et al.*, 1998). Así, las respuestas del organismo pueden diferenciarse según el momento de su aparición (agudas o crónicas) y el sistema biológico afectado (neuromuscular, sensorial, metabólico, endocrino, óseo y cartilaginoso).

3.1. Efectos agudos

3.1.1. Sistema neuromuscular

A mediados de los años 60 se describieron tres efectos motores que resultaban de la aplicación de una vibración directa al músculo o al tendón (Bishop, 1974):

1) *El músculo sometido a vibración se contrae de manera activa,* efecto al que se le dio el nombre de Reflejo Tónico Vibratorio (RTV) (Eklund & Hagbarth, 1965; Eklund & Hagbarth, 1966; Johnston *et al.*, 1970; De Gail *et al.*, 1966; Hagbarth, 1967; Marsden *et al.*, 1969). Este reflejo ha sido observado en todos los músculos esqueléticos excepto en los de la cara y la lengua (Eklund & Hagbarth, 1966). Aunque la fuerza de su respuesta es muy variable entre individuos, su respuesta ha demostrado ser muy reproducible en todo tipo de sujetos (Eklund & Hagbarth, 1966; Johnston *et al.*, 1970). La fuerza de respuesta del RTV depende de cuatro factores: localización del vibrador (sobre músculo o tendón), longitud inicial del músculo (cuanto más estirado mayor respuesta) (Johnston *et al.*, 1970), estado de la excitabilidad del SNC, parámetros del estímulo vibratorio.

En la figura 2 puede observarse el arco reflejo que explica la aparición del RTV. Fundamentalmente son las terminaciones primarias de los husos musculares, por su alta sensibilidad a los cambios de longitud, las que inician la contracción refleja. Desde los husos musculares el impulso es transmitido mediante las fibras Ia aferentes hacia la médula espinal donde realizan sinapsis con las alfa-motoneuronas. Éstas transmiten la señal de vuelta, vía eferente, a las mismas fibras musculares extrafusales, lo que provoca su contracción (Johnston *et al.*, 1970). Estos efectos han sido vueltos a comprobar con técnicas modernas de microneurografía capaces de registrar la activación de las terminaciones primarias de los husos musculares (Ribot-Ciscar *et al.*, 1998). Mediante esta técnicas se demuestra que las vibraciones estimulan predominantemente las fibras Ia aferentes y en menor grado las Ib aferentes de Golgi y las secundarias aferentes (II) (Roll *et al.*, 1989). Además, el RTV no sólo parece estar mediado por las vías mono y polisinápticas de las fibras Ia, sino también por las vías de los receptores cutáneos (Abbruzzese *et al.*, 1978; Romaiguere *et al.*, 1991). Por otro lado, se ha podido comprobar con técnicas de descomposición electromiográfica que las unidades motoras adicionales que se reclutan al aplicar vibración a un músculo proceden del mismo *pool* que las que se activan al realizar un esfuerzo volitivo equivalente al 10% de la MVC. Esto implica que se respeta el orden normal de reclutamiento de unidades motoras (Mao *et al.*, 1990).

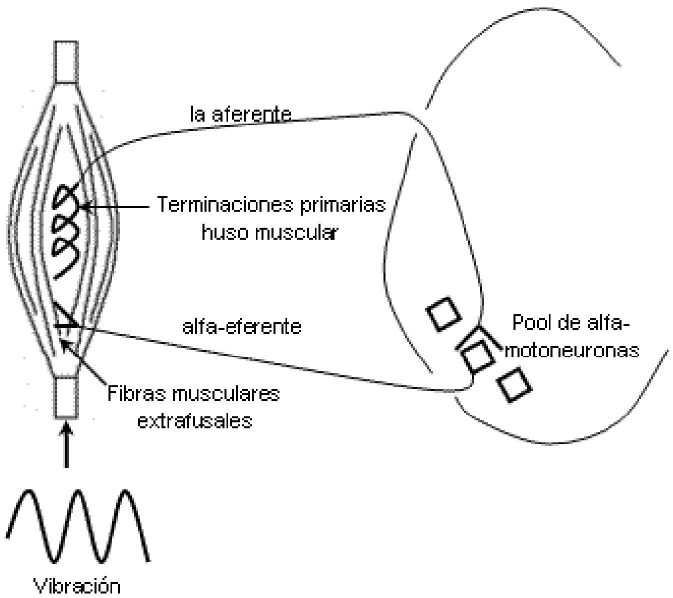


Figura 2. Arco reflejo solicitado en la aparición del reflejo tónico vibratorio (Johnston et al, 1970)

Por otro lado, recientemente se ha demostrado que la vibración aplicada al músculo o al tendón induce a un aumento significativo de los potenciales motores evocados por lo que se sugiere que la vibración afecta a la modulación de la excitabilidad de la corteza motora. Esta excitabilidad puede afectar a los impulsos voluntarios (Siggelkow *et al.*, 1999; Kossev *et al.*, 1999; Kossev *et al.*, 2001)

Cuando la vibración es aplicada mediante plataformas o mancuernas los resultados son bastante parecidos. Bosco et al encuentran, en boxeadores de élite, un aumento del 200% entre los niveles de la señal EMGrms del bíceps braquial en reposo con respecto a la puesta en funcionamiento de una mancuerna de 2,6 kg vibrando a 30 Hz con una amplitud de 6 mm (Bosco *et al.*, 1999). En el tren inferior también se ha encontrado un claro aumento de la señal EMGrms de la musculatura de la pierna al emplear plataformas vibratorias con respecto a la misma posición sin vibración (Verschueren *et al.*, 2004; Cardinale & Lim, 2003; Delecluse *et al.*, 2003; Berschin & Sommer, 2004). Además, parecen existir frecuencias de vibración que producen una mayor señal EMGrms que otras. Así, se ha descrito que frecuencias de 30 Hz son más estimulantes que las de 40 Hz y éstas a su vez que las de 50 Hz (Cardinale & Lim, 2003). Estos datos han sido corroborados en nuestro laboratorio, donde además se han encontrado frecuencias de vibración óptimas para cada músculo y persona. El comportamiento de la evolución entre señal EMG y frecuencia de vibración suele ser similar a las curvas de potencia: sube hasta alcanzar un pico para después bajar (figura 3).

Fuente	Músculo	Frecuencia (Hz)	Ampl. (mm)	Efecto EMG
Bosco et al (1999)	Bíceps braquial	30	6	+200 % RMS
Warman et al (2002)	Recto femoral	50	¿	Isom. +30,1% Isok. +43% Din.+107 % RMS
Delecluse et al (2003)	Recto femoral	35	5	+35% RMS
Cardinale y Lim (2003)	Vasto lateral	30	10 (pico a pico)	+34% RMS
Verschueren et al (2004)	Cuadriceps Gastrocnemio	35 35	¿ ¿	+17,2 % RMS +170% RMS

Tabla 1. Estudios que han registrado el efecto de la aplicación de vibraciones en la señal EMG con respecto a niveles basales (Bosco) o respecto a la misma posición sin aplicar vibración (RMS= root mean square). Los estudios de Delecluse et al (2003) y Verschueren et al (2004) presentan datos de caso único.

Un comentario aparte requiere el estudio realizado por Warman et al (2002) debido a que emplearon una estimulación vibratoria diferente. En este caso se empleó un pistón accionado por un motor que se unía al muslo mediante unas tiras de velcro para transmitir una vibración de 50,42 $\pm$ 1,16 Hz y 13,24 $\pm$ 0,18 m/s^2. Se comparó la actividad EMG durante la realización de acciones isométricas, isocinéticas o dinámicas encontrándose, como puede observarse en la tabla 1, una mayor activación para las acciones dinámicas. Los autores sugieren que la aplicación de vibraciones debería realizarse de manera concurrente a una acción muscular dinámica (Warman *et al.*, 2002).

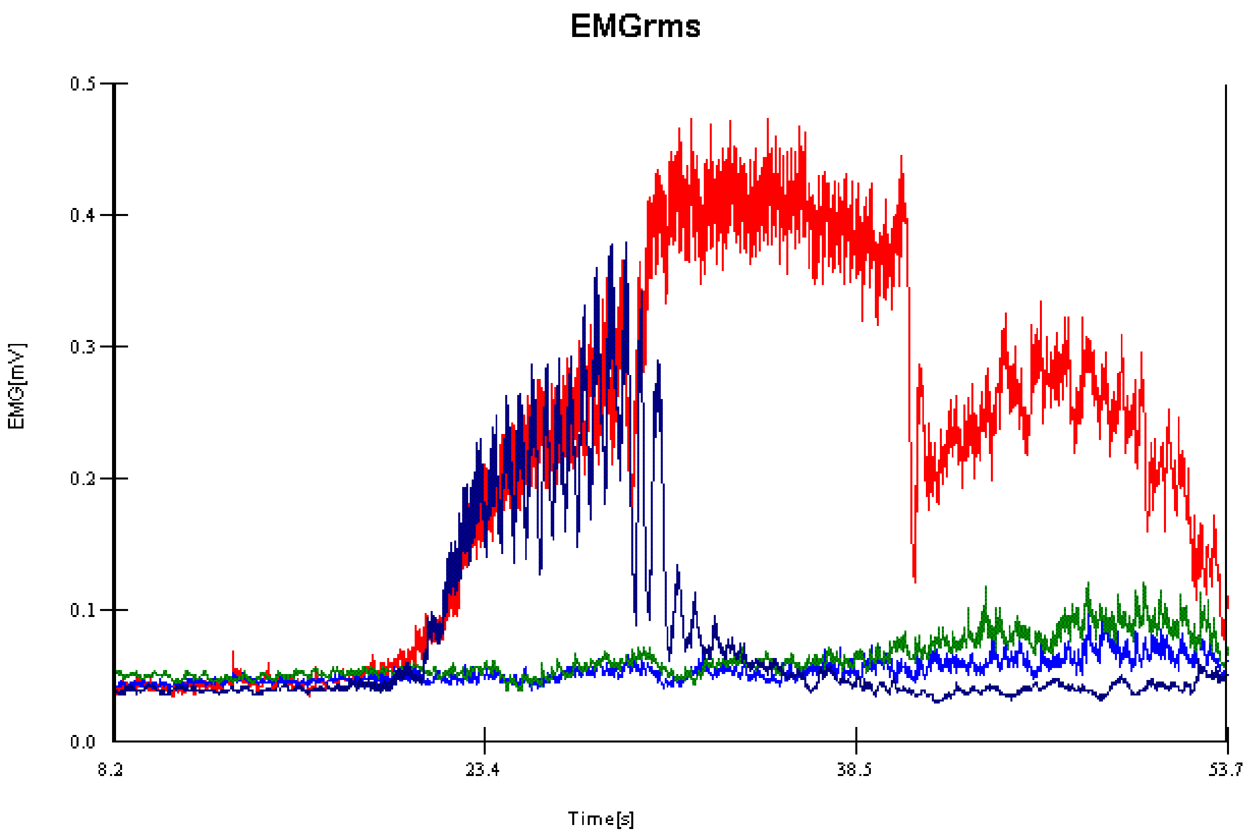


Figura 3. Evolución de la señal EMG como consecuencia del aumento progresivo (1Hz/seg) de la frecuencia de vibración. La actividad EMG comienza a subir de manera significativa a los 20 Hz. Puede observarse cómo para el vasto interno (en rojo) se alcanza la máxima actividad entre 30 y 35 Hz. Si embargo, el gemelo interno (en azul) alcanza su máximo a frecuencias inferiores (25-30 Hz). La posición mantenida sobre la plataforma es similar a la expuesta en la figura 1.

2) *La excitabilidad de las motoneuronas que inervan los músculos antagonistas queda deprimida vía inhibición recíproca* (De Gail *et al.*, 1966; Hagbarth, 1967). Esto quiere decir que si se somete a vibración al gastrocnemio se producirá una inhibición recíproca de las motoneuronas del tibial anterior y viceversa. Sin embargo, en estudios más recientes se encuentra que la vibración produce una mayor coactivación agonista-antagonista tanto durante (Rothmuller & Cafarelli, 1995; Berschin & Sommer, 2004) como después (Gabriel *et al.*, 2002) de ser aplicada, lo que podría tener un efecto positivo en la estabilización activa de la articulación (Berschin & Sommer, 2004).

3) *Los reflejos monosinápticos del músculo sometido a vibración quedan suprimidos durante su aplicación* (De Gail *et al.*, 1966; Marsden *et al.*, 1969). Por ejemplo, al someter al músculo gastrocnemio a vibración desaparece el reflejo del tendón de Aquiles al ser golpeado o el reflejo H como respuesta a la estimulación eléctrica del nervio poplíteo. Sin embargo, ambos reflejos reaparecen una vez terminada la aplicación de vibración (Arcangel *et al.*, 1971). No obstante, varios autores encuentran que el reflejo H queda alterado durante varios minutos.

Nishihira et al investigaron la evolución del reflejo H y la respuesta M antes y después de mantener una contracción isométrica sobre una plataforma Galileo (movimiento horizontal) durante 3 series de 3 minutos. La relación H/M se emplea como un índice de eficacia de la transmisión entre las fibras Ia y la-alfa motoneurona. Encontraron un aumento de la relación H/M después de la vibración. Los autores sugieren como explicación que las fibras Ia aferentes se excitan como consecuencia del estímulo vibratorio y que este hecho, unido a la contracción isométrica voluntaria, aumenta la excitación del pool de alfamotoneuronas (Nishihira *et al.*, 2002).

Rittweger et al (2003) encontraron un mantenimiento o incluso aumento de la amplitud del reflejo de estiramiento patelar como consecuencia de haber realizado sentadillas hasta la extenuación (duración de 349 ± 230 s) sobre una plataforma vibratoria (26 Hz; 12 mm) con una sobrecarga extra en las caderas del 40% del peso corporal. Sin embargo, cuando se realizó el mismo ejercicio sin vibración añadida (duración de 515 338 s), el reflejo disminuyó como es habitual después de la realización de un ejercicio exigente. Los autores sugieren que la causa de que el reflejo de estiramiento presente este comportamiento como consecuencia de la estimulación vibratoria podría residir en que ésta aumenta la excitabilidad central motora particularmente en las unidades motoras más rápidas (Rittweger *et al.*, 2003).

3.1.1.1. Influencia aguda en la fuerza máxima dinámica, en la potencia y el salto vertical

Bosco et al, sometieron a 12 boxeadores de élite a 5 series de 60 segs (1' desc.) de vibraciones con una mancuerna (modelo Galileo 2000; Novotec, Pforzheim, Alemania) a una frecuencia de 30 Hz. y una amplitud de 6 mm. Según los autores, este entrenamiento era similar a un mes de entrenamiento realizando 50 repeticiones, 3 sesiones por semana, con una carga del 5% del peso corporal. Como consecuencia de esta única sesión de entrenamiento se encontró un aumento de la potencia de los flexores del codo sometidos a vibración además de un aumento de la señal EMGrms normalizada durante el tratamiento. Aunque en este estudio se empleó como control la extremidad contraria, falta por saber si el aumento de la potencia registrado se mantuvo en los días posteriores, ya que dicho aumento pudo deberse a un mayor calentamiento y circulación en la zona y no a una adaptación neural (Bosco *et al.*, 1999).

El mismo grupo de autores realizó un estudio similar con 6 jugadoras de voleibol altamente entrenadas que fueron sometidas a 10 series de 60 segs con 1 min de descanso (parámetros: plataforma de vibración horizontal Galileo a 26 Hz y 10mm, manteniendo una flexión de rodillas a 100º), empleando también una extremidad como control de forma que sólo una pierna es sometida a vibración. Tras la sesión, se encontró un aumento de la fuerza, velocidad y potencia medias en el ejercicio de prensa de piernas con 70, 90, 110 y 130 kgs en la pierna sometida a vibración (Bosco *et al.*, 1999). Según los autores, este entrenamiento de sólo 10 minutos, equivale a un estímulo de entrenamiento consistente en realizar 150 repeticiones en el ejercicio de prensa de piernas o de media sentadilla con una carga de 3 veces el peso corporal dos veces por semana durante 5 semanas. Sin embargo, los autores no aportan los datos que les ha permitido establecer esta sorprendente equivalencia.

Similares protocolos de trabajo fueron empleados en un posterior estudio (10 series de 60 segundos con 1 min de descanso entre cada serie y 6 min de descanso después de las 5 primeras series) a 14 jóvenes deportistas de equipo (volumen de trabajo habitual: 3 sesiones de entrenamiento semanal) aunque en esta ocasión se empleó una plataforma de vibración vertical (NEMES) con una frecuencia de 26 Hz y una amplitud de 4 mm. Se detectó un aumento, después de ser sometidos a vibración, en el salto con contramovimiento y en la potencia aplicada en la prensa de piernas con una carga equivalente al 70% de 1RM. Por otro lado, se redujo la amplitud de la señal EMGrms, lo que según los autores indica una mejora en la eficiencia neuromuscular, al requerirse una menor actividad muscular para aplicar incluso una mayor potencia mecánica (Bosco *et al.*, 2000).

Lieberman e Issurin comprobaron el efecto de levantar una carga del 60%, 70%, 90% y 100% de 1RM realizando una flexión dinámica de codo con o sin la aplicación de una vibración (44 Hz y 0,6-3 mm). Para ello estudiaron a 41 deportistas de diferentes niveles (Olímpico, Nacional, Junior y Amateur), encontrando un aumento de la 1RM y una disminución de la percepción subjetiva del esfuerzo cuando se realizó el ejercicio con la aplicación de vibraciones. Además, en el grupo de mayor nivel (8 deportistas olímpicos) los efectos fueron superiores (Lieberman & Issurin, 1997). Varios años más tarde, el mismo grupo de investigadores, con igual metodología, reportaron resultados similares, encontrando mejoras en la potencia máxima de un 10,4% (élite) y un 7,9% (amateur) al levantar una carga de un 65-70% de 1RM con vibración añadida con respecto al mismo ejercicio sin vibración(Issurin & Tenenbaum, 1999).

3.1.2. Sistema cardiovascular

En cuanto a los efectos agudos que provoca este método, Rittweger et al encontraron, después de la aplicación de vibraciones con una frecuencia de 26 Hz y una amplitud de 10,5 mm (con una sobrecarga en la cintura del 40% del peso corporal en hombres y 35% en mujeres), los cambios expuestos en la tabla 2 (Rittweger *et al.*, 2000):

Parámetro	Línea de base	Fatiga	Recup (15 min)
Tiempo (s)	0	325 (125)	
Lactato (mM/l)	1,69 (0,5)	3,5 (1,6)	
FC (b/m)	98 (17)	128 (22)	95 (19)
Presión sistólica (mmHg)	114(11)	132 (16)	109 (11)
Presión diastólica (mmHg)	68 (8)	52 (14)	69 (7)
VO_2 (ml/kg/min)	7,3 (1,5)	21,3 (4,0)	
Cociente respiratorio	0,82 (0,05)	0,90 (0,08)	

Tabla 2. Cambios provocados en diferentes parámetros como consecuencia de la realización de flexo-extensiones de rodilla hasta la fatiga (con sobrecarga del 40% del peso corporal) sobre una plataforma vibratoria (Rittweger et al, 2000).

El ejercicio que realizaron los 40 sujetos participantes consistió en, después de mantenerse de pie durante 30 segundos, realizar sentadillas, flexionando las rodillas en ciclos de 6 segundos (3 segundos de subida y 3 de bajada) lo más suavemente posible.

Por otro lado, en 14 sujetos trasplantados de corazón (56 11 años) se registraron los cambios expuestos en la tabla 2. El ejercicio realizado sobre la plataforma vibratoria (26 Hz; 3 mm) demostró ser un método adecuado y seguro para la rehabilitación y mejora funcional de este tipo de sujetos (Crevenna *et al.*, 2003).

Parámetro	Línea de base	Fatiga	Recup (3 min)	Recup (5 min)
Tiempo (s)	0	248		
Lactato (mM/l)	1,2 (0,3)*	2,0 (1,5)*	2,3 (0,8)*	2,1 (0,7)*
FC (b/m)	98 (10)	121 (20)*	107 (15)	104 (14)
Presión sistólica (mmHg)	136 (17)	158 (23)*	139 (15)	139 (15)
Presión diastólica (mmHg)	90 (13)	93 (16)	93 (13)	91 (13)

Tabla 3. Cambios provocados en diferentes parámetros en sujetos trasplantados de corazón como consecuencia de la realización de flexo-extensiones de rodilla hasta la fatiga sobre una plataforma vibratoria (Crevenna et al, 2003)

En el estudio de Rittweger et al (2000), se registró la aparición de edemas y eritemas en la zona de la pantorrilla, sobre todo después en la primera sesión y particularmente en las mujeres. Sin embargo, Crevenna et al (2003) no observaron estos efectos, probablemente por la diferente amplitud de vibración empleada así como por la ausencia de sobrecarga externa añadida. No obstante, la percepción subjetiva del esfuerzo (Escala de Borg) fue igual a 18 en ambos estudios. También Russo et al (2004) corroboraron la aparición de eritemas en mujeres posmenopáusicas aunque siempre de manera transitoria, moderada y no perturbadora (Russo *et al.*, 2003).

Más recientemente, se ha investigado el efecto que provoca la aplicación de diferentes frecuencias y amplitudes de vibración así como distintas sobrecargas externas en el consumo de oxígeno. De esta manera, se encontró un aumento lineal del VO_2 con respecto al aumento de la frecuencia de vibración (18/26/34 Hz). Así, cada ciclo de vibración provocaba un aumento de 2,5 µl / kg (manteniendo la amplitud a 5 mm). Al variar la amplitud de la vibración de 2,5 a 5 y 7,5 mm, el VO2 aumentaba más que proporcionalmente. Por último, la colocación de una sobrecarga en la cadera correspondiente a un 40% del peso corporal provocó un aumento del VO_2 que fue aún mayor cuando la carga se situó en los hombros. Los autores concluyen en que la potencia metabólica puede ser controlada paramétricamente mediante la frecuencia y amplitud de vibración así como con la colocación de sobrecargas externas (Rittweger *et al.*, 2002).

Anteriormente se ha comentado la aparición de un edema en determinados sujetos como consecuencia de la aplicación de vibraciones. Incluso en el campo de la medicina del trabajo se acepta que las vibraciones de alta frecuencia provocadas por distintas utensilios industriales reducen el flujo sanguíneo pudiendo ocasionar lo que se conoce como dedo blanco inducido por vibración (Bovenzi *et al.*, 2001; Bovenzi & Hulshof, 1999; Bovenzi & Griffin, 1997). Sin embargo, Kerschan-Schindl et al (2001) encontraron un aumento del flujo sanguíneo y ensanchamiento de capilares, después de aplicar vibraciones, lo que provocaba una mejora de la circulación periférica. Además, los autores sugieren la posible existencia de un efecto tixotrópico, de forma que la viscosidad de la sangre se ve reducida y de esta manera la velocidad media del flujo sanguíneo aumenta. Los parámetros empleados fueron 26hz, 3mm y9 min de vibración en sentido horizontal, lejos de las altas frecuencias (superiores a 80 Hz) soportadas durante largos periodos a las que se ven sometidas los trabajadores, lo cual explica la diferencia en los resultados encontrados. Este aumento del flujo sanguíneo también fue encontrado por Rittweger et al (2000) empleando parámetros de vibración similares y por Nakamura et al (1996) empleando un vibrador en la mano con unos parámetros de 120 Hz y 50 m/s2 en el eje x(Nakamura *et al.*, 1996). También Zhang et al (2003) encontraron un aumento de un 20% en el flujo sanguíneo del músculo tibial anterior como consecuencia de la aplicación de vibraciones al pie (aceleración=16-46 m/s2) (Zhang *et al.*, 2003). Como aplicación práctica, este aumento del flujo sanguíneo tras ser sometido a vibraciones, podría facilitar la eliminación del lactato después de realizar un esfuerzo intenso. Sin embargo, en nuestro conocimiento, no se han publicado trabajos al respecto.

3.1.3. Sistema endocrino

Uno de los estudios que más sorpresa ha causado en los últimos años es el de Bosco et al (Bosco *et al.*, 2000) indicando la respuesta hormonal como posible causa de las mejoras tan espectaculares en cuanto a fuerza explosiva encontradas en la mayoría de estudios. Estos autores encontraron un aumento de la hormona del crecimiento (GH) de más de un 400% con respecto a los niveles basales. Además la concentración de testosterona (T) aumentó significativamente y la de cortisol (C) disminuyó, por lo que podría establecerse un entorno idóneo para el anabolismo, al aumentar el ratio T/C. Los citados grandes aumentos en la concentración de GH también se producen de manera similar o superior después de realizar un trabajo intenso con sobrecargas aunque con una duración del estímulo muy superior. Nindl et al (2000) encontraron después de realizar 6 series de 10 RM (con dos minutos de descanso) en el ejercicio de sentadilla, unos aumentos de 1,47 a 25 ng/l (hombres) y de 4 a 25,4 ng/l (mujeres)(Nindl *et al.*, 2000). Lo mismo ocurre con la testosterona, como observó Kraemer en sus numerosos estudios sobre el tema (Kraemer *et al.*, 1992; Kraemer *et al.*, 1991; Kraemer *et al.*, 1990). Sin embargo, es la disminución de la concentración de cortisol la que más dudas plantea, haciéndose necesaria la realización de más estudios sobre la respuesta hormonal a la aplicación de vibraciones.

Mccall et al (2000) fueron los primeros en encontrar en humanos que la activación de las vías aferentes de los husos musculares como consecuencia de la vibración modulaba las concentraciones plasmáticas de hormona del crecimiento bioensayable (BGH). Esta hormona es sintetizada por la glándula pituitaria, constituyendo un factor de crecimiento que estimula la formación ósea (McCall *et al.*, 2000). Aunque comparte con la clásica GH un origen pituitario y su efecto sobre el crecimiento óseo, la regulación de la BGH parece ser diferente a la de la GH (Gosselink *et al.*, 2004). En el estudio de McCall et al (2000) se aplicó directamente al tibial anterior un estímulo vibratorio (100 Hz y 1,5 mm de amplitud) de una duración de 10 min. Inmediatamente después del estímulo se registró un aumento del 94% en la concentración plasmática de BGH en el tibial anterior y un descenso de un 22% en el sóleo. Esto podría indicar que existe una regulación diferenciada en la liberación de BGH en estos dos músculos con predominio de fibra lenta que podría estar relacionada con su antagónica función flexora o extensora. Los autores concluyen en la evidencia indirecta de un eje músculoaferente-pituitario que modula la liberación de BGH de manera específica al músculo sometido a vibración. Estos hallazgos tienen aplicación para los viajes al espacio, ya que se ha observado cómo en microgravedad o en encamamiento queda alterada la liberación de BGH inducida por el ejercicio (McCall *et al.*, 1999; McCall *et al.*, 1997).

Recientemente, Di Loreto et al (2004) han realizado un ensayo controlado sobre el efecto de 25 min de estímulo vibratorio (30 Hz) en el sistema endocrino de 10 varones sanos. Encontraron una ligera reducción de la glucosa plasmática y un aumento de las concentraciones plasmáticas de norepinefrina, pero no se registraron cambios en las concentraciones circulantes de otras hormonas. Esto indica que se aumenta la utilización de glucosa por parte de la musculatura activa (Di Loreto *et al.*, 2004).

3.1.4. Sistema sensorial, propioceptivo y control postural

Es conocida la función de los mecanoreceptores en la capacidad de discriminar sensaciones. Por ejemplo, la piel de la palma de la mano posee 4 tipos de receptores: dos de adaptación rápida (FAI y FAII) y dos de adaptación lenta (SAI y SAII). Todos son sensibles a la aplicación de un estímulo vibratorio en mayor o menor medida. Así, los FAI son más sensibles a vibraciones entre 30 y 40 Hz y los FAII entre 60 y 100 Hz; por otro lado, los SAI y SAII presentan una respuesta similar pero en este caso con frecuencias inferiores a los 15 Hz (Toma & Nakajima, 1995). Se ha de tener en cuenta que la exposición prolongada a vibraciones puede alterar el rendimiento de estos receptores disminuyendo el rendimiento de los procesos perceptivos y sensorimotores (Ribot-Ciscar *et al.*, 1996).

Parece ser que las vibraciones tienen capacidad para estimular la propiocepción y provocar efectos duraderos sobre la postura en adultos sanos (Wierzbicka *et al.*, 1998; Priplata *et al.*, 2003). Además, recientemente se ha encontrado una mejora aguda del control postural y propioceptivo en sujetos que habían padecido infartos como consecuencia de la realización de 4 reps de 45 seg con 1 min de pausa (30 Hz; 3 mm) (van Nes *et al.*, 2004)

Por otro lado, Gianutsos et al, de la Universidad de Nueva York, han descrito la posibilidad de provocar el reflejo de permanecer en pie inducido por las vibraciones en sujetos con lesiones en la médula espinal (Gianutsos *et al.*, 2004; Gianutsos *et al.*, 2001a; Gianutsos *et al.*, 2001b). De este modo, las vibraciones parecen constituir un método prometedor en la rehabilitación de sujetos con disfunción motriz de origen medular.

3.2. Efectos crónicos

Los mecanismos de acción de este método a corto, medio y largo plazo han sido relativamente poco investigados hasta la fecha, aunque muy recientemente se han publicado varios trabajos al respecto.

3.2.1. Adultos sanos

A corto plazo (9-10 días de entrenamiento) existen trabajos que han encontrado mejoras significativas en la potencia y el salto vertical (Bosco *et al.*, 1998) y otros que no han encontrado significación estadística en las mejoras de salto o ninguna mejora en diferentes tests de velocidad y agilidad (Cochrane *et al.*, 2004).

Torvinen et al, estudiaron los efectos de 4 meses de entrenamiento con un protocolo de 4 sers de 60", alternando distintos movimientos. La frecuencia de estimulación osciló entre 25 y 40 Hz y la amplitud de 2 mm. Después del periodo de entrenamiento se registró un aumento de un 8,5% en CMJ y un 3,5% en la fuerza isométrica. Sin embargo, no se constató una mejora del equilibrio postural, lo cual podría estar condicionado por la amplitud de vibración empleada (2 mm en lugar de 4 mm). No obstante, el escaso tiempo de estimulación por sesión (sólo 4 min) podría ser la causa de unas mejoras tan escasas en comparación con otros estudios (Torvinen *et al.*, 2002).

Por otro lado, el primer estudio comparado con un entrenamiento de fuerza clásico (10-20RM) es el realizado por Delecluse *et al.* El programa incluyó los parámetros de vibración que observamos en la tabla 4.

Parámetros	Inicio	Final
Volumen		
Duración total de la vibración en una sesión (min)	3	20
Series por ejercicio	1	3
Ejercicios diferentes para extensores de piernas	2	6
Mayor duración de la vibración sin descanso (s)	30	60
Intensidad		
Intervalo de descanso entre ejercicios (s)	60	5
Amplitud de la vibración (mm)	2,5	5
Frecuencia de la vibración (Hz)	35	40

Tabla 4. Parámetros del programa de vibraciones al comienzo y al final del mismo (Delecluse et al(Delecluse *et al.*, 2003))

Después de 12 semanas de entrenamiento la fuerza del tren inferior aumento en igual medida que el programa de entrenamiento clásico, y sólo en el grupo que entrenó con vibraciones aumentó el salto con contramovimiento en un 7,6%. En este estudio se empleó además como novedad un grupo placebo que era sometido a una vibración ineficaz; este grupo no obtuvo mejoras de ningún tipo. De este modo se descarta la posible eficacia de realizar ejercicio sobre la plataforma sin ponerla en funcionamiento (Delecluse *et al.*, 2003).

Ronnestad (2004) comparó los efectos de la realización de sentadillas sobre una plataforma vibratoria (40 hz; 4 mm) con respecto a la realización de sentadillas convencionales. Ambos grupos entrenaron empleando el mismo porcentaje de 1RM. Después de cinco semanas de entrenamiento con las características expuestas en la tabla 5 se encontraron mejoras significativas en el test de CMJ sólo en el grupo sometido a vibración. Por otro lado, ambos grupos obtuvieron mejoras significativas en el test de 1RM. Sin embargo, no se observaron diferencias significativas entre las mejoras de rendimiento de cada grupo, aunque sí una tendencia a la significación estadística (Ronnestad, 2004).

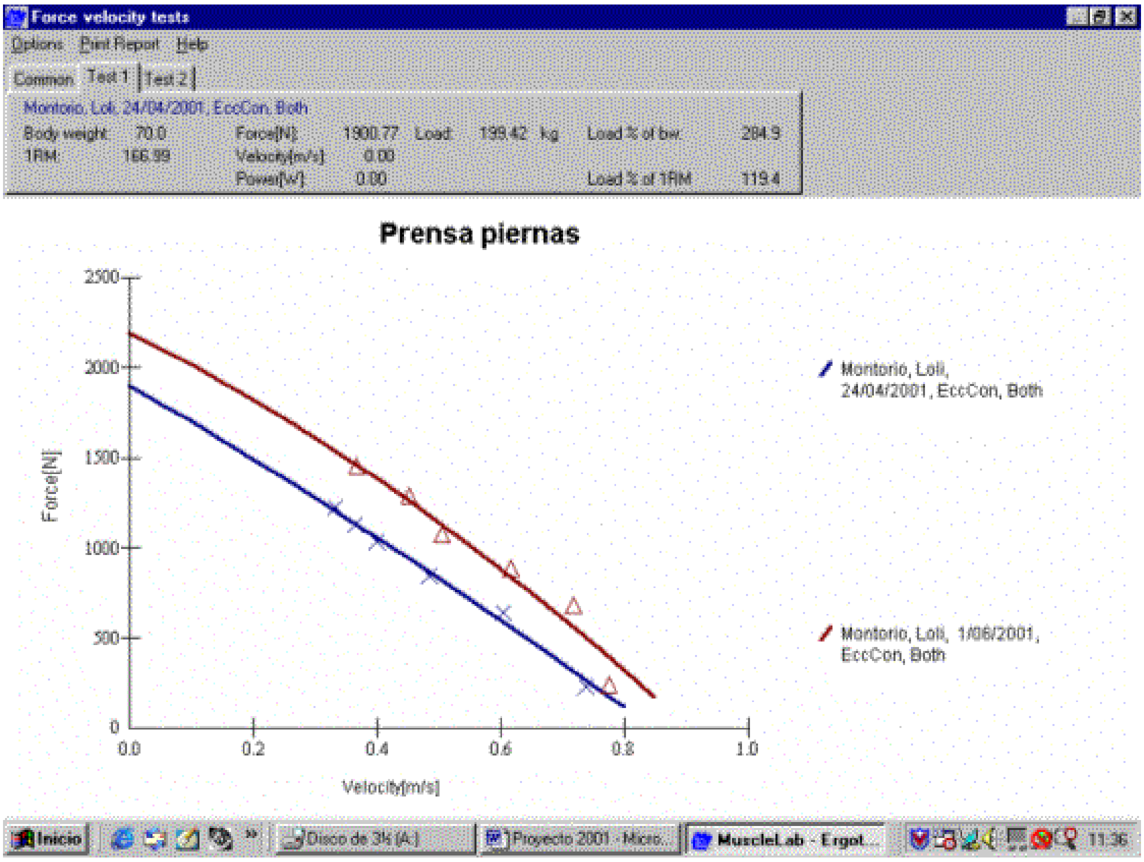
Semana	Tanda 1	Tanda 2	Tanda 3
1	3x10	3x10	4x10
2	4x10	4x8	
3	4x8	3x8	4x8
4	3x8	4x6	
5	4x6	3x6	4x6

Tabla 5. Parámetros de entrenamiento para los grupos de entrenamiento con y sin vibración (Ronnestad, 2004)

3.2.2. Adultos lesionados (rehabilitación)

Desafortunadamente, no se han localizado estudios que hayan comprobado el efecto de la estimulación vibratoria en deportistas lesionados en su periodo de rehabilitación. En los últimos años hemos realizado aplicaciones clínicas de caso único como la que se muestra en la figura 4 y 5, donde una estudiante operada de rodilla (que había seguido un plan de rehabilitación clásico sin obtener resultados positivos) logró mejorar su fuerza y potencia además de reducir su déficit unilateral, después de sólo 12 sesiones de entrenamiento con vibraciones mecánicas (30-35 Hz; 4 mm; progresión de series de 30 a 60 seg -5 a 10 min totales de exposición- con 3 min de descanso entre series).

Pese a tratarse de un estudio de caso único se pueden extraer datos interesantes de cara la aplicación de las vibraciones en el campo de la rehabilitación postoperatoria. Como ya se constató en anteriores experiencias que no fueron valoradas objetivamente, el tiempo de recuperación de una lesión después de realizar un periodo de entrenamiento mediante este método disminuye de manera dramática. En este caso la persona en cuestión había seguido anteriormente otro tipo de métodos para rehabilitar su rodilla y no había conseguido volver a su estado pre-operatorio. Como puede observarse en la figura 5, la recuperación del déficit de fuerza unilateral fue completa, pasándose de un 91% a un 3%. Por otro lado, la paciente en cuestión pudo volver a realizar su profesión habitual (profesora de aeróbic) sin molestias en la rodilla operada.



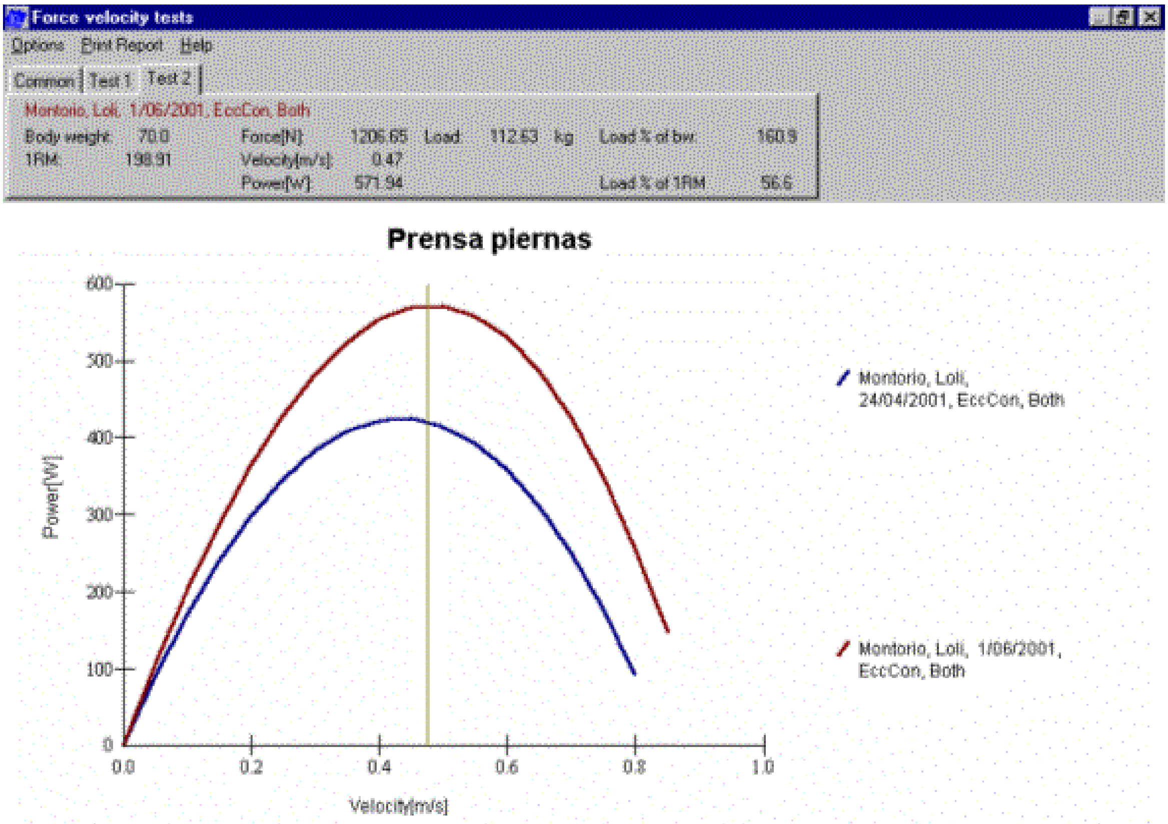
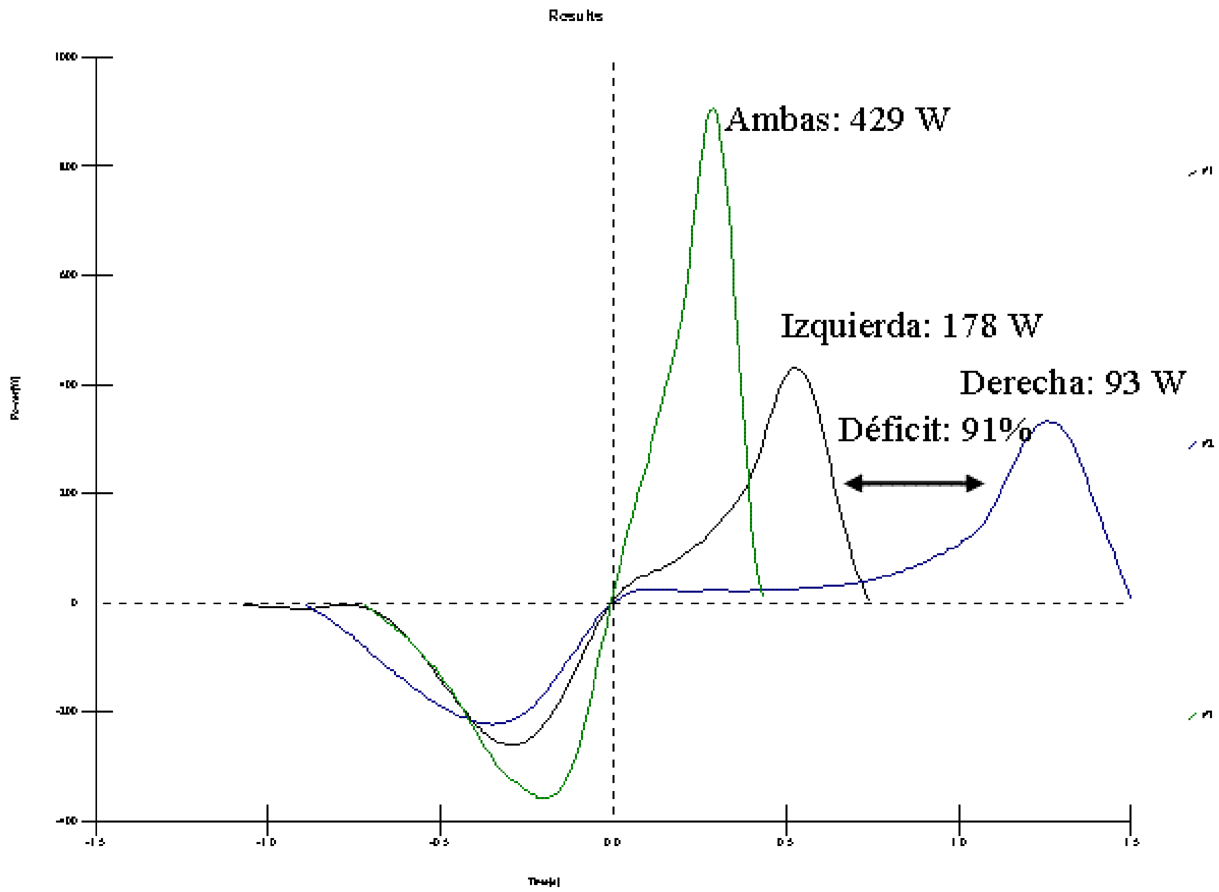


Figura 4. Efectos de la aplicación de vibraciones mecánicas en la mejoras de la curva de fuerza-velocidad y de la potencia en un sujeto operado de rodilla (Tous, 2001; datos sin publicar)



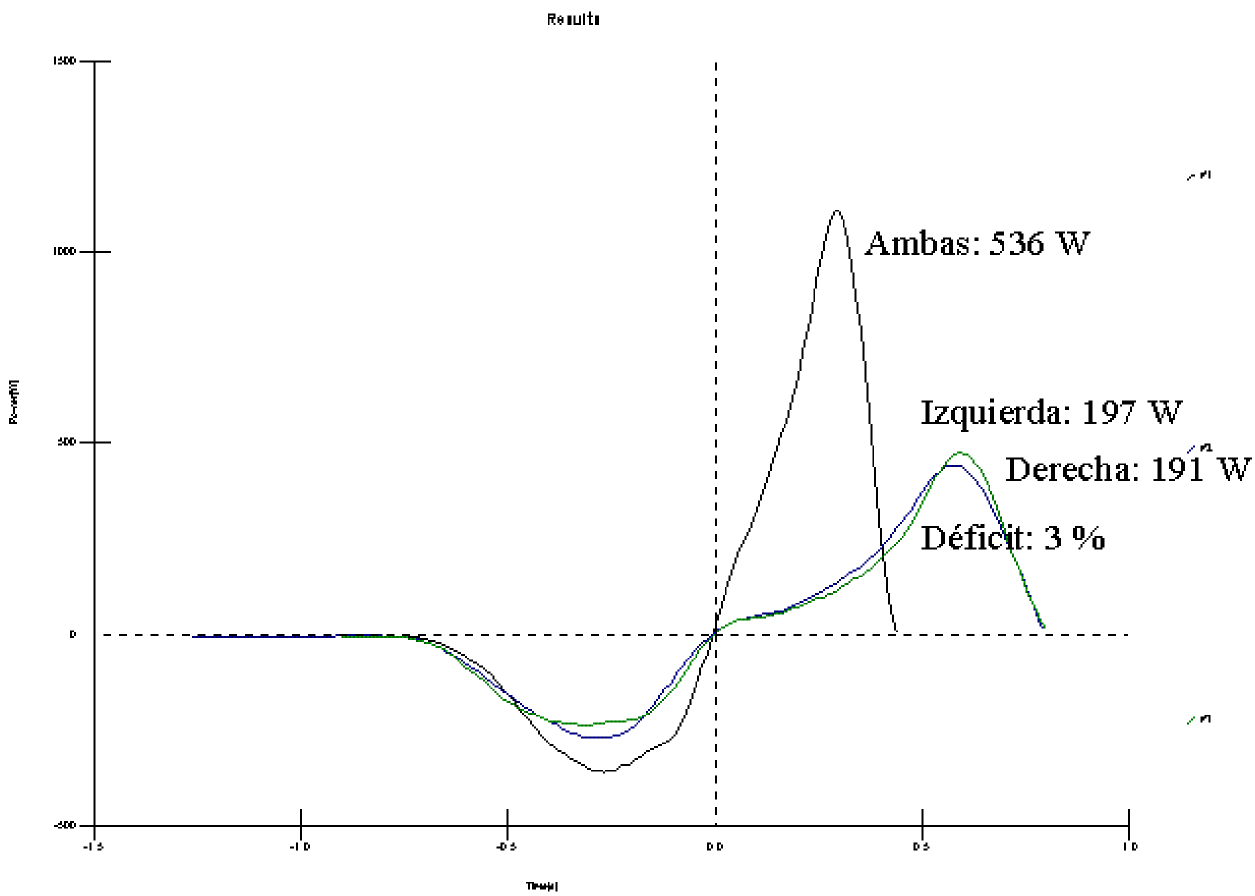


Figura 5. Efectos de la aplicación de vibraciones mecánicas en la reducción del déficit unilateral en un sujeto operado de rodilla (derecha) después de 12 sesiones de entrenamiento. La gráfica de arriba refleja una curva de potencia-tiempo con los resultados del primer test al movilizar una carga cercana al peso corporal (60 kgs); puede observarse la gran diferencia de potencia aplicada entre ambas piernas. La gráfica de abajo indica la restitución del déficit a valores normales (Tous, 2001; datos sin publicar)

Otra experiencia que pudimos controlar fue un entrenamiento por medio de vibraciones mecánicas en un jugador profesional de baloncesto que padecía una condropatía rotuliana y como consecuencia fuertes dolores en la articulación de la rodilla que le impedían ejercitarse al máximo. Los resultados fueron altamente satisfactorios tanto objetiva como subjetivamente (percepción del jugador sobre el estado de su articulación.

Peso (kgs)	% Mejora izda	%Mejora dcha	%Mejora ambas
20	23,04	35,72	34,86
40	48,74	58,51	45,90
60	28,12	16,49	37,87
80	-4,81	7,98	11,25
90	23,04	34,46	15,77

Tabla 6. Mejoras en un test de potencia en prensa 45º con diferentes cargas para cada pierna y para las dos piernas

En la tabla 6 pueden observarse las mejoras después de 12 sesiones de entrenamiento (4 semanas) empleando un volumen de 10 minutos de trabajo sobre la plataforma con 3 minutos de descanso entre serie. Pese a tratarse de una persona altamente entrenada, se pudo constatar también las mejoras que provoca la aplicación de vibraciones mecánicas. Se ha de tener en cuenta que el sujeto no realizó durante el periodo de tiempo investigado ningún otro tipo de ejercicio con el objeto de desarrollar la fuerza muscular. Se encontraron mayores mejoras en la zona de cargas ligeras que en la de cargas pesadas, lo cual concuerda con anteriores experiencias realizadas en deportistas altamente entrenados. Sin embargo, durante la realización del test posentrenamiento con la carga de 80 kgs el sujeto probablemente no se esforzó al máximo; de ahí que se observara un descenso en la potencia media desarrollada.

3.2.3. Adultos entrenados

En sujetos entrenados existen muy pocos trabajos que empleen diseños de investigación controlados. Issurin et al (1994) son los primeros en presentar en publicaciones indexadas un estudio con deportistas con una cierta experiencia en entrenamiento. Dividieron a 24 varones practicantes de diferentes deportes en tres grupos: (a) ejercicios convencionales de fuerza para los brazos y ejercicios de flexibilidad con estimulación vibratoria para las piernas; (b) ejercicios con estimulación vibratoria para los brazos y ejercicios de flexibilidad para las piernas; (c) grupo control, entrenamiento irrelevante. Las vibraciones fueron aplicadas mediante un sistema especial de cables unidos a una polea con cargas que recibía vibración por medio de n motor. Los parámetros empleados fueron 44 Hz y 3 mm con una frecuencia de 3 sesiones semanales y una duración por sesión de 20-23 min. Después de 3 semanas de entrenamiento, se encontró una mejora de la 1RM en tracción en banco sentado de un 49% en el grupo (b) sometido a vibraciones, por un 16% en el grupo convencional (a) y ningún cambio en el grupo control (c). En cuanto a las ganancias de flexibilidad, fueron equivalentes a un 43,6% en (a), un 19,2 % en (b) y un 5,8 en el grupo control (c).

Un sistema que también empleaba cables transmisores de vibración fue empleado por Becerra y Becker (2001) en nadadores bien entrenados. La muestra (n=23) fue dividida en 4 grupos: (a) vibración (20-24 Hz; 4 mm) añadida a la movilización de una carga equivalente al 50-60% de la fuerza máxima isométrica a una velocidad angular de 180º/s en la articulación del hombro (empleo de banco isocinético). 2 min de trabajo, 2 minutos de pausa, con incremento de 2 repeticiones de sesión a sesión. 3 sesiones semanales para un total de 7 sesiones; (b) mismo trabajo sin vibración añadida; (c) vibración añadida a la movilización de una carga equivalente al 90-95% de la fuerza máxima isométrica a una velocidad angular de 30º/s. 30 seg de trabajo seguidos de 90 seg de recuperación, con incremento de repeticiones de 10 a 14; (d) mismo trabajo que (c) pero sin vibración añadida. Un resumen de los resultados obtenidos puede consultarse en la tabla 7.

Grupo	Fmax (%)	Fexp (%)	50 m (%)	100 m (%)	200 m (%)	400 m (%)	800 m (%)
A	-6,6	13,9	-0,89	-2,5	-1,38	-1,88	-4,5
B	-6,1	37,6	0,0	-1,9	-1,4	0,0	1,3
C	19,2	20,6	-5,1	-5,4		-1,8	0,1
D	13,6	6,9	-5,1	-3,6		-0,2	-2,1

Tabla 7. Resultados obtenidos en los diferentes tests generales y específicos empleados. Fexp: índice de fuerza explosiva(Becerra & Becker, 2001)

La presentación de resultados en este estudio es bastante confusa por lo que los resultados han de ser interpretados con cautela hasta que otros autores puedan repetir la investigación. Sin embargo, es el único estudio que ha comprobado la influencia de la estimulación vibratoria en la mejora del rendimiento en un deporte, de ahí su interés. En este caso se encuentran mejoras en los tiempos empleados para nadar diferentes distancias, aunque dichas mejoras no alcanzan la significación estadística. Desafortunadamente, algunos datos presentados en las tablas no se corresponden con los presentados en gráficos o en el texto por lo que se hace difícil la valoración de la investigación.

Bosco et al sometieron a un plan de entrenamiento por medio de WBV a futbolistas profesionales durante la fase de pretemporada (n= 17; 21-34 años). Se realizó 1 mes de entrenamiento (5 sesiones semanales) con 5 sers de 60" con 60" de pausa; SQ 90º; 30 Hz; 5 mm (3,6g; equivale a DJ60). Se encontró un aumento significativo en CMJ, RJ15, RJ5 y test "seat and reach" (12 cms de mejora). Sin embargo, este estudio no incluyó grupo control por lo que las mejoras pudieron deberse a otros factores no relacionados con la aplicación de vibraciones (Bosco *et al.*, 2001).

Por otro lado, Berschin et al (2003) compararon en jugadores de rugby profesionales un programa de entrenamiento mediante WBV (5 series x 3´ con 2-3' de pausa; 20 Hz; 3 mm; sobrecarga sobre la espalda creciente cada semana hasta llegar al 70% de 1RM) con respecto a un programa de entrenamiento de fuerza clásico (5 x 12 reps al 70% levantado explosivo con 2´ de pausa entre serie). El grupo sometido a vibraciones mejoró más en todas las pruebas empleadas que el grupo convencional. Este fue el primer estudio en incluir un test de agilidad (cambios de dirección) en las pruebas de valoración funcional. Además los sujetos refirieron una mayor capacidad de aceleración, movilidad lateral y una mayor estabilidad en las acciones de juego (Berschin *et al.*, 2003).

Cronin et al (2004) investigaron el efecto de 10 días de entrenamiento por medio de vibraciones mecánicas (26 Hz; 5,2 mm; programa progresivo de 5 ejercicios con duración de entre 90 y 120 seg y 40 seg de pausa) en 15 bailarines experimentados. Los sujetos fueron divididos de manera aleatoria en tres grupos: (a) vibraciones; (b) mismos ejercicios sin vibraciones; (c) control (sólo entrenamiento de danza habitual). Los resultados obtenidos pueden consultarse en la tabla 7.

Parámetro	Cambio (%)	Diferencia (%)	Beneficioso (%)	Trivial (%)	Perjudicial (%)
CMJ (cm)	Vib 2,7	-			
	Nvib 1,3	1,4	34	53	13
	Con –0,4	3,1	51	43	6
DJ (cm)	Vib 3,9	-			
	Nvib -4,8	8,7	81	14	0
	Con –2,1	6,0	89	11	3
CR	Vib 7,8	-			
	Nvib -6,9	14,0	92	6	2
	Con –3,5	11,3	89	9	3

Tabla 8. Porcentajes de cambios producidos en los tres grupos investigados entre los niveles iniciales y después de 10 días. En las tres últimas columnas se incluye la probabilidad de que ese porcentaje de cambio sea clínicamente beneficioso, trivial o perjudicial (Cronin *et al.*, 2004)

Como puede observarse en la tabla 8, los efectos más claros se produjeron en la mejora del ciclo de estiramiento-acortamiento (CEA) rápido, medido mediante el test DJ (Drop Jump) y el cálculo del CR (coeficiente de reactividad = altura de salto/ tiempo de contacto). Así, existe un 89 % de probabilidad de que el programa de vibraciones empleado sea beneficioso para mejorar estos dos parámetros citados.

Durante el verano del 2001 realizamos una experiencia novedosa al combinar la preparación para los campeonatos internaciones de voley-playa femenino con un entrenamiento por medio de vibraciones mecánicas. Participaron 9 jugadoras integrantes de la selección española de voley-playa (25,4 ± 2,7 años de edad; 173,04 ± 5,1 m de altura; 65,7 ± 7,3 kgs de peso corporal). La duración del entrenamiento fue de 24 días, con un total de 11 sesiones, 10 series de 1 min con 3 min de recuperación, una frecuencia de estimulación de 30 Hz y una amplitud de 4 mm.

Se realizaron antes y después del periodo de entrenamiento tests de sobrecarga progresiva en media sentadilla para estimar la potencia mecánica desarrollada en cada carga. Los sujetos, durante el periodo de tiempo estudiado continuaron con su entrenamiento técnico-táctico y físico, añadiendo la aplicación de vibraciones. Desafortunadamente, no se pudo incluir un grupo control debido a las características excepcionales de la muestra que se encontraba en un periodo de preparación para una competición internacional. En la tabla 9 se muestran los resultados correspondientes a los porcentajes de mejora obtenidos después de las 11 sesiones de entrenamiento.

	% de mejora							
Sujeto	**20 kgs**	**30 kgs**	**40 kgs**	**50 kgs**	**60 kgs**	**70 kgs**	**80 kgs**	**90 kgs**
1	9,6	0	-2,5	-0,5	2,7	-2,6	0,6	4
2	-7,1	-2,98	-1,35	-3,8	-5,9	3,5	-3,2	8,4
3	10	15,9	-7,5	-8,6	-0,5	-4,6	0,9	-0,6
4	27	6,8	-13,5	22,7	1,4	4,8	13	4,7
5	7,7	7,5	1,06	-0,46	2,5	6,4	6,4	2,47
6	0,6	-9,5	7,4	7,9	1,5	8,1	-0,85	
7	-9,3	1,4	-0,7	1,8	5	2,6	5,7	
8	7,1	-4,5	-2,4	8,1				
9	-	-	-4,5	-	-	-	-	-
promedio	5,7	4,96	-2,67	3,39	0,96	5,08	3,22	3,79
D.S.	11,4	12	5,76	9,59	3,45	4,64	5,51	3,28
t	0,1	0,3	0,48	0,19	0,27	0,15	0,08	0,02*

Tabla 9. Porcentajes de mejora en la potencia mecánica media desarrollada para diferentes cargas en el ejercicio de media sentadilla obtenidos después de 11 sesiones en jugadoras internacionales de voley playa (Moras y Tous, 2001; datos sin publicar).

En esta experiencia nos encontramos con una situación real de entrenamiento donde se combina todo tipo de trabajo condicional con un trabajo técnico-táctico de una magnitud de carga elevada. Sin embargo, esto constituye un gran problema a la hora de investigar los efectos de la aplicación de vibraciones; ya que no se puede diferenciar los efectos de las vibraciones de los del resto de entrenamientos. De esta manera, se observa en el estudio una gran variabilidad en el rendimiento de las diferentes deportistas que puede deberse al diferente nivel de entrenamiento con que llegaron a la concentración. Aunque se producen mejoras en la potencia media desarrollada para todas las cargas (excepto para 40 ks), sólo son estadísticamente significativas para la carga mayor (90 kgs) No obstante, las mayores mejoras se encuentran en la zona de 20 kgs (no significativas) tal y como habíamos observado en anteriores experiencias. Sin embargo, el resultado más importante para este tipo de muestra y situación fue la no aparición de lesiones durante este periodo intenso de preparación para una competición internacional.

Como aplicación más importante se puede extraer que es posible combinar un periodo de entrenamiento intenso con la aplicación de vibraciones mecánicas sin que por ello se vea disminuida la potencia aplicada en un test de media sentadilla ni aumente el índice de lesiones.

3.2.3. Tercera edad

También en la tercera edad se han realizado aplicaciones de este método. Runge et al (Runge *et al.*, 2000) encontraron un aumento significativo promedio de un 18% en el test de levantarse de la silla, después de 2 meses de entrenamiento (3 días por semana; 3 series de 2 minutos) en un grupo mixto de sujetos de 67 años de media. El test de levantarse de la silla consiste en elevarse 5 veces de una silla tan rápido como sea posible sin emplear los brazos de ayuda, por lo tanto es un indicador de la potencia del tren inferior (trabajo realizado por unidad de tiempo) Los autores indican su larga experiencia con el método de entrenamiento como tratamiento en una clínica geriátrica y la exclusión de pacientes con lesiones agudas de la columna y extremidades inferiores así como en la trombosis y urolitiasis aguda.

Iwamoto et al (2004) comprobaron la eficacia de un programa de entrenamiento en la competencia ambulatoria de 25 mujeres de 72,8 7,0 años de edad. El programa de entrenamiento incluía una sesión semanal de vibraciones (4 minutos a 20 Hz; 0,7-4,2 mm) combinada con ejercicios diarios de equilibrio estático (flamencos) y de fuerza (10 sentadillas con el propio peso corporal). Después de 3 meses de entrenamiento se observó una mejora significativa en los siguientes tests: longitud de paso, máximo momento extensor de la rodilla, máximo tiempo mantenido sobre una pierna. Por otro lado, no se observaron efectos adversos como fracturas vertebrales y problemas cardiovasculares. Desafortunadamente en este estudio no se pudo separar la posible eficacia de la estimulación vibratoria con respecto a los otros dos modelos de entrenamiento. Además, la no inclusión de un grupo control limita las inferencias que pudiera realizarse al resto de población (Iwamoto *et al.*, 2004).

También Miyamoto *et al.* (2003) encontraron una mejora del equilibrio después de 6 meses de entrenamiento en una muestra de 20 sujetos de una media de 72,6 años de edad, por lo que sugieren su aplicación como prevención de las caídas(Miyamoto *et al.*, 2003). Se ha de tener en cuenta que más del 90% de fracturas de cadera se produce como consecuencia de caídas (Runge *et al.*, 2000). Además, el 80% de sujetos mayores de 80 años sufren al menos una caída al año (Armstrong & Wallace, 1994).

Russo et al (2003) investigaron el efecto de 6 meses de entrenamiento por medio de vibraciones mecánicas (28 Hz; amplitud variable) en 14 mujeres posmenopáusicas (60,7 6,1) años de edad) con respecto a 15 mujeres de similares características (61,40 7,3 años de edad) incluidas en un grupo control. El grupo de entrenamiento realizó 2 sesiones semanales (promedio de 32 sesiones y 200 minutos de exposición totales) que incluían 3 series de 2 minutos de trabajo con 1 minuto de recuperación. Después de los 6 meses de intervención, el grupo que realizó el entrenamiento mejoró un 5% su potencia, siendo esta mejora significativa con respecto al grupo control que incluso disminuyó con respecto a sus niveles iniciales. Sin embargo, la fuerza muscular no se vio afectada como consecuencia del entrenamiento. Desafortunadamente, el método administrado para evaluar la fuerza y la potencia en este estudio deja bastante que desear ya que se empleó un salto vertical sobre una plataforma de fuerzas para obtener los citados parámetros.

Roelants et al (2004) han reportado mejoras en la fuerza muscular y velocidad de movimiento de los extensores de la rodilla así como en la capacidad de salto de mujeres posmenopáusicas (58-74 años de edad) después de 24 semanas de entrenamiento en una plataforma vibratoria. Las mejoras fueron similares a las de otro grupo que realizó un entrenamiento de fuerza convencional y se produjeron fundamentalmente en las primeras doce semanas.

Parámetros	Inicio	Semana 12	Semana 24
Volumen			
Duración total de la vibración en una sesión (min)	3	20	30
Series por ejercicio	1	3	3
Ejercicios diferentes para extensores de piernas	2	6	9
Mayor duración de la vibración sin descanso (s)	30	60	60
Intensidad			
Intervalo de descanso entre ejercicios (s)	60	5	5
Amplitud de la vibración (mm)	2,5	5	5
Frecuencia de la vibración (Hz)	35	40	40
Resultados salto	**Inicio**	**Semana 12**	**Semana 24**
Salto (CMJ)			
Grupo control	-	ns	ns
Grupo WBV	-	+16%*	ns
Grupo Entrenamiento Fuerza Clásico	-	+12,1%*	ns

Tabla 10. Parámetros del programa de vibraciones al comienzo y al final del mismo (Roelants *et al.*, 2004)

3.2.4. Tejido óseo

Por otro lado, una de las aplicaciones más prometedoras de este método es la prevención y rehabilitación de osteoporosis. El equipo de Clinton Rubin de la Universidad Estatal de Nueva York, es el que mayores aportaciones ha realizado en este campo. En una serie de interesantes estudios encontraron que las vibraciones de alta frecuencia y baja magnitud provocan un efecto anabólico en el tejido óseo de ovejas (Rubin et al, 2001a) y ratas (Rubin et al, 2001b; también en Flieger et al (1998)). Más recientemente se han publicado los mismos efectos en mujeres posmenopáusicas (Verschueren et al, 2004; Rubin et al, 2004) y en niños discapacitados (Ward et al, 2004). Parece que estas poblaciones tienen mayor capacidad de beneficiarse que población joven y sana como la empleada por Torvinen et al (2003) que no encontraron ninguna adaptación ósea después de 8 meses de entrenamiento. Bien es cierto que Russo et al (2003) tampoco encontraron mejoras en la densidad ósea después de 6 meses de entrenamiento en mujeres posmenopáusicos aunque al igual que Torvinen et al, el volumen de trabajo por sesión fue muy escaso (6 y 4 minutos respectivamente con respecto a 2 sesiones de 10 min diarias en el trabajo de Rubin et al y 30 min por sesión en el trabajo de Verschueren et al).

La frecuencia y amplitud de vibración parece tener gran importancia en la proliferación de osteoblastos en cultivo, habiéndose encontrado que éstos son más sensibles a vibraciones de baja amplitud y frecuencia amplia (de 0 a 50 Hz) (Tanaka *et al.*, 2003b). Esta respuesta osteogénica a la carga mecánica parece ser aumentada si se emplea el fenómeno de resonancia estocástica. Para conseguir este efecto se ha añadir ejercicio dinámico a la aplicación de vibraciones (Tanaka *et al.*, 2003a). Estos dos estudios han sido realizados con cultivos o con ratas. En humanos, el grupo de Rubin promueve el uso de vibraciones en torno a los 30 Hz pero con una amplitud muy pequeña que resulta en una aceleración de sólo 0,3 g. En cambio, en el trabajo de Verschueren et al (2004), se emplean frecuencias similares (35-40 Hz) pero amplitudes entre 1,7 y 2,5 mm, para resultar en aceleraciones muy superiores de 2,28-5,09 g. Ambos estudios obtuvieron mejoras significativas por lo que se hace necesario realizar más estudios para conocer la posible especificidad de la respuesta osteogénica a la amplitud y frecuencia de vibración.

Otro modelo de investigación es el empleado por Rittweger y Felsenger (2004) para prevenir la pérdida de masa ósea en sujetos que permanecieron encamados durante 8 semanas. El grupo de entrenamiento recibió vibraciones mecánicas en posición supina (19-23 Hz), a razón de 4 series de 1 minuto, 2 veces al día, 6 días a la semana. Después del entrenamiento la pérdida de masa ósea no fue significativa pero sí diferente a la pérdida obtenida en el grupo control (Rittweger & Felsenberg, 2004).

3.2.5. Tejido cartilaginoso

El tejido cartilaginoso, al contrario que otros tejidos conectivos, no posee vasos sanguíneos o terminaciones nerviosas propias. Por esta razón, la regeneración del mismo ante una lesión es sumamente dificultosa requiriendo de una neovascularización e inervación de la zona. Para evitar degradarse, este tejido necesita recibir cargas dinámicas mecánicas externas (Liu *et al.*, 2001). En nuestro conocimiento no se han publicado estudios que hayan comprobado la posible adaptación del tejido cartilaginoso ante un estímulo vibratorio como el que puede provocarse con una plataforma disponible comercialmente. Sin embargo, se han realizado estudios con cultivos de condrocitos articulares de conejo cuyos resultados son muy prometedores. De este modo, Liu et al (2001) encontraron que una vibración de 300 Hz y 1,4 g provocaba un aumento considerable de la síntesis de ADN en dichos condrocitos así como un aumento en la síntesis de proteoglicanos. Sin embargo, frecuencias de 200 Hz y 400 Hz provocaban un efecto contrario.

Esta es una de las líneas de trabajo donde más se ha de investigar para comprobar si en sujetos con osteoartritis se producen mejoras significativas como consecuencia de la aplicación de estímulos vibratorios.

3.2.6. Efectos perjudiciales

La aplicación prolongada de altas frecuencias de vibración ha demostrado ser nociva en otros aspectos. Así, Necking et al (1996) aplicaron vibraciones a ratas a una frecuencia de 80Hz durante 5 horas diarias y 5 días consecutivos, encontrando como respuesta una degeneración fibrilar en distintos músculos (Necking *et al.*, 1996). También Bovenzi (1991) encontró que aquellos trabajadores que empleaban la sierra mecánica tenían una menor fuerza de prensión con la mano que los que no la utilizaban (Bovenzi *et al.*, 1991). En estudios epidemiológicos se ha descrito la aparición de los primeros síntomas del síndrome por vibración después de una exposición de 2000 horas (2-8 horas diarias) a herramientas de mano vibradoras (Miyashita *et al.*, 1983). Por otro lado, la aplicación prolongada de bajas frecuencias ha demostrado guardar una relación con el low back pain (Lings & Leboeuf-Yde, 2000; Bovenzi & Hulshof, 1999). Sin embargo, un trabajo reciente del grupo de Rittweger ha encontrado todo lo contrario en una muestra de 50 sujetos de 51,7 ± 5,8 años y un historial médico de LBP crónico de 13,1±10,0 años. Los sujetos participantes realizaron 18 sesiones de entrenamiento durante 12 semanas, de forma que durante las primeras 6 semanas se realizaban 2 sesiones y durante las segundas sólo una sesión semanal. La amplitud de la vibración tuvo su máximo en 6mm y la frecuencia se estableció en 18 Hz; por otra parte la duración del ejercicio fue incrementándose hasta alcanzar un máximo de 7 min. A partir de la 10ª sesión se añadió una sobrecarga en los hombros de hasta un 30% del peso corporal. Después del periodo de entrenamiento se encontró una reducción de la percepción de dolor similar a la de otro grupo que entrenó con máquinas MedX y un aumento del momento flexor lumbar que en este caso fue menor que el del grupo MedX. De esta manera se concluye que la aplicación controlada de vibraciones mecánicas puede ser la cura y no la causa del LBP (Rittweger *et al.*, 2002).

4. Conclusiones

La aplicación de vibraciones mecánicas al organismo humano parece representar un intenso estímulo para las diferentes estructuras que lo componen. Mientras la exposición crónica a estas vibraciones parece ser perjudicial, el empleo de vibraciones con frecuencias de entre 25 y 40 Hz y amplitudes entre 2 y 10 mm aplicadas en sesiones de una duración total inferior a lo 30 minutos ha demostrado provocar efectos beneficiosos en diferentes parámetros de rendimiento físico. De esta manera, se ven aumentadas vía refleja las respuestas musculares y propioceptivas, lo que provoca mejoras a medio y largo plazo en los niveles de potencia, fuerza y equilibrio postural en diferentes poblaciones. Asimismo, diversos tejidos que requieren de impactos mecánicos para regular su metabolismo, como es el caso del óseo y del cartilaginoso, han demostrado adaptarse positivamente a la estimulación vibratoria. Resta por comprobar la posible adaptación positiva de tejidos elásticos (fascias, ligamentos, tendones) a la vibración, por la incidencia que tendría la misma en la mejora de la economía del movimiento.

La respuesta a las vibraciones parece ser bastante específica al individuo y a los parámetros (frecuencia, amplitud y duración) de estimulación empleados. El conocimiento de estos parámetros es sumamente importante a la hora de analizar los diferentes estudios y los resultados obtenidos, ya que en muchas ocasiones se han empleado vibraciones totalmente diferentes a las que aplica una plataforma disponible comercialmente. Por esta razón se hace necesaria la realización de estudios adicionales a largo plazo de cara a conocer la dosis óptima para cada individuo y si podrían llegar a provocar los efectos perjudiciales descritos ampliamente en medicina ocupacional.

Notas

1. Se emplea la traducción propuesta en la Enciclopedia de Salud y Seguridad en el Trabajo

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Vibration Exposure and Biodynamic Responses during Whole-Body Vibration Training

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[1]*Wyle Laboratories, Inc., Houston, TX;* [2]*Human Performance Laboratory, University of Houston–Clear Lake, Houston, TX;* [3]*Laboratory of Integrated Physiology, University of Houston, Houston, TX;* [4]*Department of Physical Therapy, Hardin–Simmons University, Abilene, TX; and* [5]*Human Adaptations and Countermeasures Division, National Aeronautics and Space Administration, Houston, TX*

ABSTRACT

ABERCROMBY, A. F. J., W. E. AMONETTE, C. S. LAYNE, B. K. MCFARLIN, M. R. HINMAN, and W. H. PALOSKI. Vibration Exposure and Biodynamic Responses during Whole-Body Vibration Training. *Med. Sci. Sports Exerc.*, Vol. 39, No. 10, pp. 1794–1800, 2007. **Purpose:** Excessive, chronic whole-body vibration (WBV) has a number of negative side effects on the human body, including disorders of the skeletal, digestive, reproductive, visual, and vestibular systems. Whole-body vibration training (WBVT) is intentional exposure to WBV to increase leg muscle strength, bone mineral density, health-related quality of life, and decrease back pain. The purpose of this study was to quantitatively evaluate vibration exposure and biodynamic responses during typical WBVT regimens. **Methods:** Healthy men and women (N = 16) were recruited to perform slow, unloaded squats during WBVT (30 Hz; 4 $mm_{p\text{-}p}$), during which knee flexion angle (KA), mechanical impedance, head acceleration (Ha_{rms}), and estimated vibration dose value (eVDV) were measured. WBVT was repeated using two forms of vibration: 1) vertical forces to both feet simultaneously (VV), and 2) upward forces to only one foot at a time (RV). **Results:** Mechanical impedance varied inversely with KA during RV (effect size, η_p^2: 0.668, $P < 0.01$) and VV (η_p^2: 0.533, $P < 0.05$). Ha_{rms} varied with KA (η_p^2: 0.686, $P < 0.01$) and is greater during VV than during RV at all KA ($P < 0.01$). The effect of KA on Ha_{rms} is different for RV and VV (η_p^2: 0.567, $P < 0.05$). The eVDV associated with typical RV and VV training regimens (30 Hz, 4 $mm_{p\text{-}p}$, 10 $min \cdot d^{-1}$) exceeds the recommended daily vibration exposure as defined by ISO 2631-1 ($P < 0.01$). **Conclusions:** ISO standards indicate that 10 $min \cdot d^{-1}$ WBVT is potentially harmful to the human body; the risk of adverse health effects may be lower during RV than VV and at half-squats rather than full-squats or upright stance. More research is needed to explore the long-term health hazards of WBVT. **Key Words:** ISO 2631-1, ESTIMATED VIBRATION DOSE VALUE, MECHANICAL IMPEDANCE, HEAD ACCELERATION, RISK

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Whole-body vibration training (WBVT) has been shown to elicit beneficial effects including improvements in isometric/dynamic leg muscle strength (18,22), bone mineral density (BMD) (20,22), back pain (12,17), health-related quality of life, and decreased fall risk (5). However, the proposed benefits of WBVT are equivocal (16), and it is possible that deleterious side effects of WBVT exist (6,7,19). It is well accepted that chronic whole-body vibration (WBV), which is unintentional vibration exposure resulting from an individual's chosen occupation has been reported to have a number of negative side effects that are known to disturb normal physiology and structure in the back, digestive, reproductive, visual, and vestibular systems (4,9,14,21). For example, operators of off-road vehicles, tractors, helicopters and armored vehicles are frequently exposed to high-magnitude vibration for prolonged durations. The resulting vibration of the spinal column is believed to cause intervertebral disc displacement, spinal vertebrae degeneration, and osteoarthritis (9,14,21), and vibration that is transmitted through the spinal column to the head may induce hearing loss, visual impairment, vestibular damage, and can even induce brain hemorrhaging at very high vibration magnitudes (2,8,9,11). Quantitative techniques exist to quantify the severity of occupational WBV exposures and relate those WBV exposures to health risks; however, we are unaware of any previous attempts to apply these techniques to WBVT.

Vibration exposure may be quantified using estimated vibration dose value (eVDV, ISO 2631-1) (10), which is calculated using direction, frequency, magnitude, and duration of the vibration applied to a human and amalgamated into a single metric. The eVDV is classified as potentially harmful if it exceeds an ISO upper limit of 17.

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The potential for negative side effects associated with WBV can also be assessed by measuring head and spine acceleration and mechanical impedance (9). Relative apparent mass magnitude (RAMM) is a measure of relative mechanical impedance; increased RAMM is associated with decreased joint compliance, which increases the body's absorption of vibration energy (9,15). Joint compliance limits transmission of vibration energy to the head and upper body (13).

A combination of eVDV, head acceleration, and RAMM measurements are useful in quantitatively defining the risk of negative side effects for a given dose of WBVT. Thus, we hypothesized that: 1) RAMM would vary inversely with knee flexion angle (KA), 2) root mean square (RMS) head acceleration (Ha_{rms}) would be greater during VV than during RV, 3) Ha_{rms} during RV and VV would vary inversely with KA, 4) the direction of platform vibration (RV vs VV) would significantly affect the relationship examined in hypothesis 3, and 5) the eVDV associated with typical RV and VV training regimens (30 Hz, 4 $mm_{p\text{-}p}$, 10 $min{\cdot}d^{-1}$) would exceed the recommended daily vibration exposure as defined by ISO 2631-1. The purpose of this study was to quantitatively evaluate and compare the severity of vibration exposure during typical WBVT regimens using two different directions of vibration.

METHODS

Approach to the problem and experimental design. A single-group study design with repeated measures was employed in which Ha_{rms}, RAMM, and eVDV were the dependent variables. The independent variables were KA (10–15, 16–20, 21–25, 26–30, and 31–35°) and vibration direction (RV vs VV).

Subjects and study design. Nine male (32.7 ± 7.0 yr; 178 ± 2.8 cm; 85.8 ± 7.9 kg) and seven female (32.7 ± 8.3 yr; 167 ± 7.8 cm; 67.2 ± 11.3 kg) subjects were recruited through the NASA–Johnson Space Center Human Test Subject Facility. All subjects were screened for contraindications to vibration exposure. Exclusion criteria included a history of back pain, acute inflammations in the pelvis and/or lower extremity, acute thrombosis, bone tumors, fresh fracture, fresh implants, gallstones, kidney or bladder stones, any disease of the spine, peripheral vascular disease, or pregnancy. Written informed consent was obtained for each subject, and all procedures were approved by the institutional review boards at NASA–Johnson Space Center and at the University of Houston.

Each subject participated in a single data-collection session, consisting of exposure to each of two different directions of WBV: rotational vibration (RV) and vertical vibration (VV). After a 15-s exposure to each vibration direction for familiarization, subjects performed dynamic squats during each of the two vibration conditions while Ha_{rms}, RAMM, eVDV, and KA were measured. Each subject performed two 15-s dynamic squats on each vibration platform, separated by 60 s with 5 min of rest between vibration directions, for a total vibration duration of 30 s on each vibration platform. The order in which vibration directions were presented was balanced among all subjects, to control for any possible confounding effects of muscular fatigue or adaptation to the WBV. Although biodynamic responses to WBV are likely to vary with exposure duration, this effect was not investigated directly in this study. The estimated effect of exposure duration on the likelihood of deleterious health effects in this study was based on the time dependence incorporated within the eVDV calculation in ISO 2631-1 (10).

Vibration conditions. Subjects completed WBVT at 30 Hz and 4-mm peak-to-peak (*p-p*) amplitude using a Power Plate (Power Plate North America LLC, Culver City, CA) and a prototype Galileo 2000 (Orthometrix, Inc., White Plains, NY) WBVT platform. The Power Plate platform (VV) vibrates in a predominantly vertical direction with 4-$mm_{p\text{-}p}$ amplitude (Fig. 1). The Galileo 2000 (RV) rotates about an anteroposterior horizontal axis such that positioning the feet farther from the axis of rotation results in larger-amplitude vibration. In addition to the mediolateral component of the vibration force, RV also differs from VV because of the asynchronous nature of the RV, whereby force is applied alternately to the left and right foot. The result is an asymmetric perturbation of the legs during RV exposure. Conversely, the VV platform translates vertically under both feet at the same time, which results in simultaneous, symmetrical movement of both sides of the body during VV exposure. In this study, VV was applied with 4-$mm_{p\text{-}p}$ amplitude at 30 Hz. During RV at 30 Hz, subjects' feet were positioned 10.3 cm from the axis of rotation corresponding to 4-$mm_{p\text{-}p}$ amplitude. The same stance width was used during VV. The appropriate foot positions were marked on each platform to ensure consistency between platforms and among trials. During

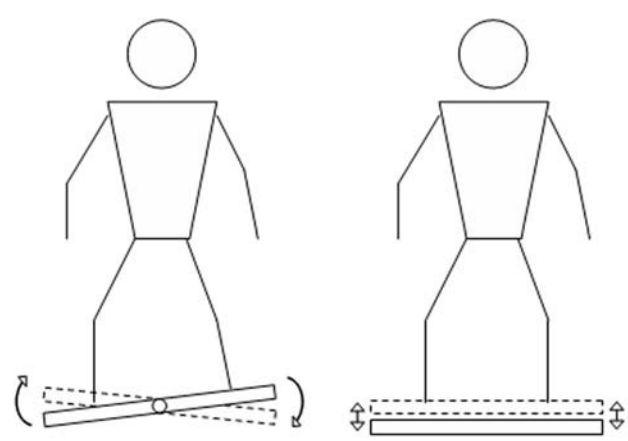

FIGURE 1—Comparison of rotational vibration (RV, *left*) and vertical vibration (VV, *right*). Platform displacements are exaggerated for demonstrative purposes.

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testing sessions, subjects wore the same type of sports socks to standardize any damping of vibration attributable to footwear. Subjects did not wear shoes during testing. To minimize unwanted foot movement during vibration, fine-grade sandpaper with adhesive backing was attached to the vibration platforms, which improved traction between the subjects' socks and the platform.

Posture conditions. After instrumentation, a test operator demonstrated the slow dynamic squatting movement to be performed during the testing protocol. Starting from an upright posture with 5° knee flexion, subjects slowly squatted until 40° of knee flexion was achieved. After holding the 40° knee flexion posture for 2 s, subjects slowly returned to the starting posture. To control the angular velocity of the flexion and extension movements, a test operator used a metronome at 60 bpm concurrently with verbal commands such that the flexion and extension phases of movement each lasted 4 s, with a 2-s pause between phases. The limited range of KA was chosen to allow unsupported squatting during WBVT without inducing loss of balance.

Before commencing data collection, test operators instructed subjects on the appropriate foot placement on each platform, as described above. Subjects were given instructions to be followed during all data-collection trials: stand with head and eyes forward, stand with equal weight on each foot, stand with weight distributed over the whole of each foot, stand with arms outstretched with palms facing down, and do not touch the handrail during data collection unless support is required.

The squat movement was practiced before data collection until a consistently smooth movement was achieved. All conditions were performed twice, and the average head and platform acceleration values were calculated for each KA (described below). Trials were repeated if subjects touched the handrail or if their feet moved noticeably from the required positions.

Safety and fatigue. To minimize fatigue, each trial was limited to a maximum of 15 s in duration, and each vibration trial was separated by at least 1 min. The cumulative exposure to WBVT, including data collection and practice trials, did not exceed 3 min for any subject.

Throughout the testing protocol, subjects were asked to rate their perceived exertion using Borg's 20-point rating of perceived exertion scale (3). No subjects reported exertion as *somewhat hard* (13 on the 6–20 scale) or greater. During and after the testing protocol, subjects were instructed to report any discomfort to the test operators or the responsible physician at the human test subject facility. During testing, one subject experienced itchiness in both feet from mild edema. Symptoms were relieved quickly after the subject walked around the laboratory. No other adverse effects were reported during or after testing.

Knee flexion angles. Unilateral position data from the lateral malleolus, lateral tibial head, and greater trochanter were recorded using an optoelectronic motion-analysis system (Optotrak 3020, Northern Digital, Inc., Waterloo, Canada; RMS error: ± 0.1 mm). Position markers were also attached to each WBVT platform to measure displacement immediately anterior to the right foot of each subject. Position data were sampled at 400 Hz using NDI Toolbench software. The Optotrak camera unit was positioned to view subjects in the sagittal plane. KA was calculated using the angle between ankle, knee, and hip kinematic markers in the sagittal plane. Data from all trials were visually inspected. Because some subjects did not squat to fully 40°, only data from KA between 10 and 35° were analyzed.

Head and platform acceleration. Triaxial accelerations of each WBVT platform and the head of each subject were measured using miniature triaxial accelerometers (EGAXT3, Entran Devices, Inc., Fairfield, NJ). A 25*g* accelerometer was attached to each WBVT platform immediately anterior to the right foot of the subject, in accordance with the ISO 2631-1 standards for the evaluation of whole-body vibration (10). A 5*g* accelerometer was attached to a custom-made plastic bite-bar, which measured subjects' head acceleration when held firmly between the teeth. Accelerometers were powered on 1 h before commencing data collection, to ensure a constant accelerometer temperature during testing. Signals were sampled at 2000 Hz synchronously with kinematic data using a 16-bit Optotrak Data Acquisition Unit II and NDI Toolbench software (Northern Digital, Inc., Waterloo, Canada). Accelerometer data were digitally low-pass filtered before further processing (40 Hz low pass; 10th-order Butterworth; f_{pass} = 40 Hz, f_{stop} = 100 Hz; minimum 50-dB stop-band attenuation; maximum 0.01-dB pass-band ripple).

Instantaneous triaxial head and platform accelerations were expressed as a root sum square, a_{rss}, to reflect the overall magnitude of acceleration for each subject at each instant during each trial. For all a_{rss} data points, RMS values were calculated to yield measures of RMS head acceleration (Ha_{rms}) and RMS platform acceleration (Pa_{rms}) that reflected the mean power of head and platform accelerations. RMS acceleration is the ISO 2631-1 recommended measure of sinusoidal vibration magnitude. RMS values were calculated using a 250-ms moving window with successive windows overlapping by 249 ms.

Mechanical impedance. Apparent mass magnitude (AMM) is a measure of mechanical impedance defined as the ratio of force to acceleration. When the peak force applied by the platform during each cycle of vibration is constant but unknown, the reciprocal of platform acceleration magnitude defines a measure of RAMM that will vary in direct proportion to variation in actual AMM. Because the subsequent analysis required within-subject comparisons only and did not compare vibration directions, measurement of vibration force was unnecessary. For all conditions, RAMM of each WBVT platform was calculated as the reciprocal of Pa_{rms}. For each subject, the average values of Ha_{rms}, Pa_{rms}, and RAMM were calculated for each of the 5° increments between 10 and 35°, and these mean values were used in the subsequent statistical analysis.

eVDV. eVDV was calculated according to the procedures defined by ISO 2631-1 (10). RMS platform acceleration was calculated in each orthogonal axis and was averaged across all KA. RMS acceleration values were then weighted according to the frequency-weighting coefficients defined in ISO 2631-1. In this process, RMS acceleration values in each axis are multiplied by specific coefficients, such that values were adjusted to more closely reflect the health hazard posed to the human body. Coefficients are defined by ISO 2631-1 on the basis of the frequency and the direction of vibration being applied to the body, both of which are known to affect the likelihood of the vibration causing bodily harm. Coefficients of W_k = 0.426 (cephalocaudal axis) and W_d = 0.067 (anteroposterior and mediolateral axes) were applied to yield frequency-weighted RMS accelerations in each axes (a_{wx}, a_{wy}, and a_{wz}) for RV and VV platforms. The rotational motion of the RV platform meant that the coordinate system of the accelerometer rotated with respect to the gravity vector during RV; however, the amount of rotation was calculated as approximately ± 1.1°, which corresponds to a maximum overestimate in true vertical and horizontal accelerations of less than 0.02%. Thus, comparison between RV and VV using the weighting coefficients defined by ISO 2631-1 was considered valid.

eVDV was calculated as follows: $eVDV = 1.4a_wT^{1/4}$, where a_w is the frequency-weighted RMS acceleration and T is the duration of daily vibration exposure in seconds. When combining accelerations in multiple directions a_w is replaced by the vibration total value, $a_v = (k_x^2a_{wx}^2 + k_y^2a_{wy}^2 + k_z^2a_{wz}^2)^{1/2}$, where k_x, k_y, and k_z are multiplying factors defined in ISO 2631-1 (11). For evaluation of health effects, k_x = 1.4, k_y = 1.4, and k_z = 1. The average eVDV across all subjects was computed for each vibration direction for durations up to 1000 $s \cdot d^{-1}$.

ISO 2631-1 specifies that vibration during sitting or standing should be measured at the interface between the vibrating surface and the human. Although weighting coefficients are defined in ISO 2631-1 for WBV during standing, their use in the evaluation of health effects of WBV exposure during standing is not recommended, because research on pathological responses to WBV is limited primarily to vibration of the head and upper body during sitting (10). It follows that relating eVDV during standing to ISO health guidelines is only valid if the calculated eVDV reflects the actual severity of upper-body vibration. Because the legs serve to damp mechanical energy, particularly at larger angles of knee flexion (13,23), the vibration at the interface (feet) does not necessarily represent the vibration of the upper body. The ratio between the vibration magnitude of the spinal column and the feet can be expressed as foot-to-spine transmissibility (FST). By calculating eVDV for a range of FST values, a calculation of eVDV is achieved that reflects the amount of upper-body vibration, provided that the approximate value of FST is known (see Discussion). Accordingly, eVDV was calculated for FST values up to 1.1, under the assumption of equal FST in all axes: measured acceleration values in each axis were multiplied by coefficients of 0.05 to 1.1, and eVDV was then calculated as described above.

The average values of a_v used in the calculation of eVDV for RV and VV platforms were 22.48 and 16.75 $m \cdot s^{-2}$, respectively. Data were processed using MATLAB version 7.0 (The Mathworks, Inc., Natick, MA).

Statistical analysis. Before statistical analysis, acceleration data were examined (probability–probability plot) to evaluate the assumption of normality, which was satisfied. To correct for violations of the sphericity assumption as indicated by Mauchly's test, the Huynh–Feldt correction was used to adjust the degrees of freedom in the repeated-measures (RM) ANOVA.

A 5 × 2 (knee angle × direction) RM ANOVA was performed to evaluate the hypothesis that Ha_{rms} is affected by KA, by vibration direction (D), and by their interaction (KA × D). For each direction, a one-way RM ANOVA was performed to test the hypothesis that RAMM would decrease as knee flexion increased. Effects were tested using the multivariate criterion of Wilks' Λ. Follow-up polynomial contrasts were used to statistically test the quadratic trends in Ha_{rms} means during RV and VV. Bonferroni-adjusted paired t-tests compared Ha_{rms} between RV and VV conditions. One-sample t-tests were conducted to evaluate whether the mean eVDV values (at FST = 1) for each direction were significantly different from 17, the upper limit of the ISO 2631-1 health caution zone (10). In all tests, $P \leq 0.05$ was considered significant. Statistical analyses were performed using SPSS 13.0 for Windows (SPSS, Inc., Chicago, IL).

APPLIED SCIENCES

RESULTS

Means and standard errors of RAMM and Ha_{rms} with respect to KA are displayed in Figures 2 and 3, respectively. The stick figures indicate the squatting position at the smallest and largest knee angles. The RAMM data are normalized to the maximum RAMM for each vibration direction.

Results of the one-way RM ANOVA indicate significant effects of knee angle on RAMM during RV (Wilks' $\Lambda = 0.332$, $F = 6.05$, $P = 0.007$, $\eta_p^2 = 0.668$) and during VV (Wilks' $\Lambda = 0.467$, $F = 3.42$, $P = 0.044$, $\eta_p^2 = 0.533$).

Results of the RM ANOVA for RMS head acceleration indicate significant main effects of knee angle (Wilks' $\Lambda = 0.314$, $F = 6.57$, $P = 0.005$, $\eta_p^2 = 0.686$), direction (Wilks' $\Lambda = 0.235$, $F = 48.94$, $P < 0.001$, $\eta_p^2 = 0.765$), and a significant knee angle × direction interaction (Wilks' Λ =

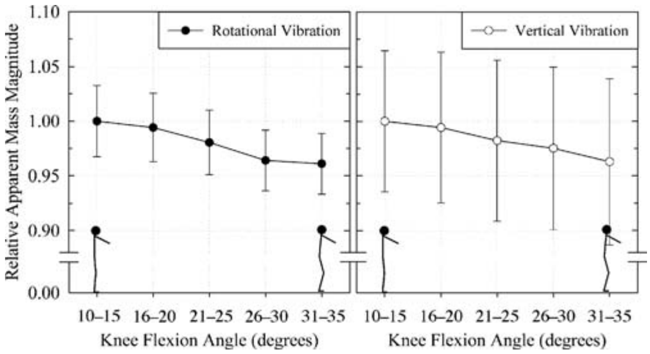

FIGURE 2—Relative apparent mass magnitude (RAMM) variation with respect to knee flexion angle during rotational vibration and vertical vibration. Data are normalized to the maximum RAMM for rotational and vertical vibration. *Stick figures* indicate the squatting position at the smallest and largest knee angles.

0.433, F = 3.93, P = 0.029, η_p^2 = 0.567). Follow-up polynomial contrasts indicate significant quadratic trends in Ha_{rms} data through the range of knee angles during RV (F = 24.43, P < 0.01, η_p^2 = 0.620) and VV (F = 26.34, P < 0.01, η_p^2 = 0.515).

The eVDV calculated for a 10-min daily exposure at 30 Hz and 4-$mm_{p\text{-}p}$ amplitude was significantly greater than 17, the upper limit of the ISO 2631-1 health caution zone, for RV ($t(15)$ = 30.95, P < 0.01) and for VV ($t(15)$ = 14.19, P < 0.01). Figures 4 and 5 show the mean eVDV for each vibration direction calculated for daily exposures between 60 and 1000 s and an FST of 0.05–1.1.

The RMS root sum square accelerations of the RV and VV platforms averaged across all KA were 58.5 and 39.9 $m{\cdot}s^{-2}$, respectively. The difference was attributable in part to the mediolateral component of the RV platform motion. Furthermore, inspection of platform-displacement data revealed that, once loaded, VV amplitude was approximately 0.5 mm (± 0.1 mm) lower than RV amplitude as measured by optoelectronic motion-capture markers attached to each platform. However, in the only direct comparison between the two modalities, Ha_{rms} was significantly greater during VV than during RV. Thus, the difference in vibration magnitudes was not a confounding factor; the only effect may have been to underestimate the size of the difference in Ha_{rms} between VV and RV.

DISCUSSION

To our knowledge, this is the first study to quantitatively evaluate vibration exposure and biodynamic responses during WBVT. The key findings were that, during WBVT with slow dynamic squatting from 10 to 35° KA, 1) RAMM during RV and VV varies inversely with KA, 2) Ha_{rms} is greater during VV than during RV, 3) Ha_{rms} during RV and VV varies inversely with KA, 4) the effect of KA on Ha_{rms} is different for RV and VV, and 5) the eVDV associated with typical RV and VV training regimens (30 Hz, 4 $mm_{p\text{-}p}$, 10 $min{\cdot}d^{-1}$) exceeds the recommended daily whole-body vibration exposure as defined by ISO 2631-1.

Our present findings regarding RAMM and KA are consistent with those of Lafortune et al. (13), who report that a decrease in mechanical impedance was associated with decreased transmission of mechanical energy to the head. We found that WBVT with a knee flexion angle of 10–15° was associated with the greatest RAMM and, thus, the greatest transmission of mechanical energy transmitted to the upper body and head. On the basis of ISO health standards, this suggests that the use of small knee flexion angles during WBVT increases the likelihood of negative side effects and should, therefore, be avoided.

Damping of mechanical energy by the legs is achieved by compliance of ankle, knee, and hip joints, and also by the

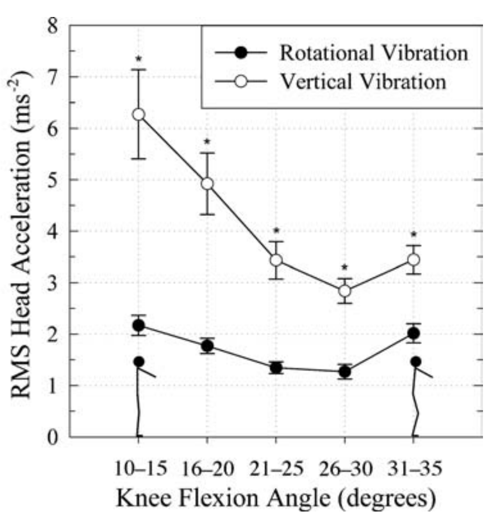

FIGURE 3—Mean ± SE of RMS head acceleration variation with respect to knee flexion angle for rotational vibration and vertical vibration. * VV significantly greater than RV (P ≤ 0.01). *Stick figures* indicate the squatting position at the smallest and largest knee angles.

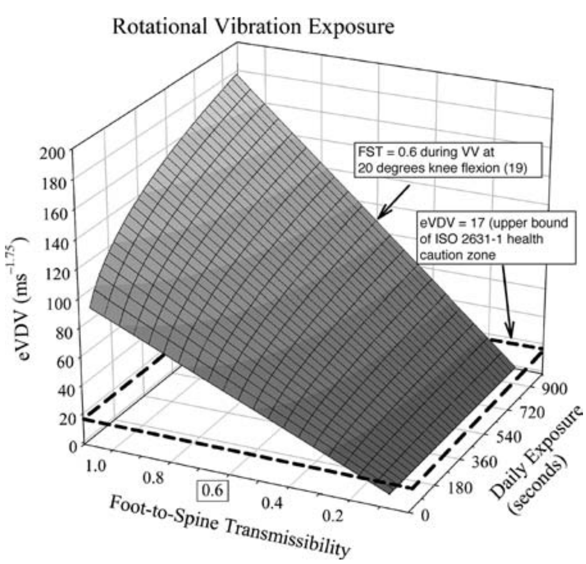

FIGURE 4—Estimated vibration dose value (eVDV) with respect to daily exposure duration and foot-to-spine transmissibility for rotational vibration. The upper limit of the ISO 2631-1 health caution zone is eVDV = 17.

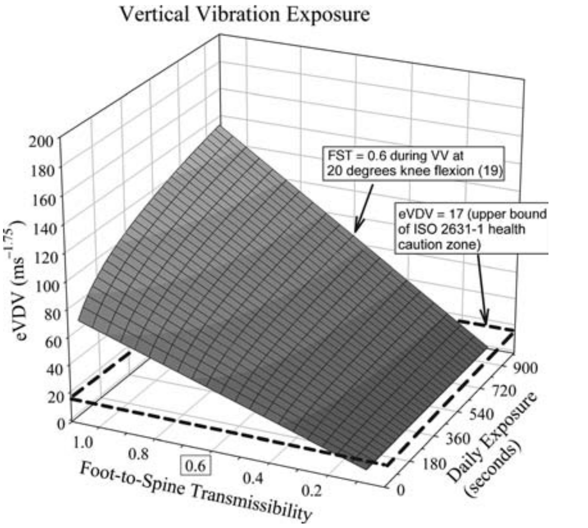

FIGURE 5—Estimated vibration dose value (eVDV) with respect to daily exposure duration and foot-to-spine transmissibility for vertical vibration. The upper limit of the ISO 2631-1 health caution zone is eVDV = 17.

modulation of leg muscle activation in a process known as *muscle tuning* (13,23). Contrary to our hypothesis, the relationship between KA and Ha_{rms} was not linear. Ha_{rms} decreased as KA increased from 10 to 30°. When KA increased beyond 30°, Ha_{rms} also increased, which we interpreted as an indication that the ability of legs to damp mechanical vibration energy decreased when KA was greater than 30°. Whereas the effectiveness of joint compliance in damping mechanical energy increases with KA up to at least 40° (13), we have suggested elsewhere that the contribution of leg muscles to the dissipation of mechanical energy via muscle tuning during WBVT may decrease as KA increases (1). Increased Ha_{rms} above 30° KA might also result from the increased baseline neuromuscular activation affecting joint compliance.

We also found that the transmission of vibration mechanical energy to the upper body and head was 71 to 189% greater during vertical than rotational vibration, which may be attributed to damping of vibration energy by rotation of the pelvis during RV, because of the alternating upward forces being applied to the left and right feet during RV. Others have reported temporary decrements in visual acuity (11) and visual–motor tracking performance (24) during low-magnitude VV ($Pa_{rms} \leq 2.5$ ms^{-2}, 8–80 Hz) while sitting. Reports of torn utricular otolithic membranes, abnormal semicircular canals, and fatal brain hemorrhaging caused by head vibration in monkeys demonstrate the importance of avoiding unnecessary head vibration (9). Our present findings suggest that head vibration during WBVT is minimized by using RV and by squatting with 26–30° KA.

Greater variability was found in Ha_{rms} during VV than in RV; however, decreased variability during VV as Ha_{rms} decreased suggests that this may be the result of a floor effect whereby variability decreases as Ha_{rms} approaches zero. It is possible that a floor effect was also responsible for the larger RAMM variability during VV than in RV, but this cannot be evaluated from our data, because absolute AMM values were not measured.

Some intersubject variability in the vibration magnitude of each platform was observed but could not be explained by body mass or height differences among subjects when examined statistically using RM analysis of covariance ($P >$ 0.05). Although body mass is expected to affect the magnitude of platform vibration, it is likely that intersubject variability in posture, anthropometry, body mass distributions, and possibly other physical characteristics of the human body not measured in this study contributed to the observed intersubject differences in platform vibration magnitude.

We found that the vibration stimulus in both VV and RV exceeded ISO 2631-1 health guidelines; however, because subjects experienced WBVT during standing rather than sitting, these values are overestimates of the true vibration dose values to which the upper body was exposed. To account for posture, we calculated eVDV for RV and VV for FST values between 0.05 and 1.10. This range was chosen on the basis of what others have reported (19). We relied on the literature because we were unable to accurately quantify spine acceleration, because of the invasive nature of this measurement. Rubin et al. (19) measured FST by surgically implanting pins into the greater trochanter and into the spinous process of the L4 vertebrae of five human subjects. They report that FST at 30-Hz VV was approximately 0.70 with knees locked and approximately 0.60 with 20° knee flexion. In the present study, VV was associated with a lower vibration total value than RV; however, our findings suggest that VV had a higher FST and, therefore, a higher eVDV.

After adjustment for the ameliorating effect of the legs, the ISO health guidelines' upper limit for eVDV was still exceeded during 10 min of RV or VV when FST was greater than 0.10. This evaluation of WBVT according to ISO 2631-1 represents the first quantification of the potential for regular WBVT protocols to cause harm, and it demonstrates the need for caution and prescreening when using WBVT for the intended improvement of health or performance. ISO health guidelines on WBV exposure were developed to assess the chronic exposure of healthy individuals to vibration on a daily basis. Thus, this comparison may not be useful for assessing the adverse health effects from infrequent WBVT. Furthermore, biodynamic responses to WBV are likely to change as subjects become fatigued; this was not measured in the present study because the protocol was designed to minimize subjects' vibration exposure. For the purposes of comparison between vibration directions, fatigue was also minimized by exposing subjects to short durations, and any possible confounding fatigue effect was controlled for by balancing the order in which subjects experienced each vibration direction.

This study investigated vibration exposure and biodynamic responses only at 4-mm$_{p\text{-}p}$ amplitude and 30-Hz frequency, and these results cannot be assumed to generalize to other frequencies and amplitudes. Both platforms can be operated at different frequencies (RV: 5–30 Hz; VV: 30–50 Hz) and at different vibration amplitudes (RV: 1–14 $mm_{p\text{-}p}$; VV: 2 or 4 $mm_{p\text{-}p}$). Although we have found that RV may pose less health risk than VV at 30 Hz and 4 $mm_{p\text{-}p}$, it is possible that RV may pose the greater health risk when the feet are positioned further from the axis or rotation, which would result in vibration amplitudes of up to 14 $mm_{p\text{-}p}$. Future research in the area of WBVT should attempt to develop a new standard for the assessment of the adverse health effects associated with intermittent use of WBVT as a treatment or rehabilitation modality.

In summary, the least hazardous WBVT protocols are theoretically those involving low mechanical impedance, low head acceleration, and low eVDV, although such conditions are not necessarily the most effective in terms of inducing the desired training outcome. Our key finding was that short-duration exposures to rotational vibration at small knee flexion angles (26–30°) have the lowest risk of negative side effects on the basis of head acceleration and mechanical impedance. WBVT health risk cannot be accurately calculated using ISO health standards, because of the intermittent nature of WBVT as a treatment modality. More research is needed to develop a new method of assessing negative side effects when the WBV is intermittent.

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Medical Vibration Therapy in Osteopenic patients with Galileo900/2000

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Probably due to lack of standardization, there is no consistency regarding the effect of whole body vibration (WBV) on bone mass. We invited 37 consecutive patients with osteopenia (t -1,0) to enter a study on the effects, efficacy and safety of WBV once a week (32 Hz. during 9 minutes). 35 patients completed the study. The increase in BMD of the femoral neck was about 4% in two years and the increase of the BMD of the lumbar spine was about 2.5% in two years. One half of the patients were suppleted with calcium and vitamin D; this suppletion had no extra effect on BMD. The acceptance for WBV was sufficient (compliance 90% and was without any adverse events).

Group I (n=19 (13 F / 6 M)

Age: 61 yrs ± 7

10 post menopausal

WBV on Galileo2000

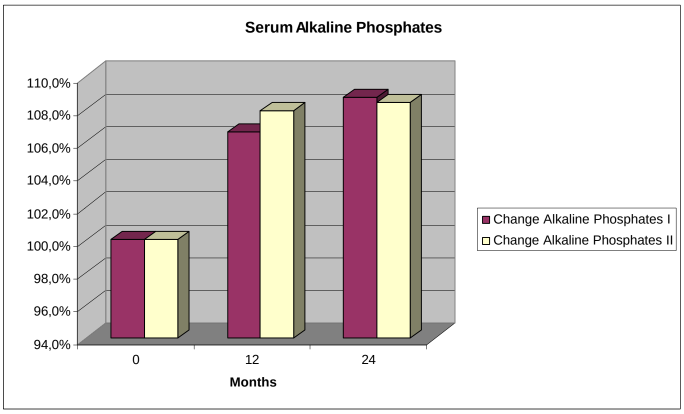
1x/week: 3 x 3 min @16 Hz

Group II (n=18 (13 F / 5 M)

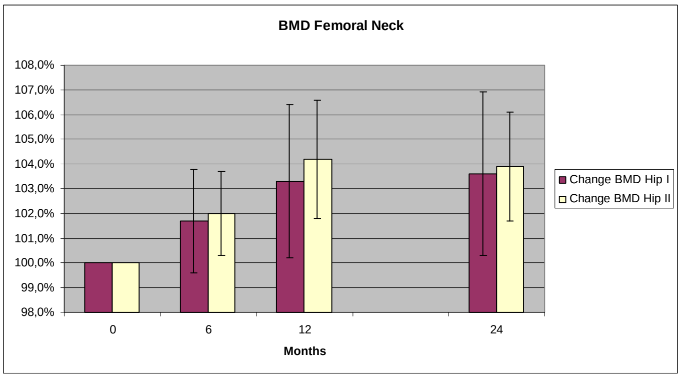
Age: 64 yrs ± 5

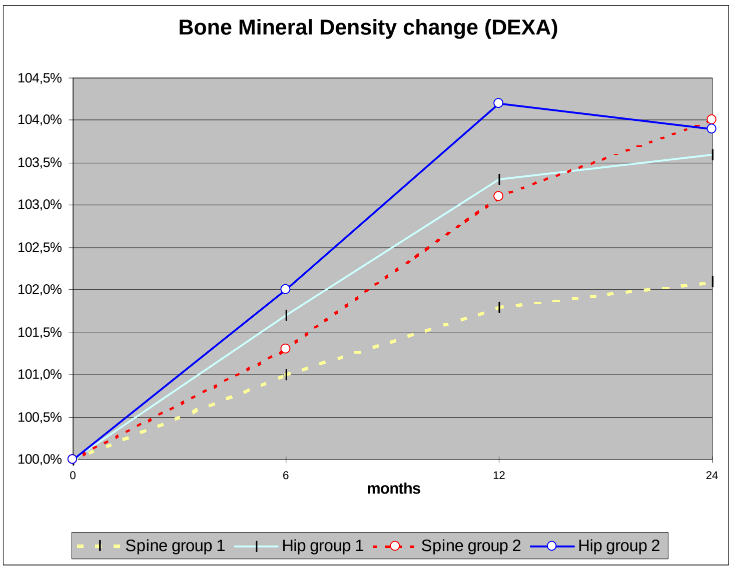
8 post menopausal

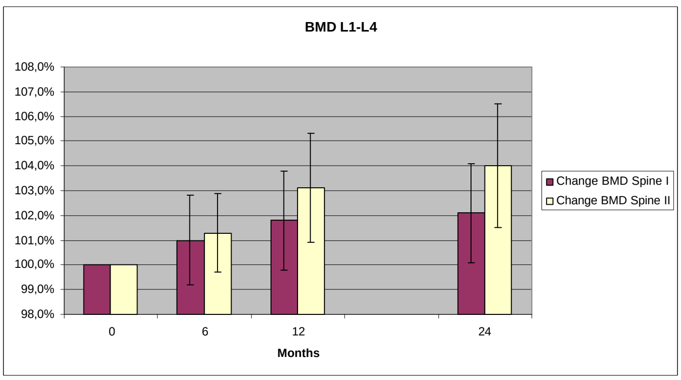
- WBV on Galileo2000
- 1x/week: 3 x 3 min @16 Hz
- Vitamin D 400 I.U. / day
- Calcium 500 mg / day



Dual Energy X-Ray Absorptiometry (DEXA)
At 0 – 6 – 12 and 24 months







"Whole body vibration" training in sports and rehabilitation; the scientifical status quo

On 30 october 2004 the Catholic University of Leuven (Belgium) organized a symposium with the title (translated) "Whole Body Vibration" training in sports and rehabilitation; the scientifical status quo. After a preface the effects of the Leuven studies were presented. The principles, possibilities, and effects of other systems, like the Galileo, have not been reviewed.

Below is a first abstract, with comparance to Galileo studies. Why comparing with the Galileo ? The Galileo was the first "Whole Body Vibration" training and rehabilitation machine in the market. The world patented tilting principle, frequency settings (from 5 up to 30 Hz), and variable amplitudes (from 0 up to over 13 mm) of the Galileo **offer possibilities and have training and therapeutical applications and effects that differ essentially from what are called the "vertical vibration plates".** This vertical principle, firstly brought into the market under the name "Nemes", has become famous under the branche name "Powerplate". The "Powerplate" works with another movement and stimulation principle, other frequencies (30, 35, 40 and 50 Hz), and less variable amplitude (2 or 4 mm*). It is interesting to know for what reasons people have decided to produce this vertical vibrating machine with another principle, and wether or not this new system will offer the same possibilities and effects compared to the Galileo tilting principle.

* published scientific articles show that the amplitudes noted by the manufacturer are not correct.

The effect of Galileo training versus Powerplate training on sport performance

In short: several long term studies exist where the effects of WBV training application into a sports program on sports specific and functional performances, like jump height, 30 meter sprint time, and time of a slalom run are studied. **Applicating Powerplate training in a sports program did not induce better results. After Galileo application significant improvements are found for sports specific performances.**

Study University Leuven, Belgium (PowerPlate)	Study University Marburg, Germany (Galileo)
- competitive track sprinters (athletics, Belgie) - WBV inserted into the training - frequency 35-40 Hz - 6 weeks, 3 x per week - No change in performance after 6 weeks. No difference compared to control group (training without PP). Measured are isometric, dynamic force during knee extension and flexion, movement speed of knee extension, counter movement jump, starting time, starting speed, accelleration in 40m sprint. (presented during symposium 31 october 2004, univ. Leuven)	- first division Rugby players (Germany) - WBV group: 5 x 3 minutes x slow squat on Galileo with extra weight (progressive from 30 up to 70% 1RM in different sessions), pause = 2 minutes /// Control group 5 x 12 Reps explosive power squat x 70% 1RM, pause = 2 minutes - frequency 20 Hz - 6 weeks, 3 x per week - Maximal force (1RM) in both groups up approx. 10%. Significant bigger improvement in WBV group compared to control group in 30m sprint, counter movement jump and slalom run. (published in "Leistungssport" no. 4, 2003)

CONCLUSIONS:

	POWERPLATE	versus	GALILEO
> PP within program **did not alter** performance Galileo within program **improved performance significantly**	**no change**	**vs**	**improved**
> used frequency in Powerplate study versus frequency in Galileo study**:**	**35-40 Hz**	**vs**	**20 Hz**

> Programs equal in length (6 weeks) and occurrence (3 x per week).

Other long term effect-studies (Harbrecht, 2002):

> Harbrecht studied the effects of implementing Galileo training within Volleybal training (Olympic Center Berlin, youth teams 19-20 years old)

> The last 3 year groups are compared (because of publication not all data were shown). The Galileo training was implemented by 5 to 10 minutes x 3 times per week. Weights for weight training dropped from 50-70 kg to 20 kg.

> mean length and weight of the different groups were comparable (Control - Control - WBV group: 184 - 182 - 183 cm / weight: 72 - 69 - 71 kg).

> Results after 24 weeks:

- jump height increased 4 to 11 cm in WBV group

- jump height was 4 to 8 cm more compared to control groups

- **athletes had less physical complaints and were able to play faster and more stabil, and were better coordinated. They also were able to play at high level for a longer time.**

Galileo training is more effective compared to Powerplate in lowering Osteoporosis

In short: 9 studies are known in which the effects of WBV on bone quality are compared in people. 6 of those studies are done with a Galileo. Well comparable studies are the Leuven study (Powerplate) and the Rotterdam Research Center study (Galileo). A much shorter Galileo program lead to more improvement in hip bone density compared to PP program. In the lumbal area the Galileo training was the only one to improve bone density.

Study University Leuven, Belgium (PowerPlate)	**Study Rotterdam Research Center, Netherlands (Galileo)**
- postmenopausal women	- postmenopausal women
- 24 weeks, **3 x per week**	- 6 months, **1 x per week**
- progressive build-up of program, **up to 30 minutes training time**.	- fixed program, **12 minutes total training** time
- frequency build-up from 35 to 40 Hz	- frequency fixed 16 Hz
RESULTS after 6 months:	RESULTS after 6 months - 12 months - 24 months
- bone density HIP + 0,93%	- bone density HIP + 1,7% - + 3,3% - + 3,6%
- bone density LUMBAL no significant change	- bone density LUMBAL + 1,0% - + 1,8% - + 2,1%
- no change in markers of bone remodeling in serum	- bone markers not measured - + 6,0% - + 8,2%

CONCLUSIONS:	POWERPLATE	versus	GALILEO
> the PowerPlate program **was much more extensive** compared to Galileo**:**	**90 minutes per week**	**vs**	**12 minutes per week**
> the frequency used in the Powerplate study was much higher compared to Galileo**:**	**35-40 Hz**	**vs**	**16 Hz**
> Effects on bone density HIP**:**	**+ 0,93%**	**vs**	**+ 1,7%**
> Effects on **bone density LUMBAL:**	**no change**	**vs**	**+ 1,0%**

Galileo training versus PowerPlate training in lowering Low Back Pain

In short: **a shorter Galileo program lead to a bigger lowering in LBP compared to the Powerplate program**. Balance did not improve in PP training and was even worse in the healthy group. After Galileo training balance improves significantly (15,7% after 1 session, Torvinen 2002). Galileo training did not induce problems in the training group, in the PP group one person had to quit because of severe complaints in the neck region (according to the researchers plausible as a consequence of PP training).

Study University Leuven, Belgium (PowerPlate)	Study University Berlin, Germany (Galileo)
- 6 weeks, 2 x per week	- 6 weeks 2 x per week, thereafter 6 weeks 1 x per week
- WBV group build-up to 30 minutes, 14 exercises	- control group Lumbar extension, WBV group Galileo training build-up 4 to 7 minutes.
- frequency build-up from 35 to 40 Hz	- frequency 18 Hz, amplitude 6 mm (1e 3 sessions build-up), in the proceeding of the training up to 5 kg extra weight was added.
- pain decreased from about 1,4 to 0,9* (VAS score, O-10) * scores deduced from graphics	- pain decreased comparable in both groups (after 6 weeks VAS score went from 4 to 2).
- force in hamstrings and quadriceps muscles do not change, back muscle endurance increased.	- Lumbal extension force improved in both groups
NOTE:	

> 1 fall out because of severe neck complaints > no improvement in postural balance, lowering of balance in healthy group	> **previous studies with the Galileo (Torvinen 2002) show an improvement in balance after Galileo training (and no improvement in balance after training on a vertical vibrating plate)**

CONCLUSIONS:	**POWERPLATE**	**versus**	**GALILEO**
> the PP program was **much more extensive** compared to Galileo, up to	**30 minutes**	**vs**	**7 minutes**
> The frequency used in the Powerplate study was much higher compared to Galileo	**35-40 Hz**	**vs**	**18 Hz**
> The **decrease in pain in the Powerplate study is much lower** compared to Galileo	**35% lowering**	**vs**	**50% lowering**

The University of Leuven symposium;

Surely not an overview of the scientific status quo in Whole Body Vibration training

Is the public mislead deliberately or undeliberately ?

Much has to be investigated in order to elucidate scientific knowledge and development in Whole Body Vibration as a training or rehabilitation tool. More than 130 studies - of which half published - are known. Comparing studies is hard because of differing protocols, statistics, and populations. In dispite, some comparable effects can be deduced. Over 40 universities and even more training and therapeutical research centers concentrate on the subject. For optimal development of knowledge it is crucial that knowledge is brought in the open, and scientists study other studies. This way new studies can be started more intelligently and thus more effectively.

During the symposium in Leuven it appeared that the researchers were not interested in elaborating on other studies and principles than their own. All research objectives the university of Leuven has focussed on have been performed by other researchers, and their publications can easily be found. During the presentations it was not allowed for those who do know all of these studies to ask questions - although there was room for questions after every presentation - because according to the presenters this was disturbing the vision of the public. Surely this was pittyful, because now the public was restraind of other essential information on the subjects and - worse - some errors could not be corrected. In a reaction the university noted that if others wanted to present their studies, they should organize their own symposium. This seems strange for a symposium with the title: "a scientific status quo of Whole Body Vibration".

In the pause the public - mostly people interested in buying a WBV machine - was able to try the 'new' Powerplate. This is strange because the studies were mostly performed on the 'old' Powerplate, that now is sold under another branche name. Stranger was the fact that it was not allowed to present and try out other principles like the Galileo.

Variation in Neuromuscular Responses during Acute Whole-Body Vibration Exercise

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[1]Wyle Laboratories, Inc., Houston, TX; [2]Human Performance Laboratory, University of Houston, Clear Lake, TX; [3]Laboratory of Integrated Physiology, University of Houston, TX; [4]Department of Physical Therapy, Hardin-Simmons University, Abilene, TX; and [5]Human Adaptations and Countermeasures Division, National Aeronautics and Space Administration, Houston, TX

ABSTRACT

ABERCROMBY, A. F. J., W. E. AMONETTE, C. S. LAYNE, B. K. MCFARLIN, M. R. HINMAN, and W. H. PALOSKI. Variation in Neuromuscular Responses during Acute Whole-Body Vibration Exercise. *Med. Sci. Sports Exerc.*, Vol. 39, No. 9, pp. 1642–1650, 2007. **Purpose:** Leg muscle strength and power are increased after whole-body vibration (WBV) exercise. These effects may result from increased neuromuscular activation during WBV; however, previous studies of neuromuscular responses during WBV have not accounted for motion artifact. **Methods:** Sixteen healthy adults performed a series of static and dynamic unloaded squats with and without two different directions of WBV (rotational vibration, RV; and vertical vibration, VV; 30 Hz; 4 mm_{p-p}). Activation of unilateral vastus lateralis, biceps femoris, gastrocnemius, and tibialis anterior was recorded using EMG. During RV and VV, increases in EMG relative to baseline were compared over a range of knee angles, contraction types (concentric, eccentric, isometric), and squatting types (static, dynamic). **Results:** After removing large, vibration-induced artifacts from EMG data using digital band-stop filters, neuromuscular activation of all four muscles increased significantly ($P \leq 0.05$) during RV and VV. Average responses of the extensors were significantly greater during RV than VV, whereas responses of the tibialis anterior were significantly greater during VV than RV. For all four muscles, responses during static squatting were greater than or equal to responses during dynamic squatting, whereas responses during eccentric contractions were equal to or smaller than responses during concentric and isometric contractions. Neuromuscular responses of vastus lateralis, gastrocnemius, and tibialis anterior were affected by knee angle, with greatest responses at small knee angles. **Conclusions:** Motion artifacts should be removed from EMG data collected during WBV. We propose that neuromuscular responses during WBV may be modulated by leg muscle cocontraction as a postural control strategy and/or muscle tuning by the CNS intended to minimize soft-tissue vibration. **Key Words:** ELECTROMYOGRAPHY, POSTURE, STRENGTH, DAMPING, REFLEX

Whole-body vibration exercise (WBV) may enhance muscle strength adaptations associated with traditional neuromuscular training or rehabilitation (7,21). The potentially beneficial effects of WBV are caused by the transmission of mechanical, sinusoidal vibrations throughout the body via the feet. Isometric leg extensor strength has been reported to increase by 3.2% at 2 min after a single 4-min WBV session, returning to baseline strength levels 60 min later (23). Chronic exposure to WBV (three sessions per week, for 2–6 months) has been reported to elicit increases in isometric (16.6%, 24.4%) and isokinetic (8.3%, 9.0% at 100 = Is_{j1}) knee extensor strength similar to those observed after moderate-intensity resistance training programs (dynamic leg-press and leg-extension exercises (10–20 RM, 3× wk^{-1}) of the same duration and frequency (12,19).

Others have speculated that increased muscle strength and power after WBV results from increased neuromuscular activation during WBV, which subsequently induces adaptations similar to resistance training (1,4,5,12). Specifically, it has been suggested that Ia-afferent–mediated myotatic reflex contractions may partially explain the increases in leg extensor strength after WBV (12,18,21). Applying a vibration stimulus directly to a muscle or muscle tendon stimulates Ia-afferents, inducing a myotatic reflex contraction referred to as the tonic vibration reflex (TVR) (6,14,20). Measurement of TVR and neuromuscular activation is complicated by the common presence of artifacts in EMG data, which result from electrode/cable motion and nearby electrical noise. It is not known whether WBV elicits TVR; however, if neuromuscular responses to WBV are modulated by Ia-afferents, then the magnitude of muscle activation during WBV should be influenced by Ia-afferent

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sensitivity. Changes in relaxed muscle length alter intrafusal fiber tension and, thus, Ia-afferent sensitivity, such that tension increases in a lengthening muscle and decreases in a shortening muscle (15,17,27). The amount of muscle stretch and, thus, the amount of Ia-afferent stimulation, induced during each cycle of vibration may also increase as knee angle increases (2). We hypothesized that the changes in muscle length voluntarily induced during dynamic squatting would alter intrafusal fiber tension and Ia sensitivity such that responses to WBV would be greater in magnitude during eccentric contractions than during isometric and concentric contractions. We also hypothesized that greater knee joint compliance at larger knee angles would result in greater transient muscle stretch during each vibration cycle, and that the increased Ia-afferent stimulation would result in greater responses at larger knee angles.

A novel aspect of the present study is that we included a filtering procedure to remove vibration artifacts from within our EMG data to prevent misinterpretation of neuromuscular responses to WBV. A second unique aspect of the present study is that we examined a number of different parameters in an effort to identify optimal conditions, which maximize neuromuscular responses to WBV. We hypothesized that, for the vastus lateralis, biceps femoris, gastrocnemius, and tibialis anterior muscles, 1) neuromuscular activation (EMGrms) would increase significantly during two different directions of WBV; 2) EMGrms enhancement during two different directions of WBV would differ significantly among isometric, concentric, and eccentric muscle contraction types, with responses being greatest during eccentric contractions and smallest during concentric contractions; 3) EMGrms enhancement during two different directions of WBV would differ significantly during static and dynamic squatting exercises; 4) EMGrms enhancement during two different directions of WBV would increase significantly with increases in knee angle; and 5) vibration direction would not significantly affect the responses to WBV in hypotheses 1–4. The purpose of this study was to quantify the effects of postural variation and vibration direction on neuromuscular responses to WBV after removing EMG artifacts by digital filtering.

METHODS

Approach to the problem and experimental design. A single-group repeated-measures study design was employed in which the neuromuscular activation (EMGrms) of four leg muscles were the dependent variables. The independent variables were vibration (WBV vs baseline), contraction type (eccentric vs concentric vs isometric), knee angle (10–15, 16–20, 21–25, 26–30, and 31–35°), and vibration direction (rotational vibration, RV; and vertical vibration, VV). The study design was fully crossed, with the exception of the isometric contraction conditions, which were performed only at knee angles of approximately 16–20° during WBV and baseline conditions. For analysis purposes, exercise type (static vs dynamic squatting) was also included as an independent variable; for each vibration direction during baseline and vibration conditions, responses during dynamic squatting were calculated as the average responses during eccentric and concentric contractions at all knee angles, whereas responses during static squatting were identical to those during the isometric condition.

Subjects and study design. Nine male (32.7 ± 7.0 yr; 177.8 ± 2.8 cm; 85.8 ± 7.9 kg) and seven female (32.7 ± 8.3 yr; 164.7 ± 7.8 cm; 67.2 ± 11.3 kg) subjects were recruited through the NASA–Johnson Space Center human test subject facility. All subjects passed an Air Force Class III physical and were screened for contraindications to WBV exposure. Exclusion criteria included a history of back pain, acute inflammations in the pelvis and/or lower extremity, acute thrombosis, bone tumors, fresh fracture, fresh implants, gallstones, kidney or bladder stones, any disease of the spine, peripheral vascular disease, or pregnancy. Written informed consent was obtained for each subject, and all procedures were approved by the institutional review boards at NASA–Johnson Space Center and at the University of Houston.

Vibration conditions. Subjects were exposed to WBV at 30 Hz and 4-mm peak-to-peak (4-mm_{p-p}) amplitude using a Power Plate (Power Plate North America LLC, Culver City, CA) and a prototype Galileo 2000 (Orthometrix, Inc., White Plains, NY) WBV platform. The Power Plate platform (VV) vibrates in a predominantly vertical direction with 4-mm_{p-p} amplitude. The Galileo 2000 (RV) rotates about an anteroposterior horizontal axis such that positioning the feet farther from the axis of rotation results in larger-amplitude vibration. In addition to the mediolateral component of the vibration force, RV also differs from VV because of the asynchronous nature of the RV, whereby unilateral force is applied alternately to the left and right foot. The result is an asymmetric perturbation of the legs during RV exposure. Conversely, the VV platform translates vertically under both feet at the same time, which results in simultaneous and symmetrical movement of both sides of the body during VV exposure. In this study, VV was applied with 4-mm_{p-p} amplitude at 30 Hz with the subjects' feet 20.6 cm apart. During RV at 30 Hz, subjects' feet were in the anatomical position, 10.3 cm from the axis of rotation corresponding to vibration amplitude of 4-mm_{p-p} and a distance of 20.6 cm between left and right feet. The appropriate toe and heel positions were marked on each platform to ensure consistency of foot position and orientation between platforms and among trials. During testing sessions, subjects wore the same type of sports socks to standardize any damping of vibration attributable to footwear. Subjects did not wear shoes during testing. To minimize unwanted foot movement during vibration, fine-grade sandpaper with adhesive backing was attached to the vibration platforms, which improved traction between the subjects' socks and the platform.

Postural conditions. After instrumentation, a test operator demonstrated the slow dynamic squatting movement

APPLIED SCIENCES

and the static squatting posture to be performed with and without vibration during the testing protocol. A) *Dynamic squat*: starting from an upright posture with approximately 5° knee flexion, subjects slowly squatted until approximately 40° of knee flexion was achieved. After holding the 40° knee flexion posture for 2 s, subjects slowly returned to the starting posture. To control the angular velocity of the flexion and extension movements, a test operator used a metronome at 60 bpm concurrently with verbal commands, such that both the flexion and extension phases of movement each lasted 4 s with a 2-s pause between phases. The limited range of knee flexion angles was chosen to allow unsupported squatting during WBV without inducing loss of stability. B) *Static squat*: subjects stood with an upright posture while maintaining 20° knee flexion. A test operator instructed subjects on achieving 20° knee flexion. Subsequent analysis of kinematic data indicated that the average knee angle actually achieved during the static condition was 18.5 ± 3.0°.

Before commencing data collection, test operators instructed subjects on the appropriate foot placement on each platform as described above. Subjects were given the following instructions to be followed during all data-collection trials: stand with head and eyes forward; stand with equal weight on each foot; stand with weight distributed over the whole of each foot; stand with arms outstretched with palms facing down; and do not touch the handrail during data collection unless support is required.

The squat movement and postural instructions were practiced with and without vibration before data collection, until a consistently smooth movement was achieved. During this process, subjects were exposed to more no than approximately 30 s of each vibration condition before data collection. All conditions were performed twice, and the average EMG and acceleration values were calculated for each condition. Trials were repeated if subjects touched the handrail or if their feet moved noticeably from the required positions.

Baseline (nonvibration; BL) trials preceded each vibration trial. The order in which the vibration platforms were presented and the order of static and dynamic trials were balanced among all subjects to control for any possible confounding effects of muscular fatigue or adaptation to the WBV.

Safety and fatigue. In consideration of the possible effects of fatigue, the duration of each trial was limited to no longer than 15 s in length, with a cumulative WBV exposure for each subject of less than 3 min during a 90-min protocol. Each vibration trial was separated by at least 1 min. Throughout the testing protocol, subjects were asked to rate their perceived exertion using Borg's 20-point rating of perceived exertion scale (3). No subjects reported exertion as being *somewhat hard* (13 on the 6–20 scale) or greater. During and after the testing protocol, subjects were instructed to report any discomfort to the test operators or the responsible physician at the human test subject facility. During testing, one subject experienced itchiness in both feet because of mild erythema. Symptoms were relieved quickly after the subject walked around the laboratory, and no other adverse effects were reported during or after testing. After symptoms resolved, the protocol continued without incident, and the subject's data were included in the analysis.

Knee flexion angles. Unilateral position data from the lateral malleolus, fibular head, and greater trochanter were recorded using an optoelectronic motion-analysis system (Optotrak 3020, Northern Digital, Inc., Waterloo, Canada). Position data were sampled at 400 Hz using NDI Toolbench software. The Optotrak camera unit was positioned to view subjects in the sagittal plane. Knee angles were calculated using the angle between ankle, knee, and hip kinematic markers in the saggital plane. Small oscillations in calculated knee angles during each vibration cycle were not interpreted because of the potentially confounding effect of vibration of the soft tissues to which position markers were attached. Data from all trials were visually inspected. Because some subjects did not squat to fully 40°, only data from knee angles between 10° and 35° were analyzed. All data from static (18.5°) trials were analyzed. In the subsequent interpretation of results, knee-ankle flexion was interpreted as eccentric contraction of the vastus lateralis and gastrocnemius and concentric contraction of biceps femoris and tibialis anterior, whereas knee-ankle extension was associated with concentric contraction of the vastus lateralis and gastrocnemius and eccentric contraction of the biceps femoris and tibialis anterior. Muscle contractions were considered isometric during the static squatting condition.

Neuromuscular activation. Surface EMG was recorded from vastus lateralis, lateral biceps femoris, lateral gastrocnemius, and tibialis anterior in all 16 subjects during all conditions. Bipolar bar electrodes (99.9% Ag, 10-mm length × 1-mm width, 10-mm spacing; CMRR: > 80 dB; model DE2.1, DelSys, Inc., Boston, MA) were applied to lightly abraded, washed skin over the respective muscle belly, parallel to the pennation angle. A ground electrode was placed over the tibial tuberosity. EMG electrodes and cables were secured to subjects' skin with medical tape. Signals were amplified (1000×), filtered (20–450 Hz band pass; Bagnoli-8, DelSys, Inc., Boston, MA), and sampled at 2000 Hz synchronously with kinematic data, using a 16-bit Optotrak Data Acquisition Unit II and NDI Toolbench software (Northern Digital, Inc., Waterloo, Canada).

Data processing was performed using MATLAB version 7.0 (The Mathworks, Inc., Natick, MA). Spectral analysis of EMG data was performed by dividing each signal into overlapping segments, which were then windowed using a 1024-sample Hanning window. Short-term frequency content of each segment was computed using a 4096-sample fast Fourier transform (FFT) with sections overlapping by 1000 samples. Inspection of resulting spectrograms from each muscle indicated the presence of significant motion artifacts not only at the fundamental excitation frequency (30 Hz) but also, to a lesser degree, at integer multiples of the excitation frequency. The excessive EMG signal power at these frequencies is attributable to vibration of the EMG electrodes and cables at the excitation frequency and at the associated harmonic frequencies. When the signal power at each frequency was averaged across an entire trial, it was evident that the magnitude of the signal at the excitation and harmonic frequencies greatly exceeded the signal power at all other frequencies (Fig. 1).

Digital band-stop filters were implemented to eliminate motion artifacts at the exact excitation frequency of each platform and also at integer multiples of the excitation frequencies up to 450 Hz, to ensure that all motion artifacts were removed from the EMG signals. Filters were applied to EMG data from all baseline and vibration conditions using direct–form II second-order sections implementation: for N = 1:15, band-stop filters were applied at Nf_v, where f_v is the fundamental vibration frequency; 17th-order Chebyshev type II; stop-band = $(Nf_v) \pm 1$ Hz; $f_{pass1} = (Nf_v) - 1.5$ Hz, $f_{pass2} = (Nf_v) + 1.5$ Hz; minimum 100-dB stop-band attenuation, maximum 0.01-dB pass-band ripple. In addition to the antialiasing filter, a digital band-pass filter was implemented: 20–450 Hz band-pass; 18th-order Chebyshev type II; f_{stop1} = 17 Hz, f_{stop2} = 500 Hz; minimum 60-dB stop-band attenuation; maximum 0.01-dB pass-band ripple.

Motion artifacts caused by harmonic vibration at 60 Hz (at $2f_v$) would coincide with any line interference that may have arisen from nearby electrical equipment and power lines. Comparison of the frequency content of EMG data before and after the filtering procedure indicated that artifacts were successfully removed from EMG signals without excessive loss of overall signal power (Fig. 1).

After filtering, bias was calculated and removed from each EMG signal, after which the data were rectified and the root mean square (EMGrms) was calculated in 100-ms windows around every data point. For each subject, EMGrms of each muscle was then calculated for all levels of the independent variables, thereby quantifying neuromuscular activation under all conditions. Because EMGrms values were being compared with equivalent baseline (no vibration) squatting conditions, normalization relative to maximal voluntary contractions was unnecessary.

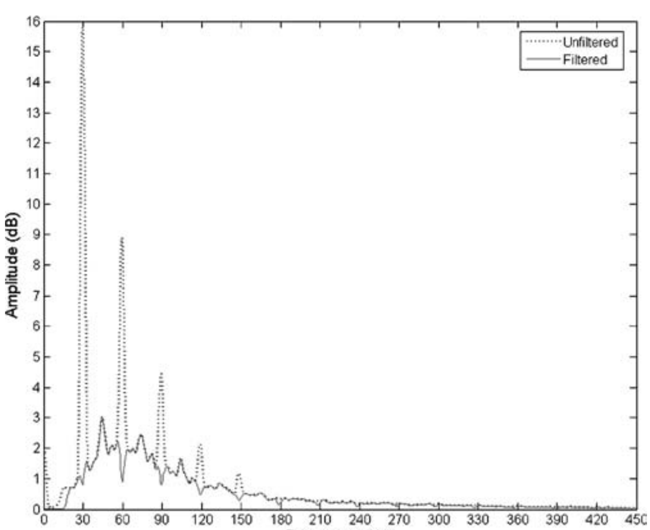

FIGURE 1—Typical mean frequency content of vastus lateralis EMG signal during a VV condition before and after removal of artifacts by filtering with Chebyshev type II band-stop filters. Motion artifacts are apparent in unfiltered data at the excitation frequency (30 Hz) and at the associated harmonic frequencies.

Statistical analysis. The dependent variables in all statistical tests were EMGrms, measured from vastus lateralis, biceps femoris, gastrocnemius, and tibialis anterior. Before statistical analyses, data were examined (probability–probability plot) to evaluate the assumption of normality. A fourth-root transformation was applied to data to decrease skewedness and kurtosis. To correct for violations of the sphericity assumption as indicated by Mauchly's test, the Huynh–Feldt correction was used to adjust the degrees of freedom in the repeated-measures ANOVA. For the tests of hypotheses 1–4, repeated-measures ANOVA were used to test the effects of interest within each vibration direction. In all tests, the vibration main effect and its interactions were evaluated to test the hypotheses, because enhancement of EMGrms above baseline levels was of interest; absolute EMGrms values were not compared among different conditions. The statistical significance of differences in the effects between vibration directions (hypothesis 5) was tested using interactions in repeated-measures ANOVA in which vibration direction (D) was included as a factor.

The average knee angle during isometric conditions was 18.5 ± 3.0°. Therefore, to evaluate the effect of contraction type independently of knee angle, only EMGrms data from eccentric and concentric conditions between 16 and 20° were used in the comparison with the isometric conditions. A 2 × 3 × 2 repeated-measures ANOVA was calculated for each muscle, with vibration (VB), contraction type (CT), and vibration direction (D) as factors with repeated measures. The VB × CT × D interaction was used to evaluate whether the effects of contraction type on neuromuscular responses differed between vibration directions (hypothesis 5). Separate 2 × 3 (VB × CT) repeated-measures ANOVA were used to evaluate the effect of contraction type (VB × CT interaction; hypothesis 2) within each vibration direction. Paired t-tests were used to compare the mean differences between baseline and vibration neuromuscular activation for eccentric, concentric, and isometric conditions during each vibration direction for descriptive purposes.

When comparing the average neuromuscular responses between static and dynamic exercise types (ET; hypothesis 3), data from eccentric and concentric conditions at all knee angles (dynamic squatting) were averaged and compared with data from isometric conditions (static squatting) using 2 × 2 (VB × ET) repeated-measures ANOVA for each vibration direction. Because data from all knee-angle and contraction-type conditions were included, the vibration main effects from the VB × ET repeated-measures ANOVA were used to evaluate whether neuromuscular activation was increased, on average, during WBV on each vibration platform (hypothesis 1). Three-way (VB × ET × D) repeated-measures ANOVA were used to determine whether the effects of vibration and exercise type differed between the two vibration directions (VB × D and VB × ET × D interactions; hypothesis 5).

The role of knee angle (KA) in neuromuscular responses to each vibration direction (hypothesis 4) was assessed using 2 × 5 (VB × KA) repeated-measures ANOVA, using only data from dynamic conditions (10–35°). The VB × KA × D interaction from separate repeated-measures ANOVA compared the effect of knee angle between the two vibration directions (hypothesis 5). After the two-way repeated-measures ANOVA, polynomial contrasts were used to evaluate trends in response variation with respect to knee angle (hypothesis 4). Although not explicitly required by our hypotheses, paired t-tests were used to compare all baseline EMGrms values with the associated EMGrms values measured during vibration, thereby enabling evaluation of neuromuscular responses at each knee angle for all eccentric, concentric, and isometric conditions.

Initially, gender (G) was included as a between-subjects factor in the repeated-measures ANOVA used to test the hypotheses; however, the VB × G interaction and all higher-order interactions involving VB and G were nonsignificant for all muscles. Therefore, male and female data were grouped for further analysis. In all tests, $P \leq 0.05$ was considered significant. Statistical analysis was performed using SPSS 13.0 for Windows (SPSS, Inc., Chicago, IL). For descriptive purposes, percent increases between vibration and baseline conditions were calculated using untransformed data.

RESULTS

Effect of vibration. When averaged over all knee angles and contraction types, neuromuscular activation of all four muscles increased significantly during RV and during VV. The average magnitude of neuromuscular responses differed significantly between the two vibration directions in the vastus lateralis, gastrocnemius, and tibialis anterior, such that average responses of the extensors (vastus lateralis and gastrocnemius) were significantly greater during RV than VV, whereas responses of the tibialis anterior were significantly greater during VV than RV. The percentage increases in untransformed EMGrms associated with the significant VB main effects in all conditions are given in Table 1.

Effect of exercise type. Neuromuscular responses of all four muscles to both vibration directions were greater during static squatting than during dynamic squatting, with only two exceptions: there was no significant difference in response magnitude between static and dynamic squat conditions in the biceps femoris during RV or in the tibialis anterior during VV. The effect of exercise type on responses to vibration differed significantly between platforms in these

TABLE 1. Percent increases above baseline EMGrms during rotational vibration (RV) and vertical vibration (VV) for dynamic (eccentric and concentric combined, all knee angles), static (isometric, 18.5 ± 3.0° knee angle), eccentric (16–20° knee angle), and concentric (16–20° knee angle) conditions.

	Percent EMGrms Increase Above Baseline							
	Dynamic		Static (Isometric)		Eccentric		Concentric	
Muscle	RV	VV	RV	VV	RV	VV	RV	VV
Vastus lateralis	26	NS	103	77	26	30	26	NS
Biceps femoris	30	NS	10	9	NS	NS	48	NS
Gastrocnemius	106	34	151	132	123	40	89	29
Tibialis anterior	57	145	328	223	50	28	63	261

NS, no statistically significant difference from baseline.

two muscles. The only muscle in which neuromuscular responses were greater during VV than during RV was the tibialis anterior, though only during dynamic squatting. Dynamic and static responses were greater during RV than VV in all other instances, with the exception of static squatting responses in the biceps femoris and gastrocnemius, which did not significantly differ between RV and VV.

Effect of contraction type. Neuromuscular responses of all four muscles to both vibration directions were significantly affected by contraction type, with only two exceptions: responses of the biceps femoris and gastrocnemius were not significantly affected by contraction type during RV. When knee angles were between 16 and 20°, neuromuscular responses in isometrically contracting muscles were significantly greater than responses in muscles that were contracting eccentrically or concentrically. The only two exceptions were the tibialis anterior during VV and the biceps femoris during RV, where responses during concentric contractions were greater than static and eccentric responses. The vibration × contraction-type effect differed significantly between platforms only in the vastus lateralis and the tibialis anterior. The filtered untransformed EMGrms for each muscle under all conditions including isometric contractions are shown as means ± standard error in Figures 2–5.

Effect of knee angle. Neuromuscular responses of the vastus lateralis, gastrocnemius, tibialis anterior, but not biceps femoris, were significantly affected by changes in knee angle during both vibration directions. Significant within-subjects linear contrasts confirmed that, contrary to our hypothesis, the magnitude of neuromuscular responses above baseline was greatest at small knee flexion angles for vastus lateralis, gastrocnemius, and tibialis anterior, and that response magnitudes decreased as knee angle increased. Responses of the biceps femoris to either direction of vibration were not significantly affected by changes in knee angle. The effect of knee angle on neuromuscular response magnitudes differed significantly between RV and VV only in the tibialis anterior, which reflects the noticeably different responses of the tibialis anterior to RV and VV, particularly when considered over the full range of concentric contractions (Fig. 5). The asterisks in Figures 2–5 indicate the specific conditions in which neuromuscular activation was significantly increased above baseline.

DISCUSSION

To our knowledge, this is the first study to determine the effects of static and dynamic squatting, muscle contraction type (eccentric, concentric, isometric), vibration direction (RV, VV), and motion artifact removal on measured neuromuscular responses to WBV in the same group of subjects. The key findings were that 1) motion artifacts must be removed from EMG data collected during WBV at the excitation frequency and also at the associated harmonic frequencies; 2) neuromuscular activation (EMGrms) of vastus lateralis, biceps femoris, gastrocnemius, and tibialis anterior increased significantly during RV and VV; 3) EMGrms enhancement during RV and VV differed significantly among isometric, concentric, and eccentric muscle contraction types, with most responses being greatest during isometric contractions; 4) EMGrms enhancement during RV and VV was significantly greater during static squatting than during dynamic squatting exercises in most instances; 5) EMGrms enhancement during RV and VV differed significantly with changes in knee angle; and 6) vibration direction significantly affected EMGrms enhancement during WBV.

Spectral analysis of our unfiltered data reveals large EMG artifacts during WBV, which is contrary to reports in the literature that anchoring of EMG cables and electrodes will prevent motion artifacts (8). Despite securing EMG electrodes and cables during data collection, the localized peaks in signal power in unfiltered EMG data at 30 Hz and integer multiples thereof (Fig. 1) indicates the presence of motion artifacts caused by vibration of the EMG electrodes and cables. Although the signal power at the excitation and harmonic frequencies also reflect actual motor-unit firing, the signal power of the true EMG signal is not expected to be significantly greater at these frequencies compared with adjacent frequencies, because the power at any given frequency is a function of action potential–conduction velocity and not motor unit–firing frequency. Thus, to the extent that action potentials are being conducted within a muscle at the velocities associated with the vibration and harmonic frequencies, the application of band-stop filters will result in an underestimation of the true magnitude of the neuromuscular responses to WBV. However, if band-stop filters are not applied, then motion artifacts will cause an overestimation of muscle activation during WBV but not during baseline conditions. The more conservative approach of applying digital band-stop filters allows the assertion that increases in EMG reflect true increases in neuromuscular activation.

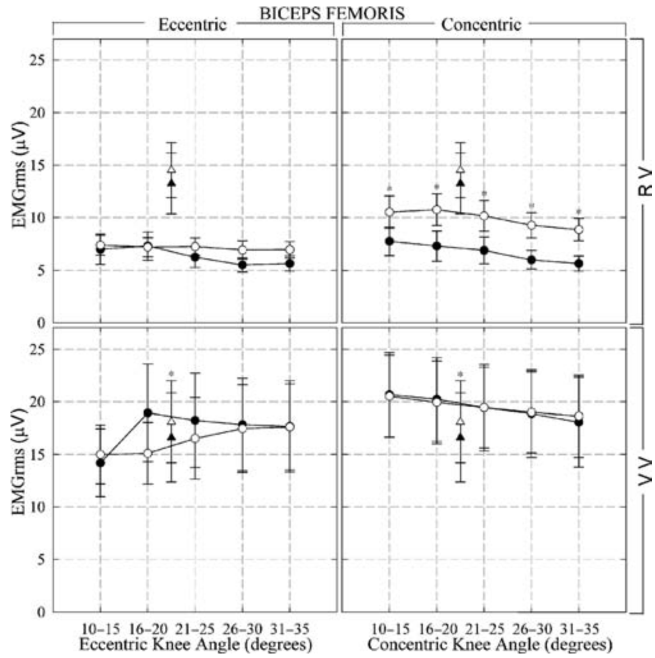

FIGURE 3—Mean ± SE of filtered, untransformed EMGrms for eccentric, concentric, and isometric contractions of biceps femoris during RV and VV compared with no vibration (baseline). ● Concentric/eccentric baseline; ○ concentric/eccentric vibration; ▲ isometric baseline; △ isometric vibration. * Vibration significantly greater than at baseline ($P \leq 0.05$).

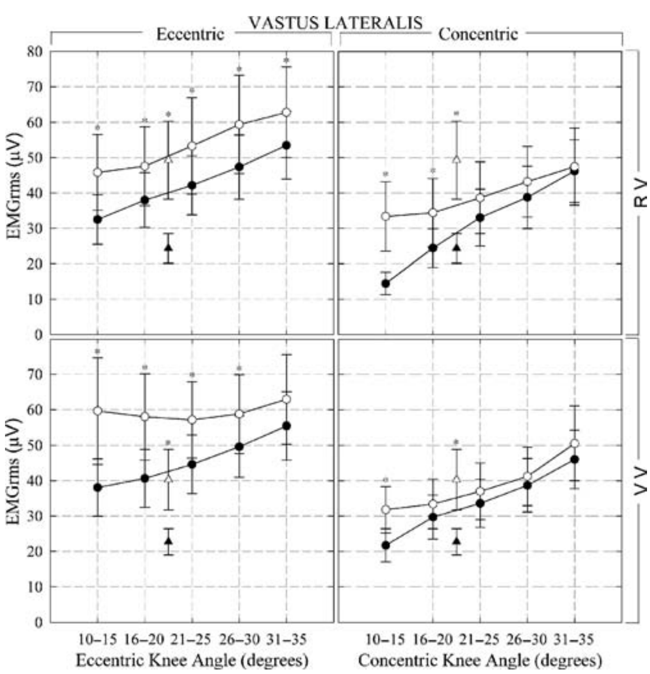

FIGURE 2—Mean ± SE of filtered, untransformed EMGrms for eccentric, concentric, and isometric contractions of vastus lateralis during RV and VV compared with no vibration (baseline). ● Concentric/eccentric baseline; ○ concentric/eccentric vibration; ▲ isometric baseline; △ isometric vibration. * Vibration significantly greater than at baseline ($P \leq 0.05$).

We hypothesized that the changes in muscle length voluntarily induced during dynamic squatting (16–20°) would alter intrafusal fiber tension and Ia sensitivity such that responses to WBV would be greater in magnitude during eccentric contractions than during isometric and concentric contractions. We also hypothesized that greater knee joint compliance at larger knee angles would result in greater transient muscle stretch during each vibration cycle, and that the increased Ia-afferent stimulation would result in greater responses at larger knee angles. Our data did not support either hypothesis; responses were greatest during

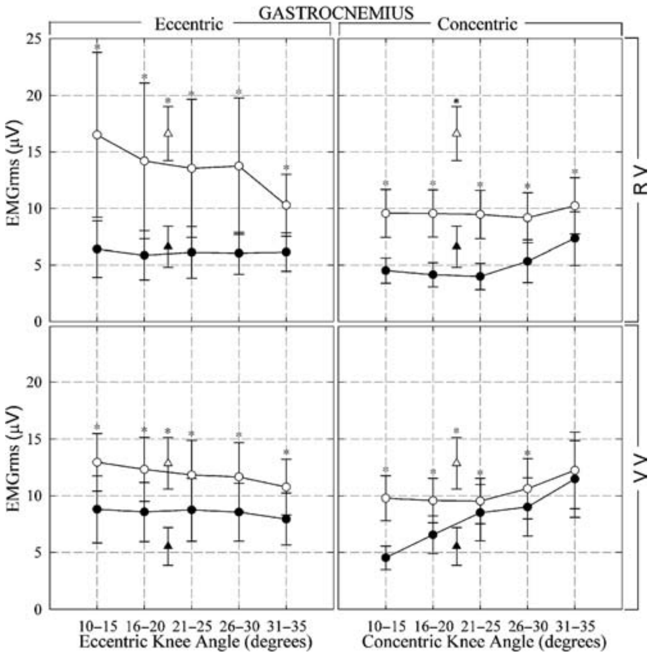

FIGURE 4—Mean ± SE of filtered, untransformed EMGrms for eccentric, concentric, and isometric contractions of gastrocnemius during RV and VV compared with no vibration (baseline). ● Concentric/eccentric baseline; ○ concentric/eccentric vibration; ▲ isometric baseline; △ isometric vibration. * Vibration significantly greater than at baseline ($P \leq 0.05$).

isometric and concentric contractions, and responses decreased as knee angle increased. It is possible that alpha–gamma coactivation during voluntary muscle contractions altered the relationship between muscle length and intrafusal fiber-tension previously documented in relaxed muscles. TVR response magnitudes in humans are affected by simultaneous contraction of muscle groups elsewhere in the body (28). It follows that variation in neuromuscular responses during WBV may be the result of involuntary TVR response magnitudes being modulated as the voluntary activation of muscles varies during the different phases of squatting and different directions of vibration.

Leg extensor muscles (vastus lateralis and gastrocnemius) may be more affected than the flexors: the triceps surae and quadriceps muscles are stretched as the upward motion of the vibration platform imposes ankle dorsiflexion and knee flexion. Because the feet are not attached to the WBV platform, plantarflexion and knee extension are not caused by the movement of the platform, and may result from the elastic properties of muscle and from myotatic muscle contractions in the triceps surae and quadriceps muscles. All of these factors may contribute to a greater enhancement of muscle activation in the vastus lateralis and gastrocnemius compared with the biceps femoris and tibialis anterior. Although the percent increases in EMGrms indicate that, overall, the biceps femoris does indeed show the least responsiveness to WBV, the tibialis anterior was, in fact, the most responsive of the four muscles during both directions of vibration.

Another possible explanation for the above finding is that increased leg neuromuscular activation reflects a postural control strategy that is adopted during WBV rather than myotatic reflex contractions. Increased activation of tibialis anterior in conjunction with deactivation of hamstrings muscles has been previously reported as a postural control response to rapid leg flexion (11); the findings of Carpenter et al. (9,10) also support the concept of a systemic postural control strategy rather than myotatic reflexive contractions in each muscle. Our data show that neuromuscular responses (vastus lateralis, gastrocnemius, and tibialis anterior) were larger at small knee angles than at large knee angles. As described above, it is possible that this effect may be mediated by the presence of a postural control mechanism. We have speculated elsewhere that small knee angles are associated with a greater postural anxiety than are large knee angles (2).

Increased muscle activation during WBV may serve to minimize the potentially damaging vibration of muscles and other soft-tissues via muscle tuning (24–26). We have previously reported that head acceleration during WBV increases as knee angles increase above 30° (2). Increased baseline muscle activation at large knee angles may affect joint compliance and/or the capacity to damp vibrations via muscle tuning. It has previously been reported that the damping coefficient of elbow flexor muscles increases as joint angular velocity increases (16). Thus, the extent of neuromuscular activation required to damp vibrations should be greatest during isometric contractions. This is consistent with our observation that the magnitude of

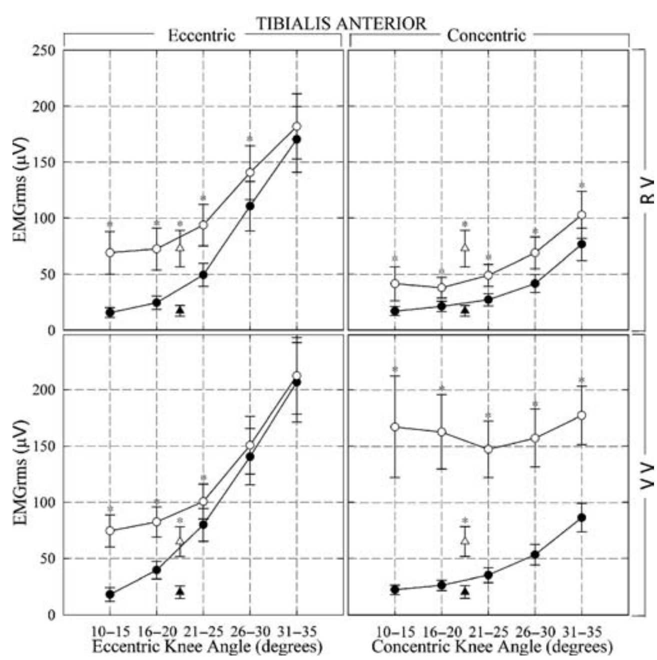

FIGURE 5—Mean ± SE of filtered, untransformed EMGrms for eccentric, concentric, and isometric contractions of tibialis anterior during RV and VV compared with no vibration (baseline). ● Concentric/eccentric baseline; ○ concentric/eccentric vibration; ▲ isometric baseline; △ isometric vibration. * Vibration significantly greater than at baseline ($P \leq 0.05$).

enhancement during isometric contractions was greater than that during eccentric and concentric contractions (16–20°) in all muscles and conditions except for biceps femoris during RV and tibialis anterior during VV.

Because vibration energy is dissipated by the ankle and knee joints and, possibly, by the muscles of the shank and thigh, the proximity of a muscle to the vibration stimulus might also affect the magnitude of muscle-tuning responses to WBV; if the proportion of vibration energy transmitted to soft-tissues is less in the thigh than in the shank, then a lesser degree of muscle activation will be required to damp the vibrations in the thigh. Our data indicate that the responses of the distal muscles were indeed larger than those for proximal muscles. This finding could also be a result of a postural control mechanism in which distal muscles are preferentially activated, as has been suggested by Slijper et al. (22), who observed increased cocontraction of distal muscles as a postural control mechanism employed by the CNS under conditions of postural instability.

From the results of our study, we suggest that static (18.5 ± 3.0° knee flexion) rather than dynamic (10–35° knee flexion) squatting during WBV exercise will maximize enhancement of leg extensor activation, and that, on average, leg extensor responses to RV will exceed responses to VV. Our data from dynamic squatting across a range of knee angles indicate that enhancement of neuromuscular activation is generally greatest at small knee angles and decreases as knee angle increases. Static squatting data were collected only at 18.5 ± 3.0°. Future research should compare neuromuscular responses to WBV between static and dynamic squatting conditions at other knee angles, to determine the optimal posture for neuromuscular enhancement during vibration, and to determine whether static conditions result in greater enhancement at a range of knee angles.

Our data show significantly different neuromuscular responses to the two different vibration directions. We have described tonic vibration reflex, postural control strategies, and muscle tuning as potential mechanisms of neuromuscular enhancement during WBV. These potential mechanisms are not mutually exclusive. Compared with VV, the asymmetric and nonvertical forces associated with RV may induce different degrees of muscle stretch, postural challenge, and/or tissue vibration in the leg muscles, each of which could contribute to the different neuromuscular responses. Although our study did not investigate performance changes after RV and VV, it follows that differing acute neuromuscular responses between vibration directions may be associated with differing chronic adaptations. Further studies are required to compare the effectiveness of RV and VV in eliciting performance improvements.

In all instances, neuromuscular responses were measured relative to baseline levels where baselines were measured in the same conditions, without vibration, immediately before the vibration condition. Although some variability was expected and observed between baseline conditions, Figure 2 shows that baseline EMGrms of the biceps femoris before VV was two to three times greater than the corresponding baseline EMGrms before RV. We suggest that this unexpected difference is attributable to a difference in the designs of the RV and VV platforms. The baseline squats were performed while standing on the respective vibration platform with the vibration turned off. The RV platform did not move perceptibly while subjects performed their baseline squats. Conversely, the design of the VV platform meant that some unmeasured but perceptible movement of the platform occurred while subjects performed their baseline squats on the platform. Although the magnitude of the VV platform movement in baseline conditions was very small, it may have been sufficient to elicit increased neuromuscular activation of the biceps femoris during VV baseline conditions to correct for displacements of the center of mass.

The findings of the present study support the further investigation of mechanisms of neuromuscular responses to WBV. Interestingly, we found that certain conditions associated with WBV may result in the adoption of different postural control strategies, which may, in turn, explain the effects that have been attributed to WBV. More research is needed to examine other mechanisms that may underlie the physiological responses and adaptations to WBV, and how these responses and adaptations may differ among people with abnormal muscle tone and soft-tissue tightness. Future studies of WBV should include controls for motion artifacts as well as differences in postural control strategies.

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Preliminary results on the mobility after whole body vibration in immobilized children and adolescents

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Abstract

The present article is a preliminary report on the effect of Whole Body Vibration (WBV) on the mobility in long-term immobilized children and adolescents. WBV was applied to 6 children and adolescents (diagnoses: osteogenesis imperfecta, N=4; cerebral palsy, N=1; dysraphic defect of the lumbar spine, N=1) over a time period of 6 months. WBV was applied by a vibrating platform constructed on a tilt-table. The treatment effect was measured by alternations of the tilt-angle of the table and with the "Brief assessment of motor function" (BAMF). All 6 individuals were characterized by an improved mobility, which was documented by an increased tilt-angle or an improved BAMF-score. The authors concluded WBV might be a promising approach to improve mobility in severely motor-impaired children and adolescents. Therefore, the Cologne Standing-and-Walking-Trainer powered by Galileo is a suitable therapeutic device to apply WBV in immobilized children and adolescents.

Keywords: Osteogenesis Imperfecta, Muscle-Bone-Unit, Whole Body Vibration, Cerebral Palsy, Physiotherapy

Introduction

Whole Body Vibration (WBV) has been recently introduced to improve impaired biomechanical function of the musculoskeletal system in adults[1]. The therapeutic principle is based on the activation of proprioreceptive spinal circuits. These reflexes can be induced by upright standing on a vibrating platform (Figure 1). Because reflexes are related to the time-differential activation of spindles in muscles and tendons, the induction of the reflective muscular answer depends on forces (acceleration of gravity x body mass) over time applied to the muscular system by vibration. The frequency of vibration characterizes the type of activated spinal reflective answer. Therefore, lower frequencies decrease the muscular tonus in contrast to higher frequencies increasing the muscular tonus[2]. The application of vibrations increased bone formation and the metabolism in skeletal muscles and skin[3,4]. Interestingly, WBV is characterized to prevent the loss of bone and muscle mass in immobilized adults. Moreover, postmenopausal women might profit from WBV regarding their muscular function. In detail, WBV improves inter- and intramuscular co-ordination over induction of high-frequent muscular contractions of agonists and antagonists in the neuromuscular system. This effect mainly improves power in motor-impaired individuals. Ward et al. applied high-frequent vibration therapy with low amplitude to improve trabecular bone density in children affected with neuromuscular diseases[5]. Negative side effects were not reported after 6 months of intensive therapy. This positive experience with vibration therapy raised the hope that vibration-therapy with individually configured applied impulses on the neuromuscular system may improve the physical ability in motor-impaired children. The present study characterizes the preliminary therapeutic effects of the Cologne Standing-and-Walking-Trainer powered by Galileo (Figure 2) on the mobility of children and adolescents affected with diseases characterized by a disease-related sarcopenia due to physical immobilization. Patients of the present report were affected with osteogenesis imperfecta (OI), infantile cerebral palsy and Meningomyelocele (MMC).

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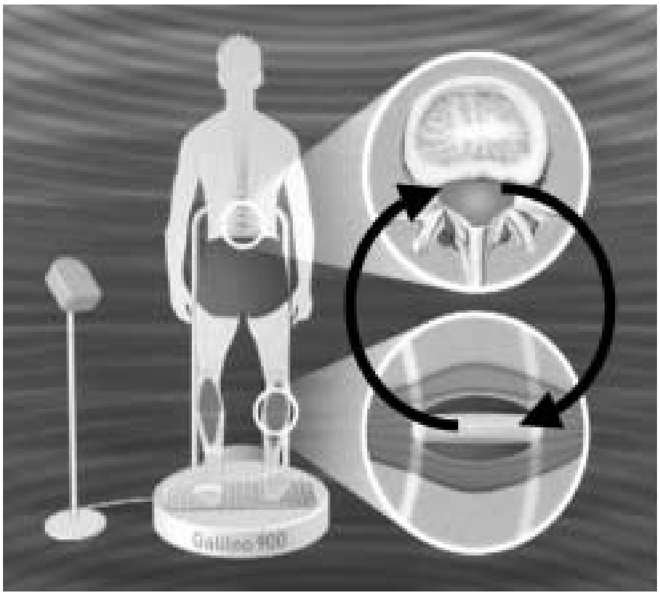

Figure 1. Schematic illustration of the reflex-circuit activated by WBV in a standing position.

Figure 2. The Cologne Standing-and-Walking-Trainer powered by Galileo for immobilized children and adolescents with severe motor-impairment.

Subjects and methods

The study group comprised 6 long-term immobilized children affected with OI (OI type III: N=2, OI type IV: N=2, aged 5.3-10.7)[6,7], infantile cerebral palsy (N=1) and a child with a dysraphic defect of the middle and lower spinal cord (N=1).

The Galileo WBV-system is a platform constructed as a see-saw with a rectangular axis to the individual's body length. The alternating platform elevates and lowers the right and left foot mutually inducing musculo-spinal reflexes. Thereby, muscles are activated on the side of the lowered foot and inhibited on the opposite side. Interestingly, inhibition is emphasized by lower frequencies in contrast to activation due to higher frequencies. Therefore, the frequency of vibration determines if WBV is characterized by tonus-increase or –decrease in skeletal muscles. Amplitude and frequency can be controlled in an analogous way. Thus, these parameters can be individually configured for the patient[8]. The Cologne Standing-and-Walking-Trainer is a Galileo WBV-system, which is supplemented by a tilt-table. The necessary force is described by F=(acceleration of gravity x body mass) x sin (tilt-angle) to keep the body in an upright position on the tilt-table. This force F is also a measure to characterize the ability to stand in a more or less vertical upright position. Mobility was characterized by a mobility score (brief assessment of motor-function, BAMF)[9].

The therapeutic program was conducted over a time period of 6 months. The patients and their parents were instructed in the use of the Cologne Standing-and-Walking-Trainer powered by Galileo before the training equipment was installed for 6 months at home. The program comprised 2 daily therapy sessions with 3 cycles each[10]. During the 6 month period of training, tilt-angle (10º-90º), frequency (15 Hz-22 Hz) and amplitude (0 mm-6 mm) were adapted in relation to the increase in the patient's physical ability. Already started therapies (e.g., drug administration such as bisphosphonates, physiotherapy) were continued during WBV.

Reports

Table 1 summarizes important parameters describing disease, diagnosis and treatment of 6 participants of the study. Individuals affected with OI are characterized by BAMF-score.

Patient 1 (OI)

The five-year-old girl was affected with OI type III. The disease was diagnosed prenatal because of ultrasonographically described malformations of the lower limbs. The infant was primarily treated with intravenous administered bisphosphonates at the age of 5 months. This treatment reduced skeletal pain, the frequency of fractures and increased the bone mineral density (BMD Z-score=-2SD at the age of 4 years). The patient had been treated with intensive physical therapy since birth. Surgical corrections of bone deformities were not applied.

Status before WBV: The participant was supported in a sitting position because of the decreased muscle force stabilizing body trunk and hips. The girl was mobilized by a wheelchair. The lower limbs were not functionally activated. Therefore the surgeons refused surgical correction of the limbs.

Status after WBV: Muscle force and mobility increased after 6 months of training with the Galileo system. The participant was able to elevate her body to an upright sitting position (+1 on the BMF-scale). Moreover, the force of the

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Diagnosis	OI III	OI IV	OI III	OI IV	ICP	MMC
Sex	F	F	F	F	F	F
Height [cm]	68	86	80	108	115	150
Weight [kg]	8.5	15	13	29	22	49.5
Age at start of WBV	5	8	9	10	5	15
Perinatal Diagnosis	Yes	Yes	Yes	Yes	No	Yes
Hereditive Disposition	No	Yes	No	No	No	No
Time period of bisphos-phonate therapy [years]	4	4.5	4	4	No	No
Osteosynthetic surgery	No	No	Yes	Yes	No	No
Constant physical therapy	Yes	Yes	Yes	No	Yes	Yes

Table 1. Characteristics of the entire study group.

lower extremities was increased to achieve a final force of 42 N. The patient started to move her limbs more frequently. Actually the surgeons are planning to correct the deformities of both lower limbs with intramedullary telescopic rods.

Patient 2 (OI)

The eight-year-old girl was affected with OI type IV. She was primarily treated with bisphoshonates at the age of 4 years. The girl was treated with physical therapy twice a week due to her delayed motor development.

Status before WBV: The girl was supported for standing. The elevation in an upright position was supported by her upper limbs (Gower-sign).

Status after WBV: The muscle force and mobility increased so that the girl stood without support and started walking with minimal support (+2 BAMF). The force development of the lower limbs increased to 109 N.

Patient 3 (OI)

The nine-year-old girl was affected with OI type III. The disease was diagnosed postnatal. The lower limbs underwent surgical stabilization with osteosynthesis because of multiple fractures. The therapy with bisphosphonates was started at the age of 6 years. Her mobility is limited to the use of a wheelchair due to her physical inability to stand or walk.

Status before WBV: The girl was characterized by a sufficient head control without the ability to sit for a longer time period.

Status after WBV: The patient achieved the physical ability to sit freely and to elevate the trunk into a sitting position without any support (+1 BAMF). With the support of the upper limbs the short time control of standing is possible. One of her intramedullary rods had already perforated the corticalis before starting the WBV. During the training period this rod caused temporary pain and the training was interrupted. There was no need for a surgical intervention. The girl increased the force to 106 N for the lower limbs.

Patient 4 (OI)

The patient was affected with OI type IV. The disease was diagnosed postnatal due to the malformations of the extremities. Several surgical interventions were necessary at the lower limbs because of those deformations. The lower extremities were stabilized by orthesis. The right upper limb was affected with a pseudarthrosis due to a fracture.

Status before WBV: The girl had the physical ability to walk 15 meters with support. Due to her muscular weakness, she was dependent on orthopaedic shoes stabilizing her ankles and she used a bandage to support her left knee. The support of walking by the upper limbs was limited by a pseudarthrosis of the right arm.

Status after WBV: The support in walking could be reduced and was only limited to support by an anterior walker. The force of the lower limbs was increased to 226 N. It was no longer necessary for her to support her joints by external fixation and she could buy normal shoes for the first time in her life.

Patient 5 (Infantile Cerebral Palsy, ICP)

The five-year-old girl was a former pre-term born infant of the 30^{th} gestational week who was affected with a spastic cerebral palsy of the lower limbs. The girl was treated with physical therapy since birth (therapy according to concepts of Bobath and Vojta). The patient accomplished to stand and walk some steps with support at the age of 3 years.

Status before WBV: The child had the physical ability to walk 30 meters with support. She was using an anterior walker or crutches with ground contact at 4 points (quadripods). The Achilles tendon was shortened, but all other muscles and tendons were not characterized by contractions. The muscular system of the lower limbs was characterized by an increased muscular tonus (spastic). It was planned to start therapy with botulinum toxin to reduce the muscular tonus in her legs.

Exercising with WBV: The participant exercised 5 days a week for 6 months. Initially, WBV was applied at a tilt-angle of 40º with 18 Hz over 3 minutes to decrease the muscular tone. This episode was followed by 3 times 3 minutes WBV with 13 Hz in an upright position. The knee joints were manually supported to minimize a deviation of the lower limbs from the vertical axis.

Status after WBV: Spastic was decreased in the lower limbs and the functionality of both feet was improved. Moreover, the physical therapy to decrease the spastics was supported by the reduction of the muscular tonus due to WBV. Therefore the neuropaediatricians decided to postpone the treatment with botulinum toxin. Her ability to walk improved during these 6 months. Actually she is only using normal crutches, she has prolonged her walking distance and can take a few steps unassisted.

Patient 6 (Dysraphic defect of the thoracolumbal spine, MMC)

The 15-year-old female adolescent was affected with lumbar MMC. She was intensively treated with physical therapy according to the Vojta concept. Contractions of muscles and tendons of the lower limbs were surgically corrected twice and a third operation was already planned. During her childhood she was able to walk with orthesis only reaching up to her lower leg. Despite intensive physical therapy she lost this capability and became dependent on orthesis reaching up to her thighs. She needed to have an external stabilization of her knees.

Status before WBV: Muscles innervated by the segments below th10 are characterized by spastic cerebral palsy. Therefore, muscles below the knee joints are completely paralyzed in contrast to upper muscles with a partial palsy. The contractions of the knee joints are described with 35º left and 40º right. The spine was characterized by a non-fixed hyperlordosis. The mobility is supported by a wheelchair because standing and walking a few steps had to be strongly supported.

Exercising with WBV: The patient exercised 3 cycles WBV daily with an oscillation frequency of 13 Hz over 6 months (5 days per week).

Status after WBV: The spine was extended due to the reduced lordosis. Moreover, contractions decreased. The right knee joint was characterized with a deficit of 10º in extension. Because of these improvements the planned operation was cancelled. The left knee joint was normalized in extension. The force of the lower limbs was increased to 312 N. This increase was especially due to an improved muscular force of her thighs. She became able to stabilize her knees on her own. Actually she started walking again with external support and orthesis only stabilizing her ankles.

Discussion

All participants were described to have profited from the conducted exercising program despite their original reasons of immobilization. Moreover, the WBV was accepted with a high compliance by all participants. Individuals affected with OI were characterized by an improved mobility (increased BAMF score) and an increase of force development in the lower limbs (increased tilt-angle in the physical therapy) after 6 months of therapy. The child affected with cerebral palsy showed a reduction of spastics and an improved functional motor pattern of walking. The indication for a therapy with botulinum toxin was reversed for the moment. The patient with the dysraphic defect was characterized by a decrease of joint-associated contractions. The surgical correction of contractures was cancelled. Both patients have been able to reduce their dependency on external support regarding crutches and orthesis. The reason for the described benefit becomes understandable for all participants despite their primary diseases when the general effect of immobilization on the musculoskeletal system is considered.

Immobilization of the musculoskeletal system is typically followed by loss of muscle mass (sarcopenia) and a subsequent decrease of bone mass (osteopenia). Therefore, immobilization is always related to sarcopenia and osteopenia despite its primary origin (e.g., cerebral palsy). The loss of muscle and bone mass decreases the functional competence of the musculoskeletal system and might be the reason of further immobilization. This consideration is the fundamental of the empirically based concept of primary and secondary bone diseases[11]. Primary bone diseases are characterized by a structural or metabolic defect of the skeletal development in contrast to secondary bone diseases based on immobilization[12]. Therefore, functional activation of the musculoskeletal system is a promising approach to improve mobility in motor impaired children and adolescents.

One of the described patients with OI developed problems with an intramedullary rod, which was already dislocated before starting WBV. Another patient who was not reported because she was training on a standing device only for a few weeks suffered a dislocation of a telescopic rod during the months of training. This patient had had a dislocation already 2 years before and another one month after she stopped the WBV. Dislocation of telescopic rods is a frequent event in individuals affected with OI[13]. Moreover, the analysis of the individual anatomical characteristics of these patients could not draw any connections between WBV and the dislocation osteosynthetic material. Nevertheless, a negative effect of WBV on the stability of implanted material cannot be excluded due to these preliminary data.

The present collective of participants was characterized by a high heterogeneity of diseases and their severity of immobility. Therefore, the present results are not comparative between different individuals. Nevertheless, the present data can be regarded as preliminary results to enhance the importance of this promising therapeutic strategy to regain mobility in severely motor-impaired children and adolescents.

Acknowledgements

This study was supported by grants from "Koeln Fortune" and "Deutsche Gesellschaft für Osteogenesis imperfecta Betroffene e.V. Landesverband N-RW". The Cologne Standing-and-Walking-Trainers were provided by "Novotec Medical". Special thanks go to all participants and to K. Kloeckner-Muenter for administrative support and to A. Stabrey for statistical analysis.

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Results of a prospective pilot trial on mobility after whole body vibration in children and adolescents with osteogenesis imperfecta

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Objective: To evaluate the effect of whole body vibration on the mobility of long-term immobilized children and adolescents with a severe form of osteogenesis imperfecta. Osteogenesis imperfecta is a hereditary primary bone disorder with a prevalence from 1 in 10 000 to 1 in 20 000 births. Most of these children are suffering from long-term immobilization after recurrent fractures. Due to the immobilization they are affected by loss of muscle (sarcopenia) and secondary loss of bone mass.
Subjects: Whole body vibration was applied to eight children and adolescents (osteogenesis imperfecta type 3, $N=5$; osteogenesis imperfecta type 4, $N=3$) over a period of six months.
Interventions and results: Whole body vibration was applied by a vibrating platform (Galileo Systems) constructed on a tilting-table. Success of treatment was assessed by measuring alterations of the tilting-angle and evaluating the mobility (Brief Assessment of Motor Function). All individuals were characterized by improved muscle force documented by an increased tilting-angle (median = 35 degrees) or by an increase in ground reaction force (median at start = 30.0 [N/kg] (14.48–134.21); median after six months = 146.0 [N/kg] (42.46–245.25).
Conclusions: Whole body vibration may be a promising approach to improve mobility in children and adolescents severely affected with osteogenesis imperfecta.

Introduction

Osteogenesis imperfecta, also known as brittle bone disease, is a hereditary disease involving collagen type 1 deficiency. Its incidence is between 1:15 000 and 1:25 000. All described gene defects associated with osteogenesis imperfecta lead to a reduced stability of the musculoskeletal system and to muscular hypotony in most patients.[1] Clinical symptoms are brittleness of bones, especially of extremities and the vertebrae, a reduced muscular tonus, reduced body length, grey sclera and dentinogenesis imperfecta in some individuals.[2] Severely affected children with osteogenesis imperfecta are mostly dependent on a wheelchair and have reduced mobility. The reduced mobility is a consequence of frequent fractures of the extremities and the immobilization after surgery. There are no neurological deficits in these patients.

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The treatment is based on three important pillars: bone surgery,[3,4] bisphosphonates[5,6] and physiotherapy.[7] The importance of surgical procedures is already well described to correct deformities. Bisphosphonates are administered to improve bone mass and vertebral morphometry. There are only a few reports on the importance of physiotherapy and the related functional outcome in children and adolescent with osteogenesis imperfecta.[8,9] This is somehow surprising because the improvement of mobility and independence should be the endpoint of all therapeutic procedures in these patients.

A close relationship between muscle force and bone strength has been described previously and the consequences of reduced mobility on the musculoskeletal system have been shown in immobilization studies.[10]

Different methods of whole body vibration have been used for many years to increase muscle force in adults in special fields.[11,12] It is used in athletes to increase their performance and in cosmonauts to prepare them for space missions.[13,14]

Recently whole body vibration has been used to improve impaired biomechanical function of the musculoskeletal system in motor-impaired adults.[15]

The therapeutic principle is based on the activation of proprioceptive spinal circuits. The proprioceptive organs in muscles and tendons detect a change of the body position by a change of their length and induce a contraction of the antagonist stabilizing the system due to the spinal reflex. This reflex can be used for a therapeutic approach using a vibration system to induce the change of body position and to activate the muscular system. Lower frequencies decrease the muscular tonus in contrast to higher frequencies, which increase the muscular tonus.[16] In detail, whole body vibration improves inter- and intramuscular coordination, inducing high-frequency muscular contractions of agonists and antagonists in the neuromuscular system.

The application of vibrations increased bone formation and metabolism in skeletal muscles and skin.[17,18] Interestingly, whole body vibration is thought to prevent the loss of bone and muscle mass in immobilized adults.[19] Different types of whole body vibration systems have been used in the rehabilitation in adults in recent years. Ward *et al.* applied high-frequency vibration with low amplitude to motor-impaired children with cerebral palsy. They measured an improvement of trabecular bone density in these children.[20] The aim of our study is to determine the functional effects of whole body vibration on muscle force and mobility in severely motor-impaired children with osteogenesis imperfecta.

Subjects and methods

In Table 1 important parameters are summarized describing the characteristics and treatment of the eight patients participating in the trial.

Table 1 Important characteristics at start of whole body vibration and incidence of fractures during the two years before whole body vibration and during the six-month training period

Patient number	Sex	Age (years)	OI type	Bisphos phonates	Telescopic rod in femur and tibia	Constant physical therapy	Fractures during 2 years before WBV	Fractures during 6-month training
1	F	4.9	III	Yes	No	Yes		0
2	F	7.7	IV	Yes	No	Yes	4	1
3	F	9.2	III	Yes	Bilateral	Yes	3	0
4	F	9.4	IV	Yes	Bilateral	No	1	0
5	M	9.9	III	Yes	Bilateral	Yes	0	0
6	M	14.9	III	Yes	Bilateral	No	4	1
7	M	8.8	III	Yes	Bilateral	Yes	2	0
8	F	9.5	IV	Yes	Bilateral	Yes	2	0

OI, osteogenesis imperfecta; WBV, whole body vibration.

The incidence of fractures during the last two years before whole body vibration and during the six months of training is reported.

In the present study we used the Cologne Standing and Walking Trainer System Galileo to improve muscle function in children with osteogenesis imperfecta. This is a modified tilt-table combined with the 'Galileo' whole body vibration system (Figure 1). The patient lies on his or her back with the feet placed on the vibrating platform during training. At the beginning of the six-month training period the patients start with a tilt angle of 10 degrees. Over the training period the table was tilted towards the vertical depending on the individual functional status of the patient. The aim was to turn the patients 10 degrees further towards the vertical every 2–3 weeks.

The patients were asked to exercise during the vibration, bending and straightening their knees. The angle in the knees should vary between 10 and 45 degrees during training. The patients should always try to press their feet as hard as possible against the platform during the vibration training.

The Galileo system is a whole body vibration system using a side alternating platform. One foot of the patient is elevated slightly while the other foot is lowered consecutively during vibration. This induces musculospinal reflexes and activates the muscles. The amplitude of the vibration varies from 0 mm exactly at the axis of the platform to 1 cm at the edge, depending on the position of the patient's feet on the platform.

The frequency of the vibration can be controlled and can be adapted to the patient's physical ability.

We calculated the ground reaction force to measure the improvement of muscle force during the treatment. The ground reaction force (F) depends on the angle of the tilt-table, the body weight of the patient and includes gravity [F = (acceleration of gravity × body mass) × sin(tilt-angle)]. As the patient becomes more vertical the applied force to the platform increases. Therefore, higher muscular force is needed to keep the patient in an upright position. The tilting-angle thus determines the applied force. Mobility of the patients was characterized with the Brief Assessment of Motor Function (BAMF).[21] This is a validated test to assess a wide range of mobility in patients regardless of age, pubertal status and physical training status.

The therapeutic programme was conducted over a period of six months. Patients and their parents were instructed in the use of the Cologne Standing and Walking Trainer System Galileo by a physiotherapist before the training equipment was installed at home. The programme comprised two daily therapy sessions with three cycles each.[22] Table 2 describes the configuration

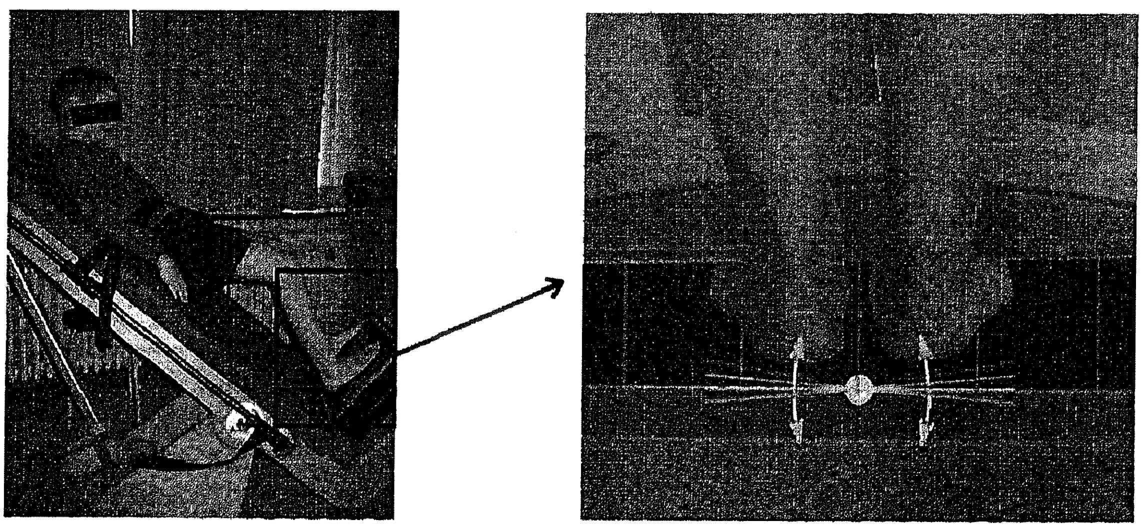

Figure 1 The Cologne Standing and Walking Trainer System Galileo.

Table 2 Exercise programme for whole body vibration in patients affected with osteogenesis imperfecta and configuration at start of training period

Tilting-angle (degrees) Frequency (Hz) Time period of applied WBV Amplitude of vibration	10 15–20 3 minutes 1 (1–2 mm)	3 minutes break	10 20–25 3 minutes 1 (1–2 mm)	3 minutes break	10 20–25 3 minutes 1 (1–2 mm)

WBV, whole body vibration.

of the equipment at the start of the programme. The tilting-angle and the frequency were adapted and increased in relation to the increase in the patient's physical ability. Tilting-angle and BAMF were measured at the start of whole body vibration (M0), after three months (M3) and after six months (M6) of training. Additional therapies (e.g. drug administration such as bisphosphonates and physiotherapy) which had been started over one year previously were continued during whole body vibration.

Differences for analysed variables were calculated by two-tailed paired *t*-tests. Simple linear correlations were calculated for the association between ground reaction and BAMF score. Statistical differences were ascribed to be significant at $P<0.05$. All statistical procedures were performed by the use of PC Statistics 4.0 (Hoffmann-Software, Giessen, Germany). The study was approved by the ethics committee of the university of Cologne, Germany, and informed consent was obtained from legal guardians.

Results

Tilting-angles at start of therapy (M0) were significantly lower than tilting-angles after three (M3) and six months (M6) of therapy (paired *t*-tests, two-tailed, $P=0.014$ and $P=0.0048$, respectively). Tilting-angles were not significantly different between M3 and M6 ($P=0.08$, $\beta=0.6$). The calculated ground reaction force (F) at M0 was significantly lower than F (M3) and F (M6) (paired *t*-tests, two-tailed, $P=0.02$ and $P=0.002$, respectively). F-values were also significantly different between M3 and M6 (paired *t*-test, two-tailed, $P=0.02$) (Table 3) (Figure 2).

BAMF at M0 was significantly lower than at M3 (paired *t*-test, two-tailed, $P=0.014$), but there was no significant difference between M0 and M6 ($P=0.11$, $\beta=0.6$). Mobility scores were not different between M3 and M6 (Table 5).

Tilting-angles were significantly linear correlated to mobility scores ($N=24$, $r=0.5$, $P<0.05$), meaning that improvement of tilting-angle reflects improvement of motor function.

F-values were significantly linear correlated to tilting-angles ($N=24$, $r=0.61$, $P<0.05$), but not to mobility-scores ($P=0.22$). The statistical results are shown in Table 3.

Each patient had individual problems of motor function at start of whole body vibration and individual benefits from the training, which were not completely reflected by the assessment of BAMF. These individual benefits of the training are displayed in Table 4. We report changes in body length and weight during the training period in Table 5. We calculated changes in body length and body weight for the study group (paired *t*-tests, two-tailed). Height and weight increased significantly over six months (mean of increase for height $3+2.4$ cm and for weight $4.2+4.9$ kg) with $P=0.009$ and $P=0.049$, respectively. But height SDS and weight SDS did not significantly increase. Therefore, the present increase of weight and height is likely associated with normal growth.

One patient developed a localized pain at the end of an intramedullary rod, which was already dislocated before starting whole body vibration. In this case, there was no need for surgical intervention. Otherwise, skeletal pain was not reported during therapy. Two patients received fractures (one forearm, one femur) in situations not related to whole body vibration during the training period. The incidence of fractures seems to be

Table 3 Results of whole body vibration in eight children with osteogenesis imperfecta at start (M0), after three months (M3) and after six months (M6)

	M0			M3				M6			
	$M \pm SD$	Median	Range	$M \pm SD$	Median	Range	*P*-value	$M \pm SD$	Median	Range	*P*-value
Mobility score	5.0 ± 1.8	5.0	3–7	5.5 ± 1.6	6.0	3–7	0.014	5.5 ± 1.7	6.0	3–7	0.11
Tilting-angle	16.9 ± 11.0	10.0	10–40	42.5 ± 22.5	35.0	20–80	0.014	55.0 ± 27.5	45.0	25–90	0.0048
Ground reaction forces related to body weight (*F*), N/kg	56.00 ± 47.56	30.0	14.48–134.21	114.63 ± 52.20	108.5	22.85–193.22	0.02	155.38 ± 73.82	146.0	41.46–245.25	0.002

comparable or even slightly decreased to the number of fractures these patients received during the last two years before whole body vibration. There were no other severe side-effects during the study. Some patients reported about some itching directly after the vibration as a result of the increased vascularization.

Another patient suffered from a dislocation of a telescopic rod after training on a standing device for a few weeks. This patient was not included in the present study. Moreover, this patient had had a dislocation already two years before and another one months after she had already stopped the whole body vibration. Dislocation of telescopic rods is a frequent event in individuals affected with osteogenesis imperfecta.[23,24] Furthermore, the analysis of the individual anatomic characteristics of these patients could not draw any connections between whole body vibration and the dislocation of osteosynthetic material. Nevertheless, a negative effect of whole body vibration on stability of implanted material cannot be excluded due to the present preliminary data.

Discussion

All participants were described to have profited from the conducted exercising programme despite their initial status of motor function. The benefits of the patients can only be compared individually because of the different status at start of therapy. Moreover, whole body vibration was accepted with a high compliance and without severe negative side-effects. Some of the patients were characterized by an improved mobility (increased BAMF). The BAMF is a validated test to characterize mobility in motor impaired patients. It is a test which can be used in different settings and is independent of age and pubertal stages. It is not possible to reflect small changes in motor function with this test, but for orientation of motor function it is reliable and useful measurement.

Regarding muscle force all patients showed a significant increase of ground reaction force after six months of training with the Cologne Standing and Walking Trainer System Galileo. The highest benefits were accomplished during the first three months of training. Further data showed a

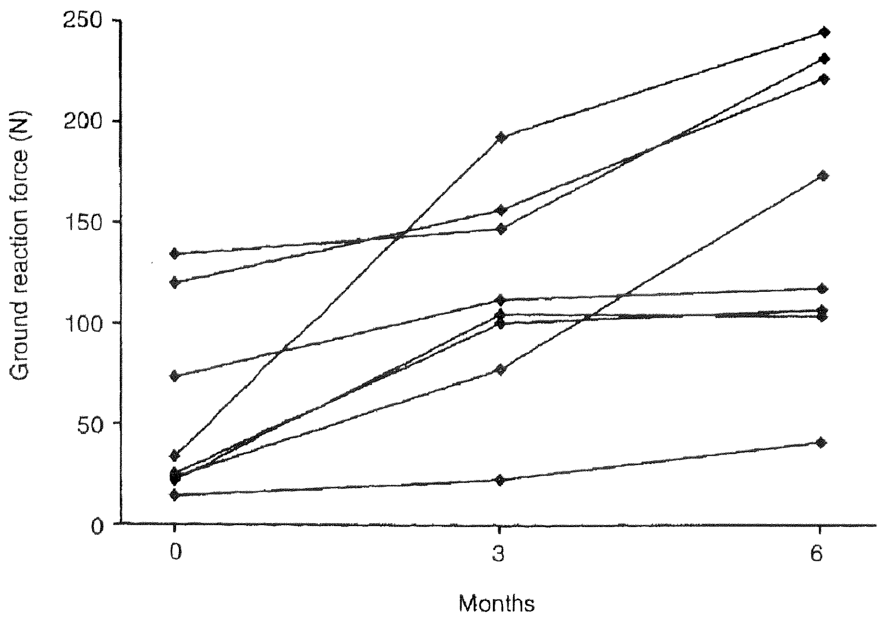

Figure 2 Changes of calculated ground reaction force during six months of whole body vibration.

stabilization of the improvement and no further improvement of BAMF in most patients. This implies that six months seem to be a good training period. In this time the patients are motivated to perform the training with a high compliance and they can achieve benefits in muscle force and mobility. Due to the lack of other studies we cannot decided if six months is the optimal training period but this interval seems to be appropriate.

Concluding, whole body vibration with the Cologne Standing and Walking Trainer System Galileo seems to be a promising approach to increase muscle force and more important mobility in immobilized children with osteogenesis imperfecta. This training should not be limited to patients with osteogenesis imperfecta, but can be also applied to most immobilized children. Recent data by Ward *et al.*[20] showed a beneficial effect of whole body vibration in motor-impaired children with cerebral palsy.

Immobilization of the musculoskeletal system is typically followed by a loss of muscle mass (sarcopenia) and a subsequent decrease of bone mass (osteopenia). Therefore, immobilization is always associated to sarcopenia and osteopenia despite its primary origin. The loss of muscle and bone mass decreases the functional capabilities and might be the reason for further immobilization. This consideration is the basis of the empirically based concept of primary and secondary bone diseases.[25] Primary bone diseases are characterized by a structural or metabolic defect of the skeletal development, in contrast to secondary bone diseases based on immobilization.[26] Therefore, functional activation of the musculoskeletal system is a promising approach to improve mobility in motor-impaired children and adolescents.

The present participants of the study were characterized by a high heterogeneity of motor impairment. Therefore, the present results are not comparative between different individuals. During the training the participants grew older but it is not likely that this contributes much to the improvement of mobility. The natural development in motor function in patients with osteogenesis imperfecta is very slow and the mobility has not changed relevant in the year before the study started. This heterogeneity and the lack of a control group are limitations in this trail. Nevertheless, the present data can be regarded as preliminary results to enhance the importance of this promising therapeutic strategy to regain mobility in severely motor-impaired children and adolescents.

Table 4 Individual benefits of whole body vibration

Patient number	Individual improvements
1	Sitting, now OP for limb deformities required
2	Walking with posterior walker
3	Standing with assistance
4	Knee and ankle orthesis not longer needed
5	Verticalization up to 90 degrees on Cologne Standing and Walking Trainer System Galileo
6	Less help needed in wheelchair (obesity)
7	Independent getting in and out of his wheelchair, walking distance 30 → 250 steps with posterior walker
8	Walking distance 3 m → 18 m with walker

Table 5 Height and weight development at start (M0) of whole body vibration and after six months (M6) of therapy and BAMF at M0, M3 and M6

Patient number	Length M0 (cm)	SDS M0	Length M6 (cm)	SDS M6	Weight M0 (kg)	SDS M0	Weight M6 (kg)	SDS M6	BAMF M0	BAMF M3	BAMF M6
1	68.0	−8.90	70.0	−9.56	8.5	−8.95	10.0	−8.36	3	4	4
2	86.0	−8.41	88.0	−8.90	15.0	−3.42	17.0	−3.43	5	6	7
3	80.0	−10.96	85.0	−9.98	13.0	−4.74	15.0	−4.19	3	4	4
4	108.0	−5.47	109.0	−5.27	29.0	−0.33	32.0	0.50	7	7	7
5	88.0	−8.82	88.0	−9.05	14.0	−4.52	18.0	−3.88	5	5	5
6	105.0	−8.71	112.0	−7.81	40.0	−1.82	56.0	0.00	3	3	3
7	77.0	−10.37	79.0	−10.45	11.7	−5.45	12.0	−5.07	7	7	7
8	108.0	−5.47	113.0	−5.20	20.0	−2.81	25.0	−2.10	7	7	7

BAMF, Brief Assessment of Motor Function.

The study was approved by the ethical committee of the university Cologne, Germany.

Clinical messages

- Whole body vibration is a promising approach to improve mobility in children with osteogenesis imperfecta.
- The Cologne Standing and Walking Trainer System Galileo is a safe system to improve muscle force in these children.
- Despite the heterogeneity of the sample population, all the patients had individual benefits from whole body vibration.

Acknowledgements

This study was supported by grants from Cologne Fortune, Deutsche Gesellschaft für Osteogenesis imperfecta Betroffene e.V. Landesverband NRW and Ch. Guenther. The Cologne Standing and Walking Trainer System Galileo systems were provided by Novotec Medical. Special thanks go to all participants and to K Kloeckner-Muenter for administrative support and to A Stabrey for statistical analysis and graphical layout.

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Perspective Article

Hylonome

Material matters: a mechanostat-based perspective on bone development in osteogenesis imperfecta and hypophosphatemic rickets

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Abstract

This perspective paper presents a hypothesis that links abnormalities of bone material with densitometric findings in two congenital metabolic bone disorders, osteogenesis imperfecta type I (OI) and X-linked hypophosphatemic rickets (XLH). Analyses of iliac bone samples from OI patients have shown that material bone density is elevated and that the bone material is abnormally stiff in this disorder. Therefore, a given mechanical load on an OI bone will generate a smaller than normal deformation. This in turn should lead osteocytes, the putative mechanosensing cells, to systematically underestimate the prevailing mechanical forces. According to the mechanostat model, bone strength should then be adapted to the underestimated mechanical loads, which means that bone architecture and mass remain below requirements. Available densitometric studies are in accordance with this hypothesis. In XLH, a mild mineralization defect persists despite treatment. This mineralization defect should lead to soft bone material. In analogy to the above model for OI, mechanical loads should be overestimated, resulting in increased densitometric parameters of bone strength. Indeed, lumbar spine areal bone mineral density is usually elevated in such patients.

Keywords: Children, Hypophosphatemic Rickets, Mechanostat, Osteogenesis Imperfecta, Osteoporosis

Introduction

Regular readers of this journal are well aware of Frost's mechanostat model, as it has been shown in its pages quite a few times. Nevertheless, a brief repetition may be useful for the present discussion. The mechanostat model proposes that bone tissue constantly monitors the deformations (strains) which result from mechanical forces (Figure 1). This monitoring job is presumably done by the osteocytes[1]. The measured deformation is compared to a pre-set target level, called 'set-point'. When bone deformation strays too far from the target, osteocytes send out signals to effector cells, which then adapt bone architecture and mass, and thereby bone strength[2]. Through these adaptations, bone deformation returns to the acceptable range and homeostasis is maintained. During growth, bone stability is continually threatened by two processes, the increase in bone length and the increase in muscle force. Longitudinal growth increases lever arms and bending moments and therefore leads to greater bone deformation[3,4]. Greater muscle force will also increase bone deformation during muscle contraction. These challenges create the need for adaptational changes in bone architecture and mass.

Many physiological and pathophysiological skeletal conditions have been examined in light of the mechanostat model. A question, which to my knowledge has not been addressed, is what happens to bone development in diseases with abnormal material bone properties? Two not so rare conditions that affect bone material properties during bone development are osteogenesis imperfecta (OI) and X-linked hypophosphatemic rickets (XLH). Much more information concerning the present discussion is available for OI, so let us start with this disorder.

Osteogenesis Imperfecta

OI is a heritable disorder with increased bone fragility. Seven types of the disease can be distinguished based on

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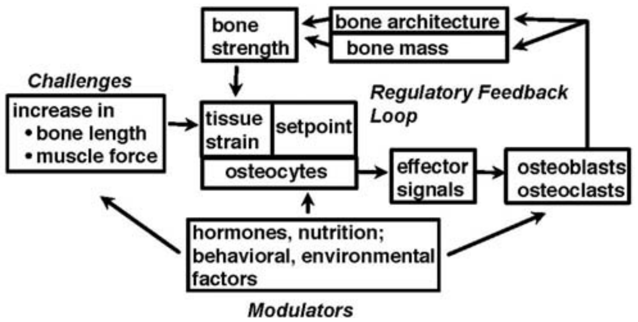

Figure 1. Mechanostat model of bone development. The central piece of bone regulation is the feedback loop between bone deformation (tissue strain) and bone strength. During growth this homeostatic system is continually forced to adapt to external challenges. Factors shown below modulate various aspects of the regulatory system.

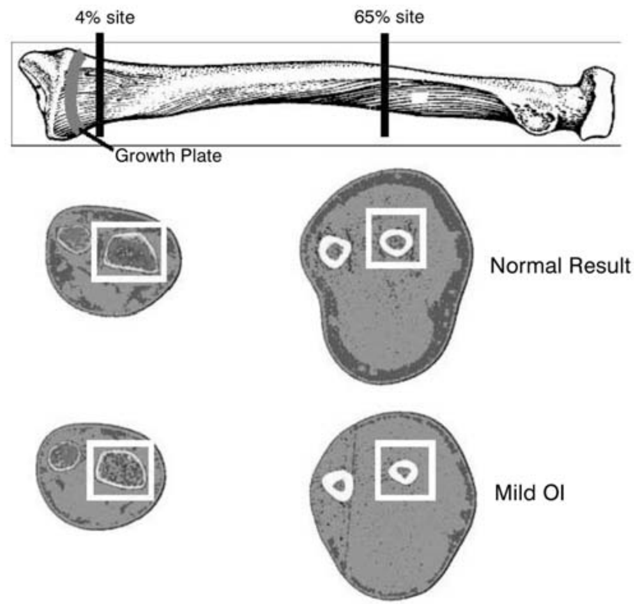

Figure 2. Measurement sites at the radius. Peripheral quantitative computed tomography was performed at the metaphysis (at the so-called 4% site) and at the diaphysis (65% site). Above, typical scan images are shown. The radius is enclosed by white boxes. The upper two scan images show the results of a 14-year-old boy without bone disorder. Trabecular bone density at the metaphysis is 193 mg/cm^3. The total cross-sectional area of the diaphysis is 104 mm^2, z-score-0.5 The lower panels show images from a 13-year-old boy with OI type I. Trabecular bone density at the metaphysis is 147 mg/cm^3, z-score -2.0. The total cross-sectional area of the diaphysis is 81 mm^2, z-score -1.8.

clinical phenotype and bone histologic findings[5]. The mildest variant, OI type I, comprises patients who do not have major bone deformities. Typical features include gray or bluish sclerae, close to normal growth and autosomal dominant inheritance. In the large majority of these patients, the disease is caused by mutations in one of the two genes encoding collagen type I alpha chains (COL1A1 and COL1A2)[6]. Frequently, mutations associated with OI type I result in a null COL1A1 allele, causing a 50% reduction in normal type I collagen synthesis[7].

Patients with OI usually have low bone mass, even after taking their often-short stature into account[5]. A popular explanation for this bone mass deficit is that the weakness of the osteoblast system prevents the normal accumulation of bone mass. However, as noted by Frost more than 35 years ago, this explanation is not entirely satisfactory[8]. Dynamic histomorphometry shows that the osteoblast system – far from being unable to produce bone – is actually depositing unusually large amounts of bone. This was later confirmed by more detailed studies in my own laboratory[9]. The weakness of the individual osteoblast is more than compensated for by the very high number of these cells. The problem is that the bone is resorbed as fast as it is deposited. This suggests that low bone mass in OI is due to some dysregulation, rather than the inability to produce bone. What kind of 'dysregulation' might this be?

Collagen type I is the most abundant organic component of bone material. Abnormalities in collagen type I therefore constitute a 'bone material disorder'. Importantly, the abnormalities in organic composites also affect the mineral phase. Compared to age-matched controls, bone from OI patients shows a higher average mineralization density[10]. Possibly this is because collagen type I fibrils in OI are thinner, leaving more space to be filled with mineral. What is of interest here is the biomechanical consequence of this material abnormality. It is intuitively clear that bone material should be stiffer when material bone density is increased. This has indeed been shown to be the case in both animal models of OI and in humans with the disease[11,12]. Thus, OI bone is dense and stiff on the material level.

Based on the mechanostat model, what is the expected consequence to abnormally stiff bone material? To answer this question we have to go back to Figure 1. A given force induces less deformation, or strain, in stiff than in soft material. For OI bone material this means that it will deform less when exposed to the same load as a normal bone. Osteocytes can 'see' only deformation, not the load itself and therefore they will systematically underestimate the mechanical loads on the bone. The consequence: bone strength will be adapted to the underestimated mechanical loads, not the actually prevailing ones. Bone architecture and mass will be weaker than the mechanical loads would dictate them to be.

This scenario is not really new, but rather is a variation of Frost's setpoint hypothesis of OI[13,14]. Frost had proposed that the clinical manifestations of OI are caused by an abnormally high mechanostat setpoint. In contrast, the present perspective argues that it is not the setpoint that is affected, but that the main problem resides in the abnormal stiffness of the bone material, thus confounding the osteocytes. However, the differences between the original Frost hypothesis and the current proposal are minor, as the downstream con-

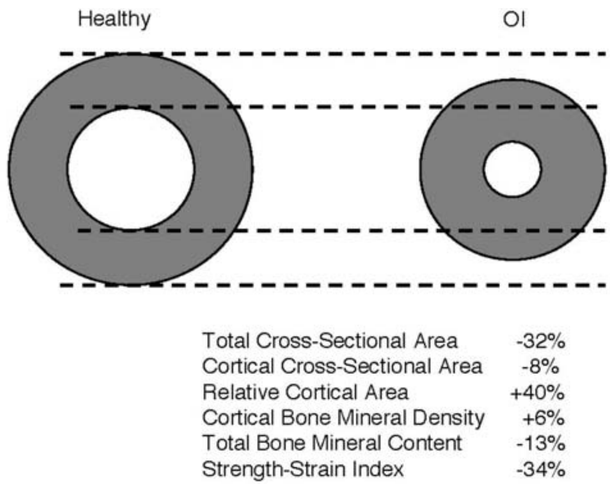

Figure 3. Schematic representation of average results at the radial diaphysis in patients with mild osteogenesis imperfecta and in healthy age-matched controls.

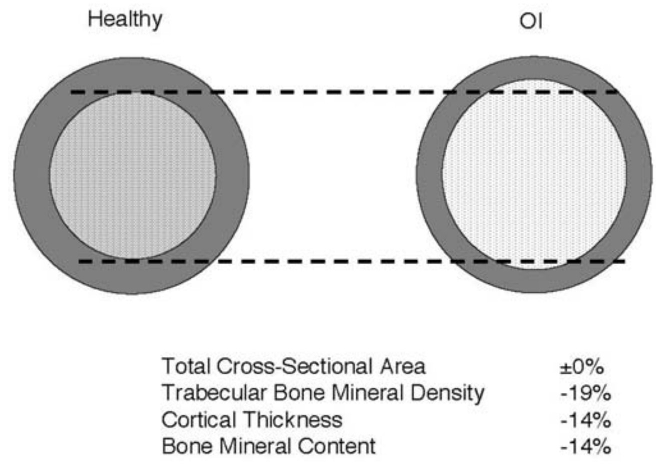

Figure 4. Schematic representation of average results at the radial metaphysis in patients with mild osteogenesis imperfecta and in healthy age-matched controls.

sequences should be identical, whether the setpoint is elevated or the mechanical loads are underestimated.

So much for the model. What about the actual findings in OI patients? A number of densitometric studies have looked at patients with OI and agree that bone mineral density is low. However, such data are notoriously difficult to interpret, as the picture is often complicated by small bone size, bone deformity, vertebral compression fractures, scoliosis, and a history of prolonged immobilization. To examine skeletal abnormalities in OI without the interference of such secondary phenomena, a recent study examined 42 children and adolescents with mild OI type I who were fully mobile and did not have long-bone deformities or compression fractures at the lumbar spine[15]. Lumbar vertebrae and the radius (metaphysis and diaphysis) were analyzed using dual-energy X-ray absorptiometry and peripheral quantitative computed tomography, respectively (Figure 2).

At the diaphysis of the radius, bone size (i.e., the total cross-sectional area) was very small, but relative cortical area was high and cortical bone density was slightly elevated (Figure 3). The overall effect of these abnormalities was that the Strength-Strain Index, a measure of the bone's resistance to bending, was 34% lower than expected for height. In contrast, the cross-sectional area of the forearm muscles was similar to that of healthy subjects who had the same height. When compared to a reference population with the same muscle cross-sectional area, OI type I patients had a 37% deficit in Strength-Strain Index. It is assumed here that muscle cross-sectional area gives an approximate idea of muscle force and therefore is a surrogate measure of the loads to which the forearm bones are exposed. These data therefore suggest that bone strength is not appropriately adapted to the prevailing loads, which is entirely in agreement with the predictions made from the mechanostat theory.

Results at the metaphysis of the radius and at the lumbar spine differed in some respects from those at the radial diaphysis. Whereas the bone's cross-sectional area was very low at the radial diaphysis, bone size was close to normal at the lumbar spine and at the radial metaphysis (Figure 4). Trabecular bone density and cortical thickness were low at the metaphysis (Figure 4).

Thus, even though the amount of bone was low at all three sites of measurement, there were marked site-specific differences in size. To explain these findings, let us consider how bone growth occurs at each skeletal location. Metaphyseal bone is a site of endochondral ossification, where most (80 to 90%) of the primary trabeculae provided by the growth plate are quickly removed[16]. When the mechanical loads are underestimated, an even larger proportion of trabeculae will be interpreted as mechanically superfluous and will be resorbed, resulting in low trabecular bone density. This scenario applies to the distal radius and also to vertebral bodies, which in fact can be seen as two metaphyses which are joined without intervening diaphysis.

Why then is bone size normal or close to normal in metaphyseal but not in diaphyseal bone of OI type I patients? The metaphysis has as its starting point the growth plate, whose cross-sectional size determines the size of the metaphysis. As the growth plate does not contain collagen type I, it should not be affected by the mutation underlying OI. The growth plate can therefore be expected to develop normally unless the underlying bone becomes too weak to support it. However, the size of the diaphysis is determined by periosteal bone apposition, the activity of which is associated with mechanical loading[17,18]. When the prevailing mechanical forces are underestimated, as is proposed here, periosteal expansion lags behind, resulting in a diaphysis with an abnormally small cross-section.

X-linked hypophosphatemic rickets

XLH is an X-linked dominant disorder that is caused by mutations in the PHEX gene (this acronym stands for Phosphate regulating gene Homologous to Endopeptidases on the X chromosome). The hypophosphatemia is due to a decreased tubular re-absorption threshold of phosphorus. Patients have normal serum levels of calcium, usually normal or slightly elevated parathyroid hormone levels, normal calcidiol, and an increased alkaline phosphatase activity. Untreated children have radiographic evidence of rickets. Bone histology reveals osteomalacia and peculiar hypomineralized periosteocytic lesions, which were first described by Frost in 1958[19].

Standard therapy of XLH consists of oral phosphate supplementation and calcitriol (the latter aims at preventing secondary hyperparathyroidism that otherwise would develop with high-dose phosphate supplementation)[20]. This treatment regimen corrects the mineralization defect at the level of the growth plates (in other words, it heals the rickets). However, although the histological appearance of osteomalacia improves, some degree of mineralization defect in the bone tissue persists despite treatment[21].

It is this persistence of some osteomalacia that makes XLH interesting in the context of the present discussion. 'Osteomalacia' means that the bone matrix is undermineralized. The bone material should therefore be softer than normal. This makes XLH in some way the mirror image of OI, where the bone matrix is hypermineralized and the bone material is too stiff. So, which are the expected consequences of abnormally soft bone material? You can work that out by looking at Figure 1.

A given mechanical load will cause more strain in the soft XLH bone material than in a bone with normal material properties. The osteocytes in XLH bone will overestimate the mechanical loads and bone will be adapted to higher loads than are actually present. This should lead to bone with increased densitometric parameters of bone strength.

Indeed it is well established that XLH patients receiving treatment with phosphorus and calcitriol have elevated bone mineral density at the lumbar spine[22,23]. They also have high trabecular bone density at the distal radial metaphysis and larger bone size at the diaphysis (unpublished observations). The latter observation may explain why areal bone mineral density is often high in these patients[22-24]. These findings are consistent with the predictions from the mechanostat model.

Limitations

Although the present proposal stresses the importance of material bone properties for the development of bone architecture and mass, it is obviously possible - and indeed very likely - that other factors play a role in determining bone architecture and mass in OI and XLH. Mutations in collagen type I and PHEX may have a myriad of downstream consequences other than making bone material too stiff or too soft.

Although the evidence base of this pathophysiologic model is quite solid for OI, data in support of the XLH model are 'few and far between'. It is clear that osteomalacia persists even in well-treated patients with XLH, but there are no data on material bone density in this context. However, it is certainly plausible that material density is low in treated XLH, as it is in other conditions with osteomalacia[25]. Since the elastic modulus of bone material is associated with material density[26], any mineralization deficit should result in soft bone material, as proposed in the model. A further limitation of the proposed model is that the densitometric characteristics of XLH have been studied in less detail than those of OI, even though it is well established that lumbar spine areal bone mineral density on average is elevated[22,23].

The model proposes that it is the softness of the bone material that is responsible for high bone density in XLH. Is this not contradicted by the fact that bone density is low in other mineralization defects, such as vitamin D deficiency? After all, the biomechanical properties of the bone tissue should be similar in all mineralization defects. Well, in calcipenic forms of mineralization disorders there is an absolute lack of substrate, whereas in the present perspective we were dealing with XLH patients receiving phosphorus supplementation. This provides enough substrate to mineralize bone matrix, albeit incompletely. In addition, XLH patients usually have normal (or only mildly increased) parathyroid hormone levels, whereas in calcipenic rickets the picture is compounded by secondary hyperparathyroidism.

Conclusions

In summary, this brief perspective argues that some of the anatomical and densitometric features of OI and XLH result from abnormal biomechanical bone properties at the material level, and that the mechanostat theory explains the link between the material abnormalities and the macroscopic features. In OI, bone material is too stiff, leading to underestimation of prevailing mechanical loads, which in turn results in low bone mass and inadequate bone architecture. In XLH, bone material is too soft, resulting in high bone density at trabecular sites and a relatively large size of diaphyses.

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ORIGINAL ARTICLE

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Human skeletal muscle structure and function preserved by vibration muscle exercise following 55 days of bed rest

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Abstract Prolonged immobilization of the human body results in functional impairments and musculoskeletal system deconditioning that may be attenuated by adequate muscle exercise. In a 56-day horizontal bed rest campaign involving voluntary males we investigated the effects of vibration muscle exercise (RVE, 2×6 min daily) on the lower limb skeletal muscles using a newly designed foot plantar trainer (Galileo Space) for use at supine position during bed rest. The maximally voluntary isometric plantar flexion force was maintained following regular RVE bouts during bed rest (controls −18.6 %, $P < 0.05$). At the start (BR2) and end of bed rest (BR55) muscle biopsies were taken from both mixed fast/slow-type vastus lateralis (VL) and mainly slow-type soleus muscle (SOL), each having $n = 10$. RVE group: the size of myofiber types I and II was largely unchanged in VL, and increased in SOL. Ctrl group: the SOL depicted a disrupted pattern of myofibers I/II profiles (i.e., type II > 140 % vs. preBR) suggesting a slow-to-fast muscle phenotype shift. In RVE-trained SOL, however, an overall conserved myofiber I/II pattern was documented. RVE training increased the activity-dependent expression of nitric oxide synthase type 1 immunofluorescence at SOL and VL myofiber membranes. These data provide evidence for the beneficial effects of RVE training on the deconditioned structure and function of the lower limb skeletal muscle. Daily short RVE should be employed as an effective atrophy countermeasure co-protocol preferentially addressing postural calf muscles during prolonged clinical immobilization or long-term human space missions.

Keywords Skeletal muscle atrophy · Neuromuscular disorders · Countermeasure · Rehabilitation · Spaceflight

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Introduction

Activity-dependent processes addressing the brain and spinal cord locomotor units or peripheral neuromuscular/musculoskeletal structures are critical for the maintenance of human performance (Baldwin and Haddad 2001). Prolonged body immobilization results in disuse-induced malfunctions and atrophy of these systems with impaired motor tasks and performance control (Fitts et al. 2001; Roy et al. 2000). The adverse structural and functional adaptations of the deconditioned neuromuscular and musculoskeletal system should be minimized through adequate physiological stimuli such as exercise in order to support performance control following clinical immobilization, in rehabilitation, or during extended spaceflight missions (Booth and Criswell 1997; Dietz 2002; Ohira et al. 1999; Shackleford et al. 2004).

Bed rest immobilization is a well-accepted analogue of inactivity-induced body deconditioning which is normally encountered by bedridden patients in clinical settings as well as by astronauts in extended spaceflight missions (Akima et al. 2000; Berg and Tesch 1994, 1998). Resistive exercise based on low repetition/maximally force-induced coupled concentric and eccentric muscle actions has been successfully applied as a countermeasure to skeletal muscle unloading and atrophy using the fly wheel device in a bed rest study (Alkner and Tesch 2004; Berg and Tesch 1994; Rudnick et al. 2004).

Resistive fly wheel training thus maintained myofiber architecture and sarcolemma membrane expression of nitric oxide synthases (NOS) suggesting altered NO-signaling pathways at functional skeletal muscle compartments (Rudnick et al. 2004). Nevertheless, we sought to test alternative modalities of muscle exercise comprising load-induced reflexive muscle actions in a short and simple regular countermeasure protocol against atrophy of lower limb postural muscle groups following prolonged immobilization.

Resistive-like muscle actions can be also initiated by vibration forces on muscle imposed by high frequency electrical or mechanical stimuli thereby supporting muscular strength as shown in animals (Schüler and Pette 1996) and humans (Adamo et al. 2002; Delecluse et al. 2003; Griffin et al. 2001; Maffiuletti et al. 2002; Roelants et al. 2004). Frequency-dependent vibration forces were successfully used as interventions to increase muscle power and force in physical training protocols or in rehabilitation (Cardinale and Bosco 2003; McBride et al. 2004). The beneficial effects of low frequency vibration forces (<30 Hz) on, e.g., limb muscle functions are thought to occur through adequate stimulation of the neuromuscular reflex loop activity (Rittweger et al. 2000, 2003) and the recruitment of high threshold motor units (Martin and Park 1997; McBride et al. 2004). We assumed that reflexive muscle contractions by adequate vibration stimuli might generate sufficient amounts of muscle cycles of contraction and relaxation exerting both ambient neuronal stimuli and mechanical strain. Resistive-like, i.e., load-induced reflexive muscle actions initiated by daily plantar vibration stimuli should at least partially mitigate atrophy of the lower limb muscles as an effective countermeasure to hypokinesia-induced atrophy.

We here report on the effects of a simple resistive-like vibration muscle exercise (RVE) training on ten healthy male volunteers (plus non-exercise control group, $n=10$) using a newly designed Galileo Space device based on a vibrating foot platform for use in supine position (Novotec Inc., Pforzheim, Germany) during 56 days of voluntary bed rest immobilization (Berlin Bed Rest 2003). The main purpose of this study was to test whether short bouts of RVE training (e.g., 2×3 min per day) preserved myofiber size and phenotype distribution, and the force production of thigh and calf skeletal muscle groups during bed rest. We further hypothesized that regular daily exercise with the Galileo Space vibrating foot platform during bed rest might stimulate activity-induced NOS expression in vastus lateralis (VL) and soleus (SOL) myofibers as recently shown with the maximally force-induced resistance exercise countermeasure during the 90-day Toulouse bed rest study (Rudnik et al. 2004). If so, short daily bouts with the Galileo Space trainer should be able to preserve muscle fiber morphology, molecular architecture and force production of the leg muscles. Thus, RVE training could be simpler than other types of exercise and should be easily implemented to future countermeasure protocols to preserve human performance control following prolonged deloading conditions on Earth or in Space.

Methods

The Berlin bed rest study (BBR) and ethical policies

A 56-day horizontal bed rest sponsored mainly by the European Space Agency (ESA) was organized at the Benjamin Franklin Hospital of the Charité University Medicine Berlin, Berlin, Germany, in 2003 and 2004. A total of twenty healthy male volunteers ($n=20$) were included in the study [mean age (years) 33 ± 5.6; mean BMI = body mass index (kg×m^{-2}) 23 ± 1.51, SD, $P<0.01$] according to defined subject characteristics (e.g., moderately active, no regular aerobic or resistance training regimen, no clinical musculoskeletal parameters, non-smokers). The candidates were randomly assigned to one of two groups, one control (Ctrl) group i.e., non-exercise, and one vibration muscle exercise (RVE) group, each having $n=10$. Five different campaigns including four subjects each (RVE and Ctrl, $n=2\times2$) were conducted to balance any seasonal effects. During bed rest the candidates were not allowed to stand up (routine video control and force transducers in bed frames), and were asked to strictly adhere to their supine position with no trunk lifting to more than 45°, and no brisk leg movements with large muscle force production other than during controlled exercise units. Physiotherapy in bed rest included passive ankle mobilization and gentle muscle massage (without stretching) twice a week to improve venous flow, and to help minimize any joint or muscle pain. Subjects were under the observations of a medical doctor daily. The diet was controlled with regards to caloric intake according to the Harris–Benedict equation with an adjustment factor of 1.2 (Harris and Benedict 1919).

All candidates gave written informed consent to participate voluntarily in the BBR study, to the risks and benefits of the study, and to the muscle biopsies. Approval was given by the local ethics committee of the Charité Universitätsmedizin Berlin, Germany. The study was conducted in accordance with the Helsinki Declaration for the Protection of Human Subjects. More detailed descriptions of the BBR study protocol including functional muscle parameters have been published elsewhere (Bleeker et al. 2005). Re-ambulation was performed on the fifty-seventh day after the onset of bed rest, between 8 a.m. and 11 a.m. Muscle function was tested immediately after re-ambulation, and in the evening of the same day (see below).

Resistive-like vibration exercise

Resistive-like vibration exercise was performed using a special Galileo Space device (Novotech Inc., Pforzheim, Germany) feasible for a daily muscle training program at the supine condition throughout bed rest immobilization. Briefly, the Galileo Space device consists of a vibrating foot platform (20–30 Hz), to which the subjects can attach themselves in supine position via elastic belts with their hips, their shoulders and their hands (see Fig. 1). The static force upon the vibration platform generated was about two times the body weight under resting conditions. The Galileo Space device generates platform vibration by means of the eccentric, anti-phase rotation of two masses under each foot. Hence, the left side and the right side of the platform accelerate alternately, i.e., when the left leg is accelerated towards the head, then the right leg is extending. As the frequency of the vibration is preset, this acceleration increases with vibration frequency, and so does the resistive-like force elicited by the leg extensor and flexor muscles. The amplitude of the vibration therefore results from the acceleration of the platform and the resistive force of the leg extension (usually in the range of 0.5–1 cm). During bed rest the vibration protocol consisted of two daily bouts (6 min each) at preset vibration frequencies of 19–25 Hz with a total of 89 exercise sessions scheduled for each subject between days BR0 and BR56 (Wednesday afternoon and Sunday off).

Calf muscle size and function

Maximum voluntary isometric plantar flexion force (MIPF) was measured in the left leg before the bed rest period (BDC-2 and BDC-1), and immediately (<1 h) after re-ambulation (BDC-56) in the morning (R1m), and in the evening of the same day (R1e). This was done

Fig. 1 The Galileo Space device used for resistive-like vibration exercise (RVE) protocols (RVE group) at supine position during 56 days of strict bed rest. During training, the bedridden candidate pushes the foot plantar region onto the vibrating Galileo platform (*left*) using elastic shoulder and hip straps and short elastic cords held in both hands (daily bouts 2×6 min at a.m./p.m.). During exercise, however, short but high repetition mechanical load (i.e., leg extension vs. acceleration) is transmitted alternately to each leg via the vibrating platform. We therefore defined this protocol RVE

with a split ground reaction force platform (Novotec, Pforzheim, Germany) and a custom-built restraint device. The subjects were tested in a seated position, with the ankle and knee joints at an angle of 90°. They placed their forefoot and the heel on either side of the split ground reaction platform. During each test, the subjects wore the same shoes, and markers were placed on the shoes in order to exactly reposition the foot on the force plate in the subsequent tests. The restraint 'clamped' the lower leg between the foot and the upper aspect of the knee, and the arms were behind the subjects' back. MIPF was then assessed as the change in ground reaction force under the forefoot. The best in three trials was taken from each testing session. During the contractions, strong verbal encouragement was given, and time was given to prevent fatigue. Also, subjects were carefully observed to maintain their body posture during the contractions. Goniometers were used to check possible flexion or extension movements within the ankle or knee joint. Data were digitized and analyzed with a PowerLab 16s analog–digital converting system and the integrated Chart software in its version 5.0 (AD Instruments, Sydney) at a sampling rate of 2,000 Hz. The reproducibility of this method to measure maximum plantar flexion force, as assessed over all subjects on days BDC-2 and BDC-1, turned out to be 3.4% of the mean.

Muscle biopsies

Skeletal muscle biopsies were taken on the second day (BR2) and close to the end (BR55) of the 56-day BBR, from the VL of the right hip flexor/knee extensor quadriceps muscle, and from the right calf soleus muscle (plantar flexor) of each volunteer according to a well-established method (Bergström 1962) and full medical care was thereafter provided according to a previously approved protocol (Rudnick et al. 2004). Because of potential anatomical variations (e.g., fiber size or type distribution), attempts were made to extract the samples from each individual at approximately the same location. All needle biopsy samples were immediately embedded in small silicone casts filled with Tissue-Tek (Sakura Fine Tek Europe B.V., The Netherlands), and immediately frozen in liquid nitrogen, and stored at −80°C until further analysis.

Myofiber structure and phenotype analysis

For histology and morphometry, samples were cryosectioned at 8-μm thickness (Leica CM 2800, Germany), mounted on glass slides (SuperFrost® Plus, Menzel-Glaser, Germany) and subjected to immunohistochemistry protocols. Muscle fiber typing was carried out with a monoclonal antibody (clone My-32, diluted 1:1500, Sigma Inc.) against fast myosin heavy chain (fMyHC) protein which also cross-reacts with the antigens IIA,B and IIC/X preferentially coexpressed in fast-type II myofibers, followed by application of the Cy-5 conjugated AffiniPure™ goat anti-mouse IgG secondary antibody (Dianova, Hamburg, Germany). In cross-sectioned profiles, only distinctly My-32 immunopositive fibers were designated as myofibers II (fast-type). The My-32 immunonegative fibers were always designated as myofibers I (slow-type). A small amount of myofibers revealing only faint My-32 immunostaining (i.e., hydrid fibers) was omitted from the analysis. Classification of myofiber types I and II into subtypes was not considered as adaptive responses of muscle fibers including time-dependent fiber transition (Pette and Staron 2001) may have occurred during the first weeks of bed rest. In addition, only very limited amounts of human biopsy tissue were available mainly due to ethical reasons (Rudnick et al. 2004).

The pattern of slow and fast-type myofiber profiles was determined by quantification of the amount of immunostained myofibers I and II in cryosections. Selective counts of My-32 immunonegative versus immunopositive fibers were made in arbitrarily chosen cohorts of 50 cross-sectioned myofibers found each in cryosections of VL and SOL biopsies from all subjects of the Ctrl and RVE group at the start (BR2) or end of bed rest (BR55) followed by subject-matched analysis (triple determination).

The size of muscle fibers was determined by mean myofiber cross-sectional area (CSA) determination in NOS1/My-32 double-immunostained cryosections (Rudnick et al. 2004). The standardized area profiles thus generated represented the square microns (μm^2) myofiber CSA. A total of 100 myofibers I and II was thus measured in double-immunostained VL or SOL cryosections of either groups at the start (pre) and end of bed rest (post).

NOS immunofluorescence intensity

The expression of NOS1 was determined by measuring the relative fluorescence intensity of immunostained sarcolemma membrane structures according to a well-established NOS1 immunostaining protocol optimized for human skeletal muscle cryosections (Rudnick et al. 2004). Briefly, the area pixel intensity of the defined regions of interest (ROI) selected from the immunostained sarcolemma structures (total 1,000 μm^2) of each myofiber type I or II was measured in digital confocal image scans and expressed as arbitrary units (a.u.) by the Leica software (in the range of 0–255 a.u.). At least ten type I and/or type II myofibers were thus measured from each cryosection. Changes of NOS1 intensity at myofiber sarcolemma membranes determined by area-based pixel intensity measurements between individual candidates and groups were calculated as percent changing of a.u. of postBR (Δ%) versus preBR (set as zero %).

In all immunostaining protocols we used either green fluorescent anti-mouse ALEXA 488-conjugated and/or red fluorescent anti-mouse ALEXA 555-conjugated affinity-purified secondary antibodies (Molecular Probes, OR) diluted at final concentrations of 1:3,000–1:5,000, respectively. Immunohistochemical staining was applied on subject-matched cryosections from the Ctrl and RVE group in one and the same incubation protocol in order to achieve identical immunostaining conditions for comparison analysis. Immunofluorescence images were scanned with a three channel confocal laser scanning microscope (Leica TCS SP-2, Leica Microsystems, Bensheim, Germany) at standardized image settings, and all digitalized images were analyzed using the Leica confocal software.

Biochemical analysis

The relative NOS 1 protein content in skeletal muscle biopsies was determined in electrophoresed subject-matched lysates of muscle biopsies, immunoblotted (Protean mini-system, BioRad Inc.), and quantified by densitometric scanning of immunostained protein bands (GS-800 device, Quantity-One™ software, BioRad Inc., Munich, Germany). Because the total amount of biopsy material was very limited only samples of three subjects were immunoblotted for each group (i.e., $2\times n=3$) in triplicate according to previously described methods (Rudnick et al. 2004). Mean optical density (OD) values were expressed as the relative percent difference of postBR versus subject-matched preBR samples (preBR arbitrarily set as the zero percent baseline).

Data analysis and statistics

MVC data of the two baseline testing sessions (BDC-2 and BDC-1) were averaged to yield a single baseline data collection (BDC) value. The SPSS software package (http://www.spss.com) was used to perform a *t* test for group differences at baseline, and a repeated measures ANOVA for time effects (BDC, R1 morning, and R1 evening) and group interactions were carried out with simple contrasts referring to BDC. Post hoc tests and *t* tests were performed in order to further analyze group time interactions for the different days. Muscle biopsy data were analyzed using the SigmaPlot software and are given as mean ± SEM. The significance of differences of data was analyzed with the Student‘s test. Differences were regarded to be statistically significant at $P<0.05$. Values represent triple determination from each immunostained cell structure or biopsy sample.

Results

RVE training by the Galileo Space device

Figure 1 illustrates the experimental set-up of the Galileo Space device during an active training session (i.e., before start of bed rest) at supine position in bed rest. In general, RVE was well tolerated by the subjects. During the 8 weeks of bed rest, exercise progression was achieved mainly through increases in vibration frequency, which was set to 19 Hz at the beginning in all subjects, and to 25.9 Hz (SD 1.9) toward the end of bed rest on average at the end (60) (Rittweger et al. 2003). During BR, lower limb pain was slightly more frequent in the RVE subjects than in Ctrl ($P = 0.035$). However, this led to the canceling of only 12 out of 770 exercise sessions because of pain.

Calf muscle force (maximum voluntary isometric plantar flexion force)

Repeated measures using ANOVA revealed significant changes in the MIPF ($P < 0.001$ for both). For comparison, relative changes are illustrated (Fig. 2). Within the RVE group, no significant change was observed from BDC to the re-ambulation day 1 (R1, $P = 0.83$). Conversely, a decrease by 18.9% (SD 9.0) was observed in the Ctrl group ($P < 0.001$). In both groups, the loss in MIPF was reduced between the re-ambulation day 1 morning (R1m) and evening (R1e) measurements. In the RVE group, this reduction was 9.2% (SD 12.0, $P = 0.015$) of the BDC value, and in Ctrl it was by 32.9 (SD 10.7, $P = 0.009$).

Myofiber size measurement (cross-sectional area)

We measured the myofiber CSA in VL and SOL muscles by the morphometric analysis of subject-matched pre and post biopsy samples. In VL, significant changes of the myofiber size were not apparent in both the Ctrl and RVE group. In non-trained SOL, CSA values, however, decreased in myofibers I and II (Fig. 3). Following RVE, the CSA increased in both myofibers I and II at the end of the bed rest period. The latter results documented an increase in SOL myofiber I and II size possibly due to fiber hypertrophy induced by the RVE training during bed rest.

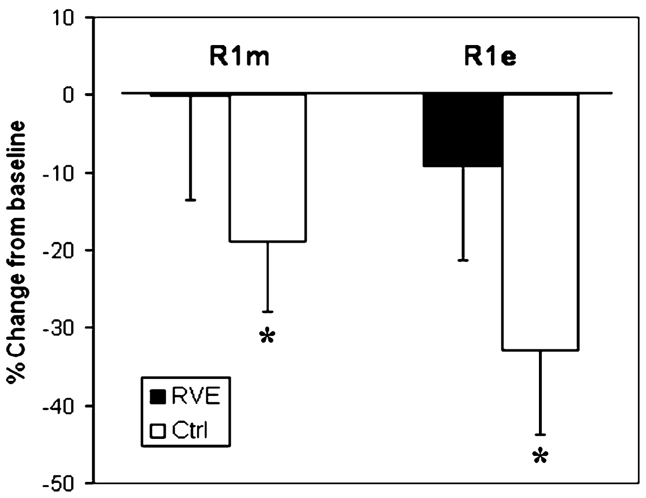

Fig. 2 Percent changes in maximum isometric voluntary plantar flexion force (MIPF) relative to baseline. Measurements were performed in the morning and in the evening of the re-ambulation day (R1m and R1e, respectively). Significant differences were found not only between groups ($P < 0.001$), but also between R1m and R1e (*asterisk*). For the RVE group alone, the change at R1m was non-significant ($P = 0.98$), indicating that force generation was unimpaired in this group directly after re-ambulation

Myofiber type and distribution pattern

Robust changes in the myofiber type I and II distribution pattern in subject-matched biopsy samples were found in SOL but not in the VL muscle using fast MyHC immunohistochemistry based on high-resolution confocal laser microscopy (Fig. 4). In the Ctrl group, the relative amount of myofibers II in a defined population of SOL myofibers increased significantly (>140% vs. preBR control) while the relative amount of myofibers I in the same population remained largely unchanged. In the RVE-trained SOL (Fig. 4), significant changes were not detectable between the relative amounts of slow and fast-type myofibers I and II. Therefore, the normal fiber

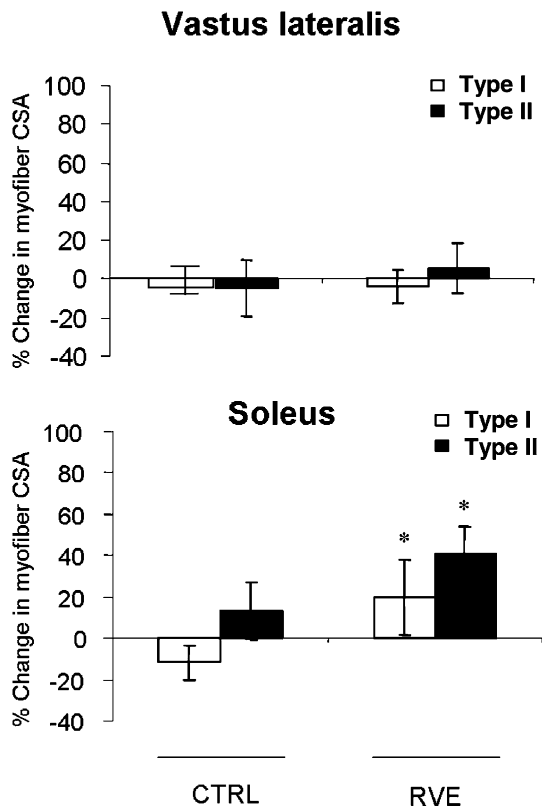

Fig. 3 Bar graphs with myofiber size measurements by cross-sectional area (CSA) determination. **a** In VL and SOL, myofiber I and II CSA changes at postBR were not significantly different from the preBR values in either of the groups. **b** In trained SOL, CSA values of myofibers I and II were significantly increased (*asterisk*) suggesting that hypertrophy was induced by RVE muscle activity

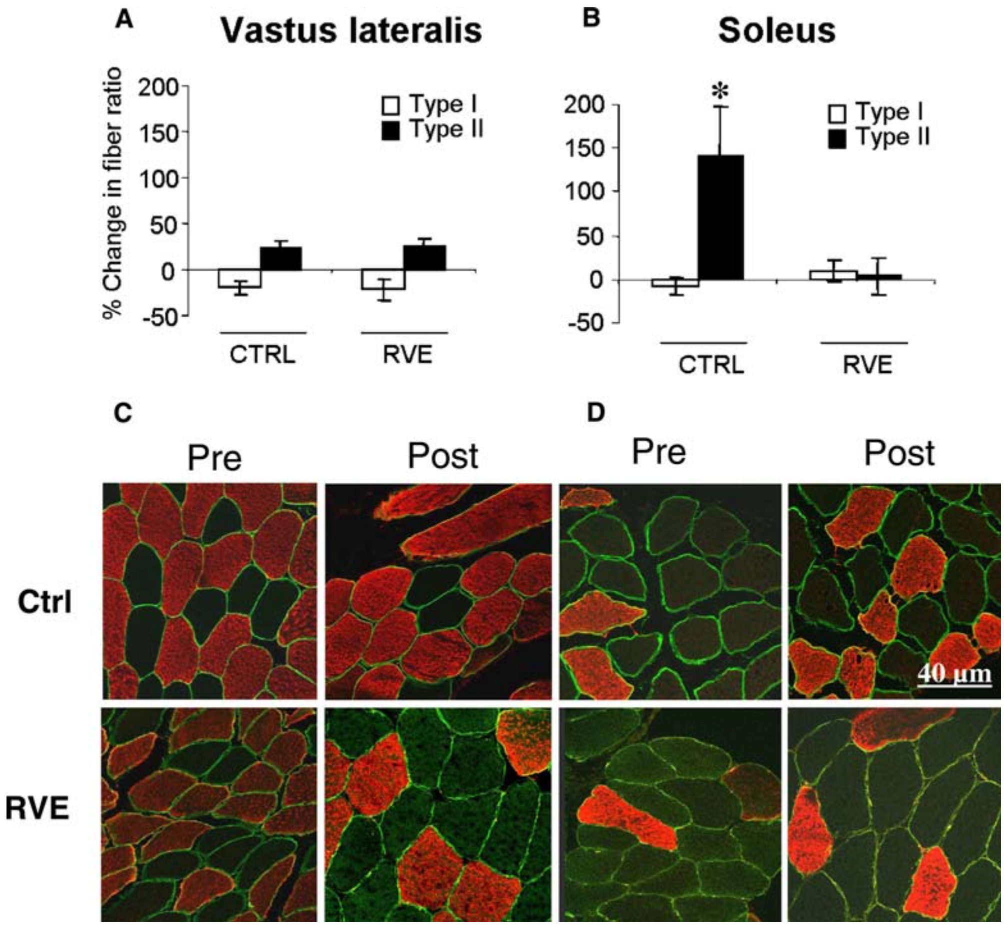

Fig. 4 Determination of myofiber ratio (type I vs. II) in VL and SOL biopsies of the control versus RVE group. **a** In VL muscle, the amount of myofibers I and II did not change significantly between the preBR and postBR samples of either groups. **b** In SOL muscle, significantly more myofibers II were detectable in the control group (+140% baseline) with bed rest only. Notably, this dramatic change was absent from the SOL trained by RVE during bed rest suggesting maintenance of muscle phenotype. **c**, **d** Representative pairs of merged confocal images (NOS1/fMyHC) that show marked changes in the presence of myofibers I (My-32 negative) and II (My-32 positive, red). *Bar* 40 µm (C, D only top)

type I > type II distribution pattern determined in SOL at the start of bed rest was clearly disrupted in untrained SOL (without RVE) at the end of bed rest period. However, similar changes were not observed in RVE-trained SOL at the end of bed rest. Given the fact that subject-matched analysis has been performed in this study, RVE training prevented the SOL from phenotype shifting toward a morphological "fast-type" muscle that is likely to contain more myofibers II (fast-type) than normally found in such a slow-type postural calf muscle.

NOS1 immunohistochemistry

In skeletal muscle, NOS1 immunofluorescence signals are concentrated at sarcolemma membrane structures that may be altered by muscle activity. We therefore used relative fluorescence intensity measurements of NOS1 protein patterns by confocal microscopy and the ROI-dependent pixel analysis as morphological indices of the functional sarcolemma membrane integrity in skeletal myofibers of both VL and SOL. In the Ctrl group, the sarcolemmal NOS1 immunofluorescence intensity significantly decreased in both myofibers I and II of both VL and SOL (Figs. 5, 6). In the RVE group, both VL and SOL showed increased relative fluorescence intensity values of sarcolemma NOS1 independently of the myofiber type I or II identified by fast MyHC in double-staining. Confocal analysis confirmed that in both VL and SOL muscle RVE training maintained or even upregulated the NOS1 immunofluorescence intensity at the myofiber sarcolemma membrane.

NOS 1 immunoblot analysis

We also determined the relative changes of NOS 1 protein concentration in VL and SOL in three subject-matched skeletal muscle biopsy samples by the quantitative immunoblot analysis of pre versus post samples of equal protein amounts in both the Ctrl and RVE groups (Fig. 7). In samples from the Ctrl group ($n = 3$), the post

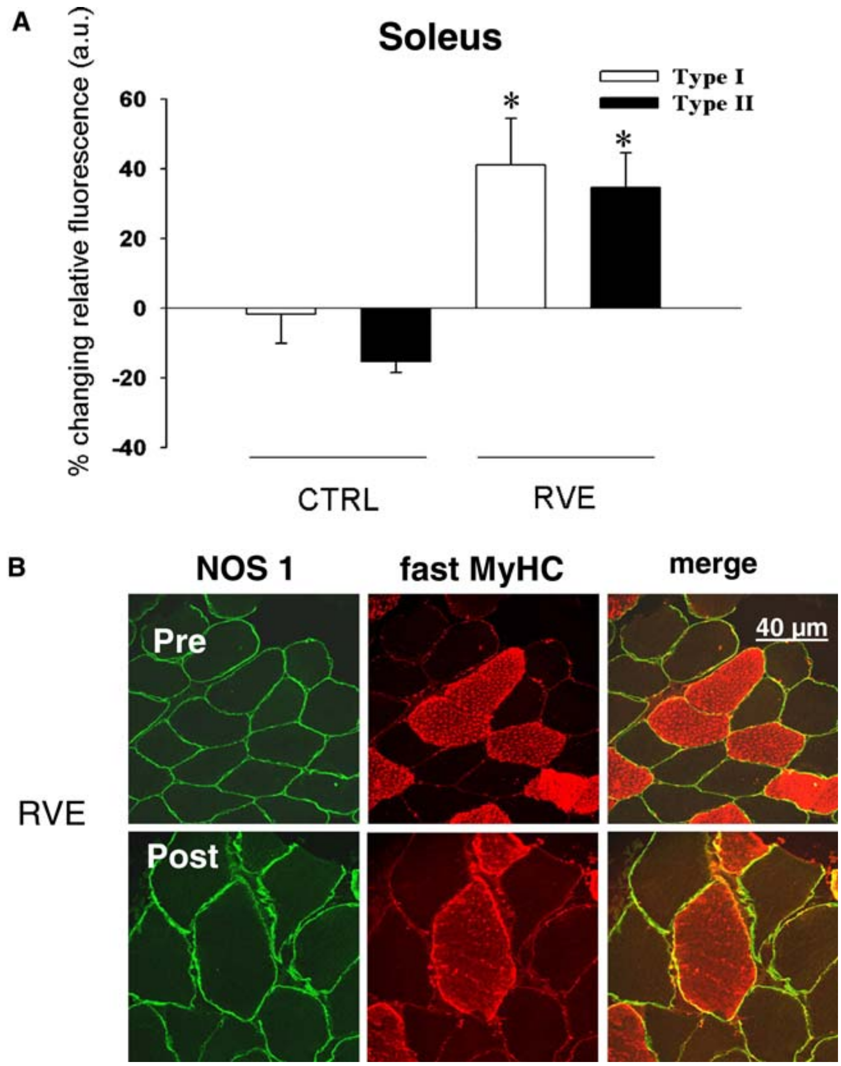

Fig. 5 Expression of muscle fiber activity marker NOS1 in subject-matched SOL muscle biopsies. **a** Graph with percent changing of the relative immunofluorescence intensity of sarcolemmal NOS1 in myofibers I (*open bars*) and II (*black bars*) of the control and RVE group. **b** Pairs of representative confocal images showing NOS 1 immunoreactivity (*green*), and NOS1/fast MyHC double-staining (*red/green merged*) from the same subjects of the RVE group (Ctrl group not shown). Sarcolemma NOS-1 immunoreactivity as well as myofiber size are significantly increased in both myofibers I and II (RVE) due to vibration muscle exercise. *Bar* 40 µm

bed rest NOS1 protein level was clearly changed as compared to the pre bed rest levels set as baseline (by minus 10–30% relative to baseline). In samples from the RVE group ($n = 3$), the post bed rest NOS1 protein level was clearly increased (by plus 20–130% relative to the baseline). Similar changes were not found in VL biopsies of either the Ctrl or RVE group.

Discussion

Vibration muscle exercise in bed rest

In the present study vibration muscle exercise was applied to lower limb muscles by a vibrating footplate for use at supine position in order to test the efficacy of the Galileo Space device as a countermeasure against the loss in skeletal muscle structure and function following extended body immobilization. The device has been constructed in order to effectively transmit the vibration stimulus (i.e., controlled by Hz and amplitude) to the leg muscles (and bone) by the pressing of the subject's feet onto the vibrating footplate using a simple system of elastic straps and belts (cf. Fig. 1). As foot and leg pressing appear to be necessary for transmitting adequate vibration stimuli generated by the oscillated foot platform acceleration (cf. ergometric lower body imbalance control), the vibration exercise protocol is based on both reflexive-loop coordination (via muscle or tendon spindles) and loading as well as unloading of the leg extensor and flexor muscle chains. The RVE protocol must be therefore characterized as reflexive plus "resistive-like" vibration muscle exercise. Simple muscle vibration or strenuous shaking impulses on local muscle groups coming from different vectors or angles have been frequently reported to show multiple adverse effects (e.g., edema, nerve conductivity problems; cf. Adamo et al. 2002; Bongiovanni et al. 1990; Gauthier et al. 1981; Ivanenko et al. 2000; Martin and Park 1997; Rittweger et al. 2003; Roelants et al. 2004). Therefore, inclusion of a second control group subjected to shaking/vibration impulses of the calf or thigh region without

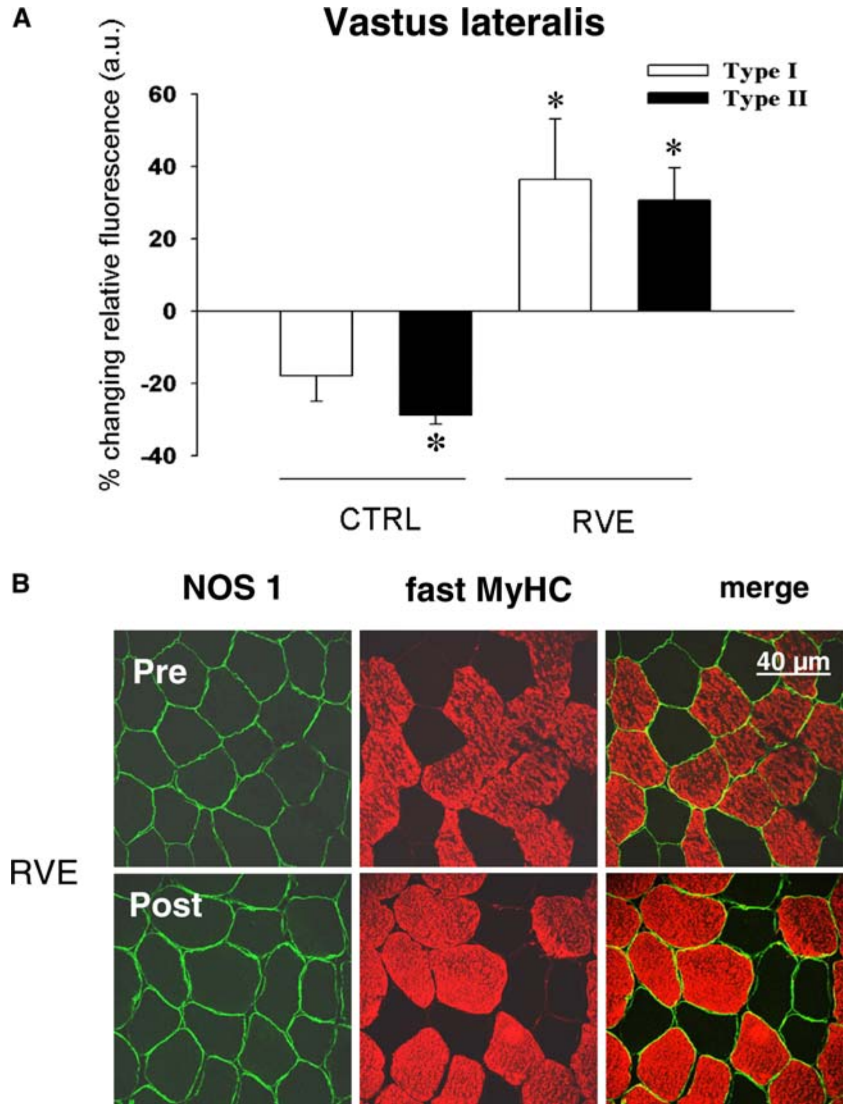

Fig. 6 Expression of muscle fiber activity marker NOS1 in subject-matched VL muscle biopsies. **a** Graph with percent changing of the relative immunofluorescence intensity of sarcolemmal NOS1 in myofibers I (*open bars*) and II (*black bars*) of the control and RVE group expressed as arbitrary units (a.u.). **b** Pairs of representative confocal images showing NOS 1 immunoreactivity (*green*), and NOS1/fast MyHC double-staining (*red/green merged*) from the same subjects of the RVE group (Ctrl group not shown). NOS 1 immunoreactivity is slightly decreased in the myofibers I and significantly decreased in the myofibers II (Ctrl) group. In trained VL, both myofibers I and II revealed elevated fluorescence intensity values reflecting increased NOS 1 immunodetectable antigen expression due to RVE-dependent muscle activity. *Bar* 40 µm

frequency-controlled RVE was not considered due to the obvious adverse effects and the overall experimental design and hypothesis tested in this study.

Multiple effects on the musculoskeletal system exposed to high frequency vibration forces were reported in animal models (Rubin et al. 2001) or in humans (Ivanenko et al. 2000). Plantar vibration exercise with the Galileo Space device (19–26 Hz) is, however, thought to be based upon reflexive muscle actions generating high numbers of muscle contraction–relaxation cycles (i.e., 26 Hz is equivalent to approximately 1,600 cycles/min). Reflexive muscle actions are likely producing mechanical strain as well as neuromuscular activation sufficient to maintain the structure and function of the musculoskeletal system (Sale 1988). The RVE protocol used in and the results from the BBR study are in support of this hypothesis. As discussed above, RVE is clearly different from the effects of whole body vibration or extremely high vibration forces to defined body regions (> 100 Hz) that might result in adverse body effects or even detrimental effects on motor firing rates and force (Bongiovanni et al. 1990). Frequency-controlled muscle vibration therefore has been previously tested for an effective training protocol in exercise and sports performance (Cardinale and Bosco 2003; Meester et al. 1999; Roelants et al. 2004) as well as in rehabilitation (Cardinale 2004). Nevertheless, the precise neuromuscular control mechanisms remain to be determined.

Muscle fiber type and size

Muscle exercise affects the distribution of the myofiber phenotype I/II profile in terms of fiber type composition in a given muscle. In previous animal hypokinesia studies, a shift from slow-to-fast or fast-to-slow myofiber pattern was documented in lower limb muscles, a process known as fiber type transition (Pette and Staron 2001). In humans, the myofiber type pattern in SOL

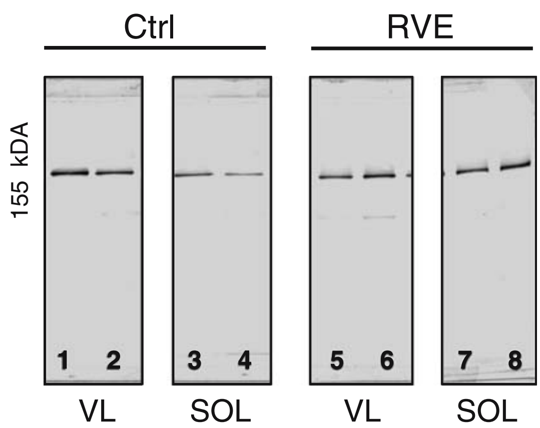

Fig. 7 NOS-1 immunoblot analysis. Subject-matched VL and SOL immunoblots showing representative pairs of pre versus post biopsy samples of the Ctrl and RVE group. Identical amounts of protein/lanes 1–8 (protein load 50 μg/ml) were electrophoresed for three subjects ($n=3$) per group in the same gels followed by subsequent immunoblotting (triple determination). As shown, NOS-1 immunostained protein bands (155 kDa) of post samples (lanes 2, 4, 6, and 8) are either decreased (Ctrl) or increased (RVE) as compared with pre samples (lanes 1, 3, 5, and 7). For densitometric analysis of immunostained bands (cf. results)

muscle (with usually more type I than II myofibers) showed a slow-to-fast shift following mechanical deloading (Caiozzo et al. 1996) confirming a similar fiber transition as previously seen in animal studies. Surprisingly, we found that in RVE-trained SOL the relative myofiber type I/II ratio was not significantly altered when compared with subject-matched pre bed rest ratios suggesting preservation of muscle fiber phenotype. Notably, soleus and vastus muscles have different fiber patterns which may explain for the muscle-specific fiber patterns resulting from inactivity/activity or microgravity responses of slow-type versus fast-type muscles. However, similar results were not found in the RVE-trained VL muscle using identical morphometric analysis and immunostaining protocols.

As shown in previous studies, the morphometric analysis of muscle fiber size as well as protein synthesis in VL and SOL suggested a relative inability of the SOL muscle to respond to resistive exercise training protocols in bed rest or ambulatory candidates (Rudnick et al. 2004; Trappe et al. 2004). Further metabolic studies using amino acid infusion into VL and SOL of ambulatory individuals as an attempt to compensate for the ineffectiveness of SOL following resistive exercise countermeasure confirmed the presence of muscle-specific protein metabolism (Carrithers et al. 2002; Carroll et al. 2004). Our results support the idea that our RVE protocol predominantly recruited the calf muscles (local ankle plantar flexors) via the single-joint muscle kinetic chain. However, the structure and function of the VL muscle was less well preserved by our RVE protocol. Therefore, we assume that plantar vibration exercise may be less effective for recruitment of the lower limb multi-joint muscle kinetic chain including the knee extensors or thigh flexor muscles.

Nitric oxide expression

Molecular domains of the muscle membrane are considered as putative targets of mechanical stimulus transmission and should be, at least partially, affected in response to mechanical stimuli. In skeletal muscle cells, NOS1 is associated with the sarcolemmal dystrophin–glycoprotein complex via syntrophin which is linked to the subsarcolemmal actin network (Bredt 1999). Nitric oxide signals generated by NOS play important roles in normal muscle physiology. The production of NO is upregulated by muscle activity. Nitric oxide signals are released from contracting muscle cells (Balon 1999) and were shown to increase force and actomyosin ATPase activity in skeletal muscle (Perkins et al. 1997). NO appears to have important functions as local modulators of functional membrane molecules such as ion channels and receptors that are involved in various transduction processes at the outer muscle cell membrane during muscle contraction (Blottner and Lück 2001). In a previous study, we found that bed rest immobilization clearly impaired NOS1, -2 and -3 protein synthesis in human skeletal muscle and decreased the sarcolemma NOS1 expression of muscle cell fibers indicating important functional roles for activity-dependent NO-signaling (Rudnick et al. 2004). The NOS 1 protein is normally found concentrated at sarcolemma structures but can also be found in the sarcosol due to intracellular redistribution as shown in mouse development (Blottner and Lück 1998). Subcellular redistribution mechanisms of signaling proteins like NOS1 detectable by immunohistochemistry may occur during extended bed rest without affecting relative protein amounts per mg of tissue. This could explain some discrepancies between relative NOS1 protein levels immunoblotted from biopsy lysates and NOS 1 immunostaining patterns found at myofiber membranes in cryosections of pre versus post bed rest biopsies.

Effects of muscle vibration in neuro-rehabilitation or clinical muscle atrophy

Human postural reflexes play important functions following body deconditioning as well as in neuro-rehabilitation. Postural reflexes have been previously investigated in underwater simulated microgravity (Dietz et al. 1989). The effects of vibration on limb muscles may occur through the stimulation of cutaneous, muscular and articular mechanoreceptors/sensors (Gauthier et al. 1981; Park and Martin 1993) and facilitation of lower limb muscle stretch reflexes as neuromuscular compensatory response to, e.g., body imbalance or gait coordination (Ivanenko et al. 2000; Verschueren et al. 2002). More recently, the plantar load receptor hypothesis has been discussed for proprioreceptive muscle stretch reflexes in human gait control (Dietz and Duysens 2000). Muscle fiber recruitment by vibration stimuli mechanisms may be also critical, for example, for bipedal body equilibrium in gait control. The load-induced proprioceptive reflexes for bipedal body equilibrium control activating intrafusal muscle fibers or Golgi tendon spindles via excitatory group Ia/b afferent input may be adapted by feedback stimuli programmed in the central nervous system (Dietz 2002). Finally, RVE could also serve as a countermeasure against neuromuscular atrophy in skeletal muscle disease. Therefore, RVE protocols may have implications not only for astronauts in space but also for patients in various clinical settings including neuromuscular diseases or rehabilitation.

In conclusion, the present findings provide provocative evidence that both calf muscle structure and force production can be maintained during 8 weeks of strict bed rest by RVE training. Similar finding were not confirmed for VL muscle following the RVE protocol. Our findings also indicated obvious functional correlations between NOS distribution at the sarcolemma membrane and RVE-driven muscle activity, underpinning the efficacy of the RVE training for maintenance of the soleus muscle architecture and its myofiber composition in particular. Short plantar RVE training protocols appear to be simpler than other types of exercise and may be implemented in future countermeasure protocols to offset disuse-induced atrophy of postural leg muscles during prolonged clinical bed rest, in rehabilitation, or in spaceflight.

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Platform accelerations of three different whole-body vibration devices and the transmission of vertical vibrations to the lower limbs

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ABSTRACT

Physical whole-body vibration (WBV) exercises become available at various levels of intensity. In a first series of measurements, we investigated 3-dimensional platform accelerations of three different WBV devices without and with three volunteers of different weight (62, 81 and 100 kg) in squat position (150° knee flexion). The devices tested were two professional devices, the PowerPlate and the Galileo-Fitness, and one home-use device, the PowerMaxx. In a second series of measurements, the transmission of vertical platform accelerations of each device to the lower limbs was tested in eight healthy volunteers in squat position (100° knee flexion). The first series showed that the platforms of two professional devices vibrated in an almost perfect vertical sine wave at frequencies between 25–50 and 5–40 Hz, respectively. The platform accelerations were slightly influenced by body weight. The PowerMaxx platform mainly vibrated in the horizontal plane at frequencies between 22 and 32 Hz, with minimal accelerations in the vertical direction. The weight of the volunteers reduced the platform accelerations in the horizontal plane but amplified those in the vertical direction about eight times. The vertical accelerations were highest in the Galileo (~15 units of g) and the PowerPlate (~8 units of g) and lowest in the PowerMaxx (~2 units of g). The second series showed that the transmission of vertical accelerations at a common preset vibration frequency of 25 Hz were largest in the ankle and that transmission of acceleration reduced ~10 times at the knee and hip. We conclude that large variation in 3-dimensional accelerations exist in commercially available devices. The results suggest that these differences in mechanical behaviour induce variations in transmissibility of vertical vibrations to the (lower) body.

1. Introduction

Because physical condition reduces with age, regular endurance training exercises are advised. It has been demonstrated that these exercises have profound benefits to prevent atrophy of muscles [1], functional impairment [2], obesities [3], cardiovascular diseases [4] and fragility fractures among elderly population [5]. Moreover, the assessment of overall physical fitness has become part of pre-operative screening in patient management. Traditional lower limb training methods like progressive resistive exercise (PRE), proprioceptive neuromuscular facilitation (PNF) and cycling exercises [6,7] may preserve or improve lower muscle strength. However, the effectiveness of these methods is reduced in elderly patients with balance or vestibular disorders [8]. A relatively new method to recruit muscles is whole-body vibration (WBV). A subject stands or sits on a vibration platform. The vibrations are induced via this platform and control and safety handles provide stability [9,10]. WBV training can be done at home, which reduces therapeutic cost and patient travel expenses.

Recently, effects of WBV training on muscle strength [11–16], bone density [9,17], cardiovascular parameters [18] and body balance have been investigated [19,20]. One proposed physiological impact of WBV on muscle performance is activation of the Tonic Vibration Reflex (TVR) [9]. Some reflexes, i.e. Hoffmann and Tendon reflexes, as well as tendon vibration response are substantially depressed when specific vibration patterns were applied to the body or to the legs of seated human subjects [21,22]. It might be that vibrations first stimulate primary muscle spindle (Ia) fibres, which subsequently result in a reflex at the level of spinal cord. It was shown that high platform accelerations are associated with high muscle activity levels [23], but it is still unclear to what extent WBV induces these reflex muscle activations and how this would lead to improved muscle performances.

Work on human responses to (whole body) vibration dates back from almost half a decade ago [24,25]. Biomechanical models

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[26,27] and human physiological measurements in sitting [28–31] and standing posture [32–36] have addressed the transmission of whole-body vibration to various body segments. Most studies that related to exposure of vibrations in sitting postures had a special focus on the prevention of low back problems. Besides different postures and the variability in activity levels of the subjects studied, the differences between effects of WBV may also be related to the variability in the vibration devices presently on the market. Mostly, WBV is induced using either a Power Plate or a Galileo. Although some of the technical specifications of these commonly used devices on vibration frequency are available, it is not fully investigated whether body mass might influence for example vibration platform accelerations. A recent study investigated gravitational forces at the vibration surface of the Galileo 2000 [32]. At present, simple and very cheap home-use vibration devices, i.e. the PowerMaxx, have become available as well. The platforms deliver different types of vibration. The PowerPlate induces vertical vibrations, the Galileo induces seesaw vibrations and the PowerMaxx induces vibrations in the horizontal plane. The purpose of the present study was to compare the mechanical behaviour of three different WBV devices in "unloaded condition" and "loaded condition". The aims of the present study were:

1. To study the 3-dimensional (horizontal (*X*, *Y*) and vertical (*Z*) direction) platform accelerations of two commonly used professional WBV devices (PowerPlate and Galileo) and that of one simple home-use device (PowerMaxx) under different loading conditions.
2. To study the transmission of vertical platform accelerations of all three devices to the lower limbs at the lowest common preset frequency.

We expected to find no differences in platform frequency and only small differences in platform acceleration under different loading conditions with respect to the PowerPlate and the Galileo. With respect to the PowerMaxx, we expected rather large changes in platform acceleration values under loading conditions. Based on these expectations, we hypothesised to find large differences in transmission of vertical vibrations between the devices at the level of the ankle, knee and hip at one common platform frequency.

2. Materials and methods

In the present study, the PowerPlate (PowerPlate International, The Netherlands), the Galileo-Fitness (Novotec Medical GmbH, Germany) and the PowerMaxx (DS-produkte GmbH, Germany) were tested, see Fig. 1 for a schematic drawing. The two professional devices, the PowerPlate and the Galileo, could be set at vibration frequencies between 25–50 and 5–40 Hz, respectively. No frequency specifications were given for the PowerMaxx; 9 levels of vibrations were indicated (S1–S9). Two electro motors, each provided with an eccentric mass, controlled the platform vibrations of the PowerPlate. The platform could be set in two different modes: 'low' or 'high' implying a low or high platform displacement to alter the level of intensity workout. The Galileo platform oscillated around a central axis. A crankshaft principle on each side of the platform translated the rotating motion of the electro motor into a vertical displacement, inducing a seesaw vibrations. Depending on the position of the feet on the platform, the displacement is either small (feet near the axis) or large (feet near the edge of the platform). The vibrations of the PowerMaxx platform were controlled by an eccentric mass that was connected to one electro motor. This mass induced horizontal platform vibrations. In each device, a control panel allowed presetting the vibration frequencies.

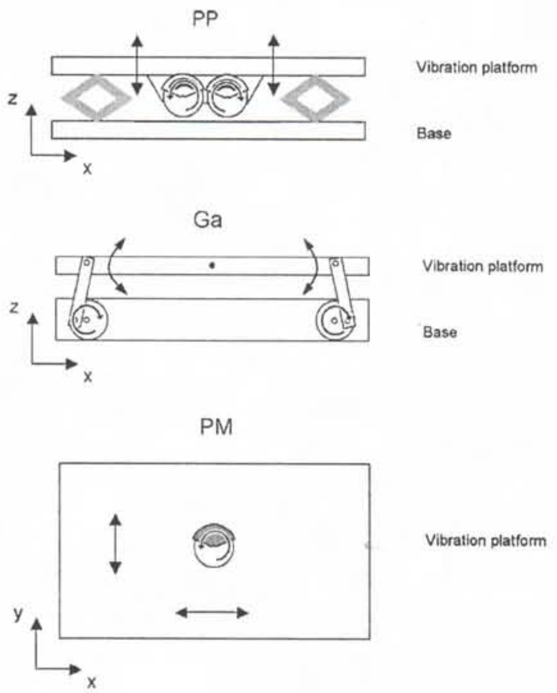

Fig. 1. A schematic drawing of the vibration directions of the three WBV devices tested: the PowerPlate (PP), the Galileo-Fitness (Ga) and the PowerMaxx (PM). Indicated are the vertical (*Z*) and the two horizontal (*X*, *Y*) directions.

2.1. Measurement setup

To measure the acceleration in the horizontal (*X*, *Y*) and vertical (*Z*) direction, three piezo-resistive accelerometers (ICSensors 3021-005-P, max. $\pm 50\,m/s^2 \sim 5\,g$) were placed in a custom made PVC container. A fourth accelerometer (Analog Devices ADXL150JQC, max. $\pm 500\,m/s^2 \sim 50\,g$) was placed in the container to measure accelerations exceeding 5G in vertical direction. The container with the accelerometers was fixed in the centre of the PowerPlate and PowerMaxx platform using two bolts. It was fixed at 185 mm from the rotating axis of the Galileo platform. The signal of each ICSensor was electronically amplified and together with the signal of the ADXL fed to a 14 bit A/D convector (National Instruments DAQmx USB-6009). The signals were sampled with a frequency of 1000 Hz and stored on a standard PC. Each accelerometer was calibrated on the basis of a two point calibration by applying zero gravity and the earth's gravity of 1 g (9.81 m/s^2). An offset equal to earth's gravity was subtracted from all acceleration signals in vertical direction to make all signals start at 0 m/s^2. A custom written LabVIEW program calculated of each 1000 samples the maximum acceleration, a_{max}, and the root mean square value of the acceleration, a_{RMS}, in each direction. The corresponding frequency component, f_{out}, was calculated from the FFT transformed acceleration signal. We selected the lowest frequency; higher harmonic frequencies were not selected for further analysis. At each preset f_{in}, platform accelerations were measured for 10 s starting with the lowest f_{in}. After 10 s, f_{in} was increased in the same recording and the platform accelerations were again measured for 10 s. The first 2–3 s of each measurement was the response time to this stepwise increase of the frequency. We therefore took the last 5 s for further analysis. After 60 s, a measurement was ended and a new measurement was done. The average and standard deviation of the a_{RMS} and f_{out} values were derived from the set of a_{RMS} and f_{out} values calculated in each second of the last 5 s. In a pilot run, we fitted a sine function through test acceleration signals of each (unloaded) device at a low preset frequency and a high preset frequency. We found very small fit errors

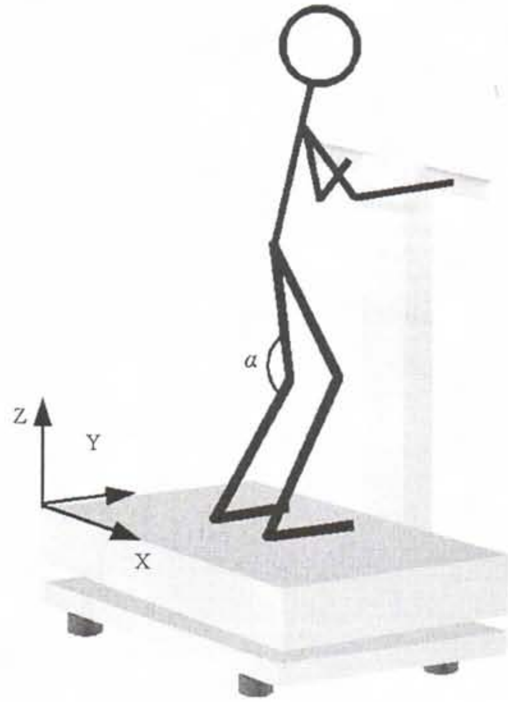

Fig. 2. A schematic drawing of a healthy subject standing in squad position with knee angle α on a WBV device. Indicated are the vertical (Z) and the two horizontal (X, Y) directions.

for the PowerPlate and the Galileo and for the PowerMaxx at low frequency (S1) of less than 0.5%. At high frequency (S9), the fit error for the PowerMaxx increased, but was still less than 2%. Based on these small errors, we assumed sinusoidal platform motions for each device and calculated the maximum platform displacement, d_{max}, at the location of the accelerometer using the following set of equations:

$$d(t) = A \cdot \sin(\omega \cdot t) \tag{1}$$

$$a(t) = d''(t) = \frac{\partial^2 A \cdot \sin(\omega \cdot t)}{\partial t^2} = -\omega^2 \cdot A \cdot \sin(\omega \cdot t) = -\omega^2 \cdot d(t) \tag{2}$$

$$d(t) = -\frac{1}{\omega^2} \cdot a(t) = -\frac{1}{f_{out}^2 \cdot 4\pi^2} \cdot a(t) \tag{3}$$

$$d_{max} = \left| -\frac{1}{f_{out}^2 \cdot 4\pi^2} \cdot a_{max} \right| \tag{4}$$

where $d(t)$ is the displacement in time, A is the amplitude, ω is the angular frequency ($=2\pi f_{out}$) and $a(t)$ is the acceleration.

2.2. First measurement series: 3-dimensional platform accelerations

In the first series of measurements, a_{RMS} and f_{out} were determined for preset vibration frequencies, f_{in}, of each device without and with a weight placed on each platform. Initial tests to apply passive weight (masses of 10 kg each up to 80 kg) to each platform failed due to movement of the weights. An additional test using sand bags of 10 kg each failed as well, despite the fact that we tried to stabilise this load with large belts. Therefore, we asked two experienced vibration platform user (62 and 81 kg) to test each platform in squat position (knee angle α of 150° measured with a manual goniometer) and a third experienced vibration platform user of 100 kg for additional testing the PowerMaxx, see Fig. 2. In this way, the platforms were equally "loaded" and a squat position was chosen to prevent excessive head oscillations. The f_{in} of the PowerPlate was preset at 25 Hz and stepwise increased in steps of 5 Hz to its maximum of 50 Hz in "high" as well as "low" amplitude mode. The f_{in} of the Galileo was preset at 5 Hz and also stepwise increased with 5 Hz to its maximum of 40 Hz. All volunteers were asked to take of shoes and socks. Each volunteer placed their feet on the prescribed Galileo platform position (at 185 mm left and right from the central axis) to warrant the same induced platform accelerations. The PowerMaxx had prescribed settings starting from S1 to S9; the magnitude of f_{in} was neither specified on the display nor in the manual. Acceleration values measured in the "unloaded condition" were reported in units of gravitational force (1 g = 9.81 m/s^2). The acceleration and vibration frequency values measured in the "loaded condition" were normalized by dividing them by the values measured in the "unloaded condition". The ratio of f_{out} values was denoted as f_{ratio}.

2.3. Second measurement series: transmission of vertical accelerations

In the second measurement series, we studied in eight healthy volunteers (age 34 (12) years and body weight 76 (15) kg; mean (SD)) the transmission of the vertical platform accelerations of each device to the lower limbs. The accelerations of three different body locations: ankle, knee and hip were measured in each volunteer. He or she was instructed to maintain a fixed squad position for at least 10 s, head straight forward and 20 s of recovery between trials. The feet had to be placed 30 cm apart. This distance was indicated with markers on each platform to warrant a reproducible position, especially important or the Galileo. Using this device, both feet were placed 150 mm from the central axis. The f_{in} of each device was set at 25 Hz, the lowest common preset frequency in all devices (calculated on the basis of the first measurement series). Now, a knee angle α of 100° was chosen, which is a typical lower limb training posture: the body weight on the front feet and the back upright. The Analog Devices ADXL150JQC accelerometer was used to measure the accelerations in the vertical direction. This accelerometer was in random order placed on the malleolus lateralis, a relatively flat part of ankle, the epicondylus lateralis, a relatively flat part of the lower part of the thighbone and finally on the spinailiaca anterior superior, the edge of the hipbone. We attached the accelerometers to each site using rigid foam tape (Kushionflex Padding tape of approximately 100 mm × 25 mm (length × width)) to ensure that the position of the sensor was secure. We did not take any potential errors of skin movement into account nor did we correct raw data. Alignment of the accelerometer with earth gravity was on the basis of the sensor's output during the calibration procedure. During the vibration measurement, we visually inspected the direction of the foam tape with respect to the vertical direction. Transmission of vibrations in vertical direction was calculated as a percentage of the measured accelerations at a given location divided by the unloaded platform acceleration at 25 Hz, i.e. PowerPlate 'high mode' 32 m/s^2, Galileo 150/185 × 60 m/s^2 = 48.6 m/s^2 and PowerMaxx 1.4 m/s^2.

3. Results

3.1. Subjects

None of the subjects reported any side effects to the exposed vibrations, such as hot feet, vertigo, dizziness, itching in the legs, cramp or calf pain.

3.2. 3-Dimensional platform accelerations

3.2.1. PowerPlate

Fig. 3, top panel, shows an example of the unloaded platform accelerations in X, Y and Z direction with f_{in} preset at 30 Hz. The

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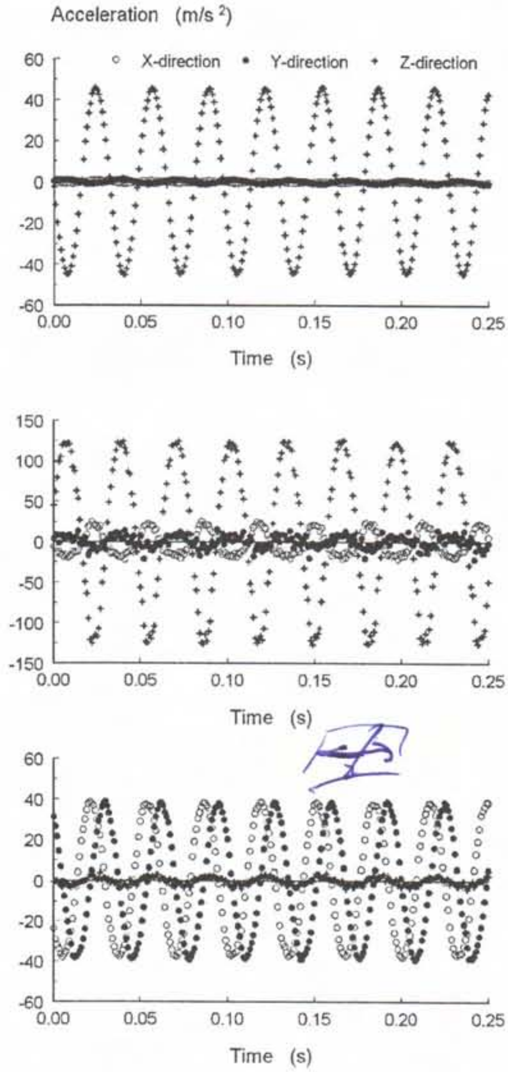

Fig. 3. Top panel: example of the PowerPlate unloaded platform acceleration against time t showing accelerations in X-direction (open circles), Y-direction (closed circles) and Z-direction (plusses) with f_{in} set at 30 Hz. The platform induced mainly vibrations in vertical direction. Middle panel: example of the Galileo unloaded platform accelerations against time with f_{in} also set at 30 Hz. This platform also induced highest vibrations in vertical directions, and some in the horizontal plane. Lowest panel: example of the PowerMaxx unloaded platform accelerations against time set at 30 Hz. The accelerations of this platform were mainly in the horizontal plane. Note the differences in y-axis scaling.

acceleration was mainly in vertical direction and described an almost perfect sine wave. Table 1 summarises the accelerations a_{RMS} in both "high" and "low" amplitude mode and the frequencies f_{out} at each preset f_{in}. The f_{out} values were within 3% comparable to the preset f_{in} values. The a_{RMS} values in the horizontal plane were less than 0.2 units of g. The a_{RMS} values in vertical direction measured in "low" amplitude mode, up to 3.8 units of g, were half of those measured in "high" amplitude mode at the same preset f_{in}. In "high" mode, the maximum vertical platform displacement, d_{max} was 2.2 (0.1) mm peak-to peak (mean (SD)); in "low" mode d_{max} was 1.2 (0.05) mm peak-to-peak. It only decreased ~0.2 mm when the preset f_{in} increased from 25 Hz up to 50 Hz in both "high" and "low" mode. Loading the platform did not affect the f_{out} values and the a_{RMS} values in vertical direction changed less than 10% when the preset f_{in} increased from 25 up to 50 Hz.

Table 1
3-Dimensional "unloaded" and "loaded" platform accelerations (a) and vibration frequencies (f_{out}) of the PowerPlate at preset vibration frequencies between 25 and 50 Hz. In the "unloaded condition", the root mean square values of the accelerations (a_{RMS}) were expressed in units of g (9.81 m/s^2) in all directions. In the "loaded condition", two volunteers with body weight 62 and 81 kg stood in squat position on this platform in 'low mode'. The a_{RMS} and f_{out} values were normalized by dividing them by the a_{RMS} and f_{out} values measured in the "unloaded condition". Thus f_{ratio} was defined as f_{out} (loaded condition) divided by f_{out} (unloaded condition).

f_{in} (Hz)	a_{RMS} (in units g)			f_{out} (Hz)
	X-direction	Y-direction	Z-direction	
"Unloaded condition"				
'High'				
25	**0.0**	**0.1**	**2.5**	**25**
30	**0.0**	**0.1**	**3.3**	**31**
35	0.0	0.1	4.3	36
40	0.1	0.1	5.3	41
45	0.1	0.2	6.5	45
50	0.1	0.2	7.7	50
'Low'				
25	**0.3**	**0.0**	**1.2**	**26**
30	**0.2**	**0.0**	**1.6**	**31**
35	0.2	0.1	2.1	36
40	0.2	0.1	2.6	41
45	0.2	0.1	3.3	45
50	0.2	0.1	3.8	50
'Low'	a_{RMS}			f_{ratio}
	X-direction	Y-direction	Z-direction	
"Loaded condition"				
62 kg				
25	**0.6**	**2.5**	**0.9**	**1.0**
30	**0.3**	**2.2**	**1.0**	**1.0**
35	0.5	1.6	0.9	1.0
40	0.5	1.0	1.0	1.0
45	0.9	0.6	0.9	1.0
50	0.7	0.7	1.0	1.0
81 kg				
25	**0.2**	**3.6**	**0.9**	**1.0**
30	**0.2**	**2.7**	**1.0**	**1.0**
35	0.3	1.8	0.9	1.0
40	0.3	1.1	1.0	1.0
45	0.4	0.6	1.0	1.0
50	0.4	0.6	1.0	1.0

3.2.2. Galileo

The middle panel of Fig. 3, shows an example of the unloaded platform accelerations in X, Y and Z direction with f_{in} preset at 30 Hz. Again, the acceleration in vertical direction, the most prominent acceleration, described a sine wave. Table 2 summarises the overall findings of this platform. In the unloaded situation, the f_{out} values were up to 30 Hz within 1% accurate. Between 30 and 40 Hz, the f_{out} values decreased with 5% at f_{in} of 40 Hz. The accelerations in the horizontal X- and Y-direction increased to about 2 and 1 units of g, respectively. The accelerations in vertical direction ranged between 0.3 and 14.7 units of g (f_{in} values from 5 to 40 Hz). Note that the maximum accelerations were location dependent: the accelerations were linearly related to the distance between the rotating axis and the location of the accelerometers. The maximum vertical platform displacement, averaged over all measurements from 5 to 40 Hz, was 3.5 (0.1) mm peak-to-peak. Loading the platform did not affect the f_{out} values nor the maximum platform displacements. However, the platform accelerations in vertical direction at f_{in} values between 30 and 40 Hz reduced ~12% respectively 7% when loaded by a body weight of 62 kg respectively 81 kg. This might have been caused by some resonance above 30 Hz, which decreased the maximum platform displacement and thus the vertical accelerations.

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Table 2
3-Dimensional "unloaded" and "loaded" platform accelerations (a) and vibration frequencies (f_{out}) of the Galileo-Fitness at preset vibration frequencies between 5 and 40 Hz. In the "unloaded condition", the root mean square values of the accelerations (a_{RMS}) were expressed in units of g (9.81 m/s^2) in all directions. In the "loaded condition", two volunteers with body weight 62 and 81 kg stood in squat position on this platform. The a_{RMS} and f_{out} values were normalized by dividing them by the a_{RMS} and f_{out} values measured in the "unloaded condition".

f_{in} (Hz)	a_{RMS} (in units g)			f_{out} (Hz)
	X-direction	Y-direction	Z-direction	
"Unloaded condition"				
5	0.1	0.1	0.3	5
10	0.2	0.1	1.0	10
15	0.3	0.1	2.2	15
20	0.7	0.2	3.9	20
25	**1.0**	**0.3**	**6.1**	**25**
30	**1.3**	**0.6**	**7.9**	**30**
35	1.7	0.8	10.4	34
40	2.1	0.7	14.7	38
f_{in} (Hz)	a_{RMS}			f_{ratio}
	X-direction	Y-direction	Z-direction	
"Loaded condition"				
62 kg				
5	1.0	0.8	1.0	1.0
10	1.0	0.8	1.0	1.0
15	0.7	0.9	1.0	1.0
20	0.6	1.0	1.0	1.0
25	**1.1**	**1.4**	**1.0**	**1.0**
30	**0.9**	**1.3**	**0.9**	**1.0**
35	0.8	1.6	0.8	1.0
40	1.0	1.6	0.9	1.0
81 kg				
5	1.0	0.8	1.0	1.0
10	1.0	0.9	1.0	1.0
15	0.6	1.3	1.0	1.0
20	0.7	0.7	1.0	1.0
25	**1.2**	**1.6**	**1.0**	**1.0**
30	**1.1**	**0.8**	**1.1**	**1.0**
35	0.9	1.3	0.9	1.0
40	0.9	1.7	0.9	1.0

Table 3
3-Dimensional "unloaded" and "loaded" platform accelerations (a) and vibration frequencies (f_{out}) of the PowerMaxx at preset settings S1–S9. In the "unloaded condition", the root mean square values of the accelerations (a_{RMS}) were expressed in units of g (9.81 m/s^2) in all directions. In the "loaded condition", three volunteers with body weight 62, 81 and 100 kg stood in squat position on this platform. The a_{RMS} and f_{out} values were normalized by dividing them by the a_{RMS} and f_{out} values measured in the "unloaded condition".

f_{in}	a_{RMS} (in units g)			f_{out} (Hz)
	X-direction	Y-direction	Z-direction	
"Unloaded condition"				
s1	1.5	1.7	0.1	22
s3	**1.9**	**1.8**	**0.1**	**25**
s5	2.4	2.2	0.1	28
s7	**2.8**	**2.8**	**0.2**	**31**
s9	3.3	3.4	0.2	33
	a_{RMS}			f_{ratio}
	X-direction	Y-direction	Z-direction	
"Loaded condition"				
62 kg				
s1	0.7	0.6	2.1	1.0
s3	**0.9**	**0.6**	**2.9**	**1.0**
s5	0.9	0.6	4.3	1.0
s7	**0.9**	**0.7**	**7.2**	**1.0**
s9	0.9	0.7	7.6	1.0
81 kg				
s1	0.7	0.4	2.1	1.0
s3	**0.7**	**0.5**	**2.9**	**1.0**
s5	0.7	0.5	4.3	1.0
s7	**0.8**	**0.6**	**8.9**	**0.9**
s9	0.8	0.6	8.1	1.0
100 kg				
s1	0.5	0.6	2.1	1.0
s3	**0.7**	**0.5**	**2.9**	**1.0**
s5	0.8	0.5	3.6	1.0
s7	**0.8**	**0.6**	**5.0**	**0.9**
s9	0.9	0.7	7.6	1.0

3.2.3. PowerMaxx

The bottom panel of Fig. 3 shows an example of the platform accelerations at a preset setting S7. This setting corresponded to an f_{out} of 31 Hz. The overall findings of this device are listed in Table 3. The platform vibrated in the horizontal (*XY*) plane between 22 Hz (S1) and 32 Hz (S9). The a_{RMS} values in the vertical direction, between 0.1 and 0.2 units of g, were small compared to those in the horizontal *XY*-plane, between 1.5 and 3.4 units of g. The average platform displacement was in the *X*-direction 2.2 (0.01) mm peak-to-peak, in *Y*-direction 2.0 (0.05) peak-to-peak and in *Z*-direction 1.2 (0.02) mm peak-to-peak. When our volunteers of 62, 81 and 100 kg loaded this platform, the f_{out} values were within 6% comparable to those measured in the unloaded condition. However, the a_{RMS} values in vertical direction increased about eight times at preset S9, while the a_{RMS} values in the horizontal plane decreased. This was confirmed in the total displacement values: displacement in the *X*-direction decreased to 1.8 (0.1) mm peak-to-peak, in *Y*-direction to 1.4 (0.1) mm peak-to-peak and increased in *Z*-direction to 0.6 (0.1) mm peak-to-peak. The decrease in accelerations was thus more pronounced in *Y*-direction (up to 40%) than in *X*-direction (up to 25%). The magnitude of these changes seemed not to depend on the weight of the volunteers.

3.3. Second measurement series (transmission of accelerations)

Table 4 summarises the percentage of platform accelerations in vertical direction transmitted to the ankle, knee and hip joints of eight healthy volunteers who stood in squad position on each of the three tested devices. The platforms generated in unloaded condition vertical accelerations of 32 m/s^2 (PowerPlate (PP) "high" mode), 48.6 m/s^2 (Galileo (Ga)) and 1.4 m/s^2 (PowerMaxx (PM)). We calculated that the PowerPlate and Galileo transmitted 55 and 85% of the vibrations to the ankle, 9 and 8% to the knee and only 3 and 2% to the hip, respectively. Thus, the platform accelerations were 1.8 and 4.2 units of g at the ankle, respectively and less than ~0.45 units of g at the knee and ~0.15 units of g at the hip. Loading the PowerMaxx resulted in amplification of the accelerations in vertical direction, see also Table 3. We calculated that the vertical accelerations were at the ankle ~1 unit of g, at the knee ~0.2 units of g and at the hip ~0.1 units of g.

4. Discussion

4.1. 3-Dimensional platform accelerations

Overall finding of the "unloaded condition" was that with increasing platform frequency, a large increase in vertical platform accelerations was measured in the PowerPlate (up to 8 units of gravitational force g) and in the Galileo (up to 15 units of g) and modest increase in horizontal platform accelerations in the PowerMaxx (up to 3.5 units of g). When we compare the three test devices at two common preset frequencies (25 and 30 Hz; printed bold in Tables 1–3), the Galileo is capable of producing the highest a_{RMS} values. Its magnitude, however, depends on the platform location, since it rotates around a central axis inducing pelvis and lumbar spine oscillations. This result, however, is different from

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Table 4
The percentage of vertical accelerations transmitted from the PowerPlate, Galileo and PowerMaxx platforms at 25 Hz to the ankle, knee and hip joints of eight healthy volunteers. The volunteers were instructed to maintain a fixed squad position with the feet 30 cm apart and the knees flexed at an angle α of 100° for at least 10 s. Summarised are the accelerations measured in vertical direction as a percentage of the "unloaded" platform acceleration at 25 Hz (PowerPlate 'high mode' 32 m/s^2, Galileo 48.6 m/s^2 and PowerMaxx 1.4 m/s^2).

nbr	Body weight (kg)	Ankle			Knee			Hip		
		PP	Ga	PM	PP	Ga	PM	PP	Ga	PM
a_{RMS} in vertical direction (%)										
1	63	59	101	610	11	6	90	2	2	60
2	80	23	41	360	8	10	140	3	2	90
3	63	52	70	890	6	6	130	3	2	100
4	75	67	111	980	9	6	190	3	4	60
5	100	89	113	1230	6	6	60	2	4	50
6	80	53	97	390	7	8	70	2	1	40
7	90	56	84	400	19	12	210	3	2	60
8	55	44	66	710	10	10	170	3	2	110
Mean	76	55	85	700	9	8	130	3	2	70
SD	15	19	25	320	4	2	60	1	1	25

PP = PowerPlate, Ga = Galileo-Fitness, PM = PowerMaxx.

the gravitational forces measured in a similar device, the Galileo 2000. It was shown, that increase in platform amplitude (1.25, 3 and 5.25 mm) only resulted in slight increase in g forces in vertical direction at platform frequencies of 10, 20 and 30 Hz, i.e. 9.67 units of g at 1.25 mm displacement and 10 Hz up to 10.88 units of g at 5.25 mm and 30 Hz [33] (Table 1). We firmly attached our accelerometers between foot position 3 and 4, at which the platform displacement was 3.5 mm. At this location, vertical accelerations ranged between 1 unit of g (10 Hz) and 7.9 units of g (30 Hz). We were not able to pinpoint the cause of these differences. It might be caused by differences in the linear accelerometers used (their 10 g versus our 50 g sensor), data analysis (their 6 Hz low pass Hamming filter versus our FFT analysis procedure) or measurement setup, but information on accelerometer attachment on the platform surface was missing. Our Galileo test device showed some resonance, but that was above 30 Hz. Platform displacement reduced and as a result the magnitude of the vertical accelerations. This device also showed moderate vibrations (~1–1.5 units of g) in the X-direction. The PowerPlate, on the other hand, induced very stable vibration patterns, i.e. its platform completely moved in vertical direction and showed very little horizontal vibrations. In the "high" amplitude mode, the a_{RMS} value was about half of that measured in the Galileo at a preset frequency of 25 Hz. The platforms of both these professional WBV devices mainly vibrated in vertical direction and loading both platforms did not influence their performance. The performance of the 'unloaded' PowerMaxx, however, was completely different from the two professional ones. The main accelerations (up to 3.5 units of g) were mainly in the horizontal plane. The a_{RMS} values in vertical direction were about a factor 7 less than that of the Galileo at comparable preset frequency. Loading this platform, however, altered vibrations primarily in the horizontal plane to vertical vibrations. It was suggested that this change in vibration direction is most likely caused by changes in the dynamics of the eccentric drive of the PowerMaxx and the added eccentricity of the body weight of the three volunteers. These altered properties, however, seemed not to depend on their weight. As we expected, each device has its specific properties, mainly in terms of accelerations (displacements).

4.2. Transmission of accelerations

It was previously shown that the magnitude of acceleration of the lumbar spine depended on the knee angle [10]. The highest accelerations of hip and lumbar spine were measured in upright position (knee in full extension), but these accelerations did not exceed 50% of the induced accelerations of the platforms with both knees in just 20° flexion. In that study, the accelerations were measured invasively. Others reported significantly greater vertical accelerations in squad position compared to standing postures [33]. It was speculated that greater muscle activation in this posture may increase total muscle stiffness, thereby enhancing the force transmission. We found in squat position that the transmission of vertical accelerations at a preset vibration frequency of 25 Hz was largest in the ankle and that transmission reduced ~6–10 times at the knee and hip. We calculated that the PowerPlate and Galileo transmitted 1.8 and 4.2 units of g at the ankle, respectively and less than ~0.45 units of g at the knee. Although loading the PowerMaxx resulted in amplification of the accelerations in vertical direction, the vertical accelerations were at the ankle ~1 unit of g and at the knee ~0.2 units of g. This indicates that storage of the vibration energy was mainly limited to the lower legs. This damping effect at frequencies >20 Hz has been reported by many others as well [32,33,18,36]. It was also shown that the transmission of vibration to the head, expressed as a transmissibility factor, decreased rapidly for frequencies >15–20 Hz [18]. These results suggest that no enhancement of muscle power can be expected in the upper body. A special point of concern is whether the head is free from vibrations or not during a WBV exercise. Although accelerations are small, it may induce high gain vestibular responses that alter visual perception and/or balance [37]. Especially in elderly, this might negatively influence the fall risk during or shortly after a WBV exercise. From a safety point of view, it has been suggested that the frequencies in vibration training for various groups should be higher than 20 Hz to avoid vibration of the head by resonance frequencies of the human body [18,33]. Furthermore, typical WBV training regimens (30 Hz, 10 min per day) exceed the recommended daily vibration exposure as defined by ISO 2631-1 and is thus potentially harmful to the human body [35,38]. Potential hazard for the fragile human musculoskeletal system may also exist at amplitudes greater than 0.5 mm due to great peak accelerations [36]. The results of the present study suggest that short training sessions on a PowerMaxx would comply with most of these safety rules stated. Its minimum vibration frequency is 22 Hz, its platform displacements are ~0.6 mm and its (vertical) acceleration are within 2 units of g. Potential hazard of this device, however, could be the large accelerations in the horizontal plane (up to 3 units of g). More research needs to be done to test the impact of these vibrations on the human musculoskeletal system. Finally, it was reported that transmission of vibration to the human body is a complicated phenomenon due to nonlinearities in the musculoskeletal system, meaning that sinusoidal waveform in terms of amplitude and frequency is modified at higher body segments [36]. We were able to partly confirm these findings in our data set. The vibration frequencies at the level of the ankle, knee and hip were within 5% comparable to the preset frequency of 25 Hz in all test persons on each tested device. However, the fit errors cal-

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culated by fitting a sine function through the vertical accelerations signals increased from ~4% at the level of the ankle to ~30% at the level of the hip, even regardless of the test device used, confirming this nonlinear behaviour past the knee. It should be noted that the platforms may induce substantial rotational vibration as well, especially the PowerMaxx may induce these vibrations around the vertical axis, although the vibrations along the translational axes alone were characterized. The human muscles response, however, also to rotational vibrations. Although the effects of rotational vibrations are not known, whether beneficial or detrimental, these may also have contributed to activation of some of the muscles in the lower and upper legs and pelvis region.

4.3. Study limitations

We measured rather high accelerations (maximum of ~15 units of g) using a 50 g accelerometer. Calibration of this sensor, however, was based on a two point calibration procedure, i.e. zero gravity and only 1 unit of g, which places the correctness of the measured acceleration under debate. The large accelerations in the first measurement series were measured with the sensors placed in the container that could be perfectly aligned to the platform's surface in all three dimensions, allowing sensitive and correct calibrating of the individual sensors. In a previous report using a vertical vibration platform (similar to the PowerPlate we used), it was shown that given a peak-to-peak amplitude of a vertical vibration of 2 mm, the theoretical maximal accelerations would be ~2.5 units of g at 25 Hz, 3.6 units of g at 30 Hz, 4.9 units of 9 at 35 Hz and 6.4 units of g at 40 Hz [19]. These theoretical values are ~15% higher at $f_{out} > 30$ Hz than we measured at the PowerPlate platform. We calculated, however, not the maximum acceleration values but the root mean square acceleration values. In addition, the peak-to-peak displacements of the PowerPlate platform were calculated ~10% higher (2.2 mm versus 2.0 mm), which presumably caused higher accelerations in the PowerPlate, see also Eq. (4). When we take these aspects into account, we conclude that the absolute magnitude of the accelerations might be a bit too high compared to theoretically expected values but accurate enough for comparison between the devices. Vertical alignment of the accelerometer to the ankle, knee and hip was much more complicated in the second series of measurements. No doubt that the two point calibration a these locations was less accurate, but the maximum accelerations measured in this series did not exceed 4 units of g.

It has been reported that measurement of acceleration with skin mounted accelerometers can be subject to inaccuracy as well, because of the movement of skin and soft tissues [28]. Probably, the foam tape to securely attach the sensor to the skin reduced the amplitude of the displacement and thus the acceleration to some extend. Not only reliable mounting of the accelerometer, but also inter-subject variability is expected to have substantial impact on the measurements accuracy, as shown by others [29,32,36]. The measurements were not repeated within each subject for a test–retest analysis to avoid an 'overload' of WBV. Indeed, the results in our subject did show rather large variations too. When realizing that individual responses may be large, we must be careful in prescribing unified physically tolerable protocols for WBV. One of our future aim is training of lower limb muscles. We therefore altered the knee angle α of 150° in the first measurement series (small head oscillations) to a knee angle of 100°. This position is known to be optimum for triggering and training of the main lower leg muscle, i.e. Quadriceps Muscle [34,39]. It could be that the outcome of the second series might change when squat position (thus knee angle) of each subject is altered. Position, however, was not directly related to our main research question. Based on the presented results, we think that posture only slightly influences platform properties of the PowerPlate and the Galileo. These two devices have shown robust mechanical properties. The platform properties of the PowerMaxx, however, may depend to some extend to differences in posture, but more research is needed to test this property.

We conclude that large variation in 3-dimensional accelerations exist in commercially available devices. The results of the present study suggest that these differences in mechanical behaviour induce variations in transmissibility of vertical vibrations to the (lower) body. We too support the call for biomechanical and/or biological markers that may determine correct timing of a vibration overload stimulus for assisting safe and effective use of WBV as a rehabilitation and training tool [33].

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Conflict of interest statement

All authors disclose any financial and personal relationships with other people or organisations that inappropriately influence (bias) this work.

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