UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE CIÊNCIAS BÁSICAS DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM NEUROCIÊNCIAS

EFEITOS DA VIBRAÇÃO DE CORPO INTEIRO NA SENSIBILIDADE CUTÂNEA, EQUILÍBRIO, VARIÁVEIS FISIOLÓGICAS E CARGAS DE ACELERAÇÃO ASSOCIADAS

TESE DE DOUTORADO

ANELISE SONZA

Porto Alegre
2014

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE CIÊNCIAS BÁSICAS DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM NEUROCIÊNCIAS

EFEITOS DA VIBRAÇÃO DE CORPO INTEIRO NA SENSIBILIDADE CUTÂNEA, EQUILÍBRIO, VARIÁVEIS FISIOLÓGICAS E CARGAS DE ACELERAÇÃO ASSOCIADAS

ANELISE SONZA

Tese de Doutorado apresentada ao Programa de Pós-Graduação em Ciências Biológicas: Neurociências, do Instituto de Ciências Básicas da Saúde da Universidade Federal do Rio Grande do Sul, como requisito parcial para obtenção do título de Doutor em Neurociências.

Orientadora: Prof[a]. Dr[a]. Matilde Achaval Elena
Co-orientador: Prof. Dr. Milton Antônio Zaro

Porto Alegre
2014

Dedico este trabalho aos meus pais, eternos incentivadores.

AGRADECIMENTOS

Aos meus pais Alberto e Celina que optaram por dar a mim e minhas irmãs como herança, o estudo. Crescemos ouvindo que essa herança ninguém seria capaz de nos furtar. Crescemos com o exemplo de que nada se conquista sem trabalho árduo e dedicação. Com essas sábias palavras e demonstrações fomos preparadas para a vida. Mãe e Pai, vocês são minha inspiração.

Ao meu irmão Albertinho, nosso anjo, que sempre olha por todos nós. Amor eterno.

Às minhas irmãs Danielle, Eliseane, Melissa e Simone. Fomos criadas na "casa das 5 bonecas"; que cresceram, transformaram-se em mulheres. Cada uma com uma luta diferente, mas todas vitoriosas. Sempre aprendo com cada uma: batalhadoras, incansáveis, corajosas, unidas pelo amor à família.

Aos mestres que participaram da minha formação do ensino básico à pós-graduação. Cada um de vocês contribuiu na formação da pessoa que sou.

Aos amigos e orientadores Prof. Matilde e Prof. Zaro por todo o apreço e consideração, por apostarem e acreditarem incondicionalmente. Prof. Matilde, mãe e defensora de seus alunos, amiga, batalhadora, pesquisadora exemplar. Não existem palavras que possam expressar todo o agradecimento.

Aos orientadores Ewald M. Hennig (Universität Duisburg-Essen) e Benno M. Nigg (University of Calgary) que me acolheram em centros de excelência em pesquisa, acreditaram no meu potencial e tanto contribuíram para meu crescimento pessoal e como pesquisadora.

Ao governo Brasileiro que através da CAPES e CNPq forneceu suporte financeiro. Ao Programa de Pós-Graduação em Neurociências da UFRGS e ao Programa Ciências sem Fronteiras (CAPES) que possibilitaram a realização do doutorado sanduíche na Alemanha. Ao Governo canadense que através da bolsa "Emerging Leaders in the Americas Program" ofereceu suporte financeiro para parte do doutorado no Canadá.

À amiga Luciane, musicista brilhante, parceira de concertos, projetos de extensão, palestras, devaneios em pesquisa... amiga para todas as horas.

À amiga Jessica, irmã de coração. Capaz de acolher com uma amizade imensa uma brasileira perdida na Alemanha. De sabedoria imensurável, sempre preocupada com os outros, com seus alunos, com o social. Longas horas de conversas, alegrias, viage fascinada com a descoberta e a troca cultural. Você é um exemplo a ser seguido!

À todos os amigos queridos pelos conselhos, apoio, risadas e tantos momentos de alegria compartilhados nesses anos em Porto Alegre e fora do Brasil, cujos nomes não ouso citar para não correr o risco da injustiça de algum esquecimento. Entretanto, vocês sabem da importância que tem e tiveram na minha vida.

Aos amigos Rudnei, Adriane e Silvia por todos os incentivos, vocês são os responsáveis por tudo isso estar acontecendo.

À querida família Zamo que tão bem me acolheu e sempre estará guardada no meu coração.

Aos colegas de Laboratório pelas risadas, trabalho exaustivo, surtos coletivos, mas sempre procurando manter o bom humor e o apoio mútuo. Tudo é um aprendizado...

Aos funcionários Andrea, Carmen e técnicos de laboratório Toninho e Silvia pela paciência, prestatividade e auxílio.

À Deus, por me dar uma família maravilhosa, por me mostrar que sou capaz de superar as provações que se colocam no meu caminho. Só tenho a agradecer.

"Aprender é a única coisa de que a mente nunca se cansa, nunca tem medo e nunca se arrepende".

Leonardo da Vinci

SUMÁRIO

LISTA DE FIGURAS

ESTUDO 1

ESTUDO 2

ESTUDO 3

ESTUDO 4

LISTA DE TABELAS

ESTUDO 1

ESTUDO 2

ESTUDO 3

ESTUDO 4

LISTA DE ABREVIATURAS

bpm	Batimentos cardíacos por minuto
CGRP	Peptídeo relacionado ao gene da calcitonina
COP	Centro de Pressão
COP A-P	Centro de Pressão ântero-posterior
COP M-L	Centro de Pressão médio-lateral
COM	Centro de Massa
CSS	Grupo controle salina sedentário
CCS	Grupo controle dor crônica sedentário
DRG	Gânglio da raiz dorsal
ET1	Endotelina 1
EVA	Etileno vinil acetato
FA	Mecanorreceptores de rápida adaptação
FPS	Quadros por segundo
rpm	Respirações por minuto
GABA	Ácido gama-aminobutírico
GCT	Grupo dor crônica tratado com esteira
GCP	Grupo dor crônica tratado com plataforma vibratória
GCP+T	Grupo dor crônica tratado com esteira e plataforma vibratória
IR	Infravermelho
IP_3	Inositol-3-fosfato
MANOVA	Análise de variância multivariada
MLCK	Proteína cinase de cadeia leve da miosina dependente de cálcio
SA	Mecanorreceptores de lenta adaptação
TENS	Estimulação elétrica nervosa transcutânea
VCI	Vibração de Corpo Inteiro
VPT	Limiar de percepção vibratória
WBV	Vibração de Corpo Inteiro

RESUMO

O estímulo vibratório gerado pela utilização das plataformas vibratórias tem sido aplicado como método eficaz para promover desempenho esportivo e também na reabilitação de pacientes com diversificadas disfunções. Acredita-se que a vibração de corpo inteiro (VCI) é capaz de diminuir os déficits de ativação muscular voluntária através de reflexos de estiramento neuromuscular, tornando-se um meio eficaz e de fácil aplicabilidade para pacientes com maiores incapacitações. Resultados controversos na literatura, com relação aos benefícios dos estímulos vibratórios, tornam a escolha dos parâmetros do equipamento (frequência, amplitude, tempo de exposição e modo de vibração) um desafio na obtenção dos melhores resultados. Assim, o objetivo desta tese visa a avaliação dos efeitos fisiológicos agudos da vibração de corpo inteiro (sensibilidade cutânea tátil e dolorosa, equilíbrio, temperatura superficial da pele, transmissibilidade da vibração) e a construção de um mapa de percepção corporal da VCI. Foram utilizados diferentes parâmetros e marcas desses equipamentos. Para investigar cada variável, quatro diferentes estudos foram realizados separadamente. O primeiro estudo investigou os efeitos da VCI na sensibilidade cutânea vibratória medidos a 30 Hz (corpúsculos de *Meissner)* e 200Hz (corpúsculos de *Pacini*) e de toque-pressão dos pés de 20 sujeitos normais e o tempo de duração dos efeitos da vibração nesses receptores. Como principais resultados, foram constatadas que as descargas aferentes dos mecanorreceptores de adaptação rápida foram fortemente afetadas pela vibração assim como a sensibilidade de toque-pressão. Após 10 min de exposição à VCI o tempo de recuperação para a sensibilidade voltar aos limiares basais nos pés foi entre 2 e 3 h. Para continuar elucidando os efeitos agudos pós-exercício com vibração, um segundo estudo foi realizado avaliando variáveis fisiológicas em quatro diferentes frequências de exposição de VCI (30, 35, 40, 44 Hz). Foram avaliadas pressão arterial, frequências cardíaca e respiratória, temperatura axilar e a temperatura cutânea através de termografia por infravermelho dos membros inferiores dos 24 participantes avaliados. Por fim, o equilibro desses indivíduos foi avaliado através das análises dos deslocamentos, da velocidade e da área do centro de pressão (COP), em uma plataforma de força. Os dados do segundo estudo mostraram que, para as frequências de 40 e 44 Hz do equipamento, houve uma alteração significativa para as variáveis velocidade e comprimento ântero-posterior do centro de pressão. Além disso, durante a vibração e 10 min após, a temperatura dos membros inferiores foi reduzida, provavelmente em virtude da vasoconstrição gerada. Na investigação da sensibilidade dolorosa um terceiro estudo foi proposto, tendo em vista que as vias dos mecanorreceptores de sensibilidade cutânea tátil diferem daqueles relacionados com a sensibilidade dolorosa. Um modelo de dor crônica com ratos Wistar foi realizado e os animais foram tratados com VCI, esteira e a combinação de esteira com VCI. Como principais resultados deste estudo, os grupos tratados com VCI mostraram redução significativa da sensibilidade de toque-pressão após todas as sessões em comparação aos demais grupos. Efeitos analgésicos através do tempo de latência medidos com o *hot plate* foram encontrados após o terceiro dia de tratamento com 5 min de exposição por dia à VCI, nos primeiros 5 dias e 10 min nos 5 dias subsequentes. Como finalização das variáveis de interesse, o último estudo combinou dados quantitativos advindos da acelerometria (com medições na cabeça, quadril e tíbia) com dados qualitativos através da escala de Borg. Sessenta e cinco adultos-jovens foram avaliados e este estudo propôs um método para escolher os diversificados parâmetros da plataforma vibratória, para alcançar os efeitos desejados na reabilitação ou desempenho esportivo. Este estudo mostrou que os índices de percepção de severidade medidos através da escala de Borg corresponderam com os dados quantitativos da acelerometria e assim os parâmetros do equipamento podem ser escolhidos com base na sensação subjetiva proveniente da escala de Borg. Os níveis de desconforto no equipamento podem estar relacionados com a frequência de ressonância das diferentes partes do corpo. Futuros estudos devem considerar aplicações clínicas da plataforma vibratória em pacientes com dor crônica musculoesquelética utilizando o modelo para escolha dos parâmetros do equipamento proposto nesta tese.

Palavras-chave: Vibração de corpo inteiro, mecanorreceptores, sensibilidade de toque-pressão, sensibilidade vibratória, equilíbrio, termografia por infra-vermelho, acelerometria, exercício, efeitos pós-vibratórios, dor.

ABSTRACT

The vibratory stimuli generated by the use of vibrating platforms have been used as an effective method to promote sports performance and also in the rehabilitation of patients with several dysfunctions. It is believed that the whole body vibration (WBV) is able to decrease the deficits in voluntary muscle activation by neuromuscular stretch reflexes making it an efficient and easy exercise method applied to patients with greater disabilities. Controversial results in the literature regarding the benefits of the vibratory stimuli make the choice of the equipment parameters (frequency, amplitude, time of exposure and vibration mode) a challenge in getting the best results. The goal of this dissertation involves the evaluation of the acute physiological effects of whole body vibration (skin tactile and pain sensitivity, balance, skin temperature and vibration transmissibility) and the construction of a WBV perception body map. Parameters settings and different brands of these devices were used. To investigate each variable, four different studies were conducted separately. The first study investigated the effects of WBV on fast adapting mechanoreceptors measured at 30 Hz (Meissner corpuscles) and 200Hz (Pacinian corpuscles) and touch-pressure sensitivity from the right foot of 20 health subjects and the duration of the vibration effects on these receptors. The main results show that the afferent discharges of the fast adapting mechanoreceptors are strongly affected by vibration and sensitivity of touch-pressure was also impaired. After a single 10 minutes exposure to WBV, the time required to recover baseline tactile sensitivity on the feet was between 2 and 3 hours. To further elucidate the acute post-exercise vibration effects, a second study was conducted assessing physiological variables at four different WBV frequencies (31, 35, 40, 44 Hz). Blood pressure, heart and respiratory rates, skin temperature and balance were measured. Skin temperature was measured by an infrared thermography of the lower limbs of 24 subjects. Balance was accessed with a force plate through the analysis of the center of pressure (COP) velocity, area and displacements variables. The results from this study show that for 40 and 44 Hz of the device's frequencies, a significant decrease in balance was found for the center of pressure variables velocity and anterior-posterior displacement. Also, during WBV exposition and 10 minutes post vibration, the temperature of the lower

limbs was reduced, probably due to vasoconstriction. To investigate the variable "pain", a third study was proposed, considering that the pathways and receptors of the cutaneous touch-pressure and vibration sensitivity differ from those related to pain sensitivity, the C and A_{δ} fibers. A chronic pain model was applied in male Wistar rats and the animals were treated with WBV exercise (vibration platform), a low intensity exercise (treadmill) and a combined treatment involving both. The main results show that the groups treated with WBV showed a significant reduction in sensitivity to touch-pressure after every session compared to the other groups. Analgesic effects through the time latency measured by the hot plate were found after the third treatment day with 5 min of exposure to WBV during the first 5 days and 10 min next 5 days. As completion of the fourth variable of interest, the last study by deriving quantitative data from accelerometry (with measurements on the head, hip and tibia) was combined with qualitative data arising from the Borg scale. Sixty five health young adults were measured and the study proposes a method for choosing the parameters settings of the vibrating platform, to achieve the desired goals in rehabilitation or sports performance. Discomfort perception ratings measured by the Borg scale corresponded well with the measured acceleration magnitudes and so the parameters settings of the device can be chosen based on the subjective sensation from the Borg scale. The level of discomfort ratings might be related to the frequency resonance phenomena of body parts. Future clinical applications with vibration platform in patients with muscle-skeletal chronic pain should be considered applying the model for choosing the parameter settings of the device proposed in this dissertation.

Key-words: Whole body vibration, mechanoreceptors, touch-pressure sensitivity, vibration sensitivity, balance, infrared thermography, accelerometry, exercise, post vibratory effects, pain.

1. INTRODUÇÃO & JUSTIFICATIVA

Com a popularização do uso de plataformas vibratórias em academias de ginástica e clínicas de fisioterapia (SONZA et al., 2013), além do preço acessível do equipamento e da grande exposição na mídia dos efeitos da “ginástica sem esforço”, o número de indivíduos adquirindo-as para uso doméstico é notório. Entretanto, dados controversos na literatura com relação aos benefícios da utilização deste estímulo vibratório (RITTWEGER, 2010) evidencia a importância de estudar-se a temática.

Pesquisas têm demonstrado que a terapia com a vibração de corpo inteiro (VCI) pode trazer muitos benefícios como: a remodelação óssea (XIE et al., 2006; JUDEX; DONAHUE; RUBIN, 2002; RUBIN et al., 2001; FLIEGER et al., 1998), a força muscular (BELAVÝ et al., 2008; BOGAERTS et al., 2007; BRUYERE et al., 2005; ROELANTS; DELECLUSE; VERSCHUEREN, 2004), a postura e o equilíbrio (SCHLEE; RECKMANN; MILANI, 2012; VERSCHUEREN et al., 2004) e a redução de dor na coluna lombar (CHEUNG; ZHANG; CHOW, 2003). Como tal, tem atraído o interesse de seus potenciais benefícios em relação a função física através de efeitos de vibração, pode ter efeitos negativos como redução da sensibilidade cutânea (SONZA et al., 2013; SCHLEE; RECKMANN; MILANI, 2012; POLLOCK et al., 2011) e potencialmente danoso ou sem efeitos, dependendo das variáveis selecionadas (RUBINACCI et al., 2008; CASTILLO et al., 2006; MIYAZAKI, 2000; FLOYD; BRODERSON; GOODNO, 1973).

A vibração gerada pelas plataformas vibratórias induz efeitos fisiológicos sob forte influência de parâmetros como frequência de vibração, amplitude, tempo de exposição. Na complexa interação entre os estímulos vibratórios e seus efeitos fisiológicos, compreende-se que estímulos vibratórios também podem gerar distúrbios motores, perda da sensibilidade e diminuição do fluxo sanguíneo como ocorre na síndrome da mão branca (PAVEL et al., 2011; HAAS, 2008).

Yan e cols. (2005) mostraram que animais vibrados 5 h por dia durante 10 dias apresentaram progressiva fraqueza das patas caudais e dificuldade de caminhada, demonstrando o efeito progressivo da vibração; já estudos de Pavel e cols. (2011) em ratos vibrados a 60 Hz, 30 min por dia durante 10 dias apresentaram redução do transporte axonal retrógrado de neurônios motores, entretanto não tiveram nenhum sinal evidente de dano neurológico, comprovando que as lesões causadas pela vibração depende de suas variáveis como número e duração dos períodos de exposição. Em contrapartida, houve um aumento no transporte axonal retrógrado nas fibras sensoriais do nervo ciático sugerindo uma resposta diferenciada entre neurônios sensoriais e motores.

Estímulos vibratórios inadequados também podem gerar alterações sensoriais. Áreas do pé que possuem menor limiar de sensibilidade são sujeitas a lesões pela perda da sensibilidade protetiva (HENNIG; ROSENBAUM, 1991). Dados da sensibilidade cutânea geram informações espaciais e temporais detalhadas sobre as propriedades da superfície de suporte, e sobre as variações de pressão plantar que diretamente resultam em mudanças no deslocamento do centro de pressão (COP) (PERRY, 2006; MAURER et al., 2001). O COP é onde está localizado o vetor vertical de força de reação à terra e representa a carga proporcional à pressão da superfície da área de contato com o solo. O centro de massa (COM) é o ponto no qual toda a massa e peso corporal estão igualmente balanceados ou distribuídos em todas as direções

(WINTER, 1995). O COP é totalmente independente do centro de massa. O aumento da atividade flexo-plantar move o COP anteriormente.

Quando falamos em equilíbrio, este é visto como uma função sensório motora que garante permanentemente a estabilidade da postura (MILANI; KIMMESKAMP, 2002). Trata-se de uma integração entre o aparelho muscular e os receptores sensoriais, e é desta forma que a sensoriomotricidade encontra os elementos de sua definição. É através dos órgãos sensoriais que se estabelece uma comunicação com o mundo exterior, permitindo, portanto a adaptação do organismo ao ambiente (PERRIN; LESTIENNE, 1998).

Em detrimento da variedade de estímulos mecânicos, físicos e químicos, existem diferentes tipos de receptores especializados para detectá-los. Um receptor pode ser uma simples terminação nervosa ou uma complexa combinação de nervos com o suporte de células, tecido conectivo, células musculares, etc. A maioria dos receptores sensoriais no sistema somatossensorial são os mecanorreceptores, os quais são sensíveis às distorções físicas tais como alongamento, pressão, vibração. Métodos utilizados para entender o papel da sensação cutânea da superfície plantar dos pés, normalmente têm envolvido pacientes com perda de sensibilidade como por exemplo, neuropatia periférica (MCGILL et al., 1999), doenças degenerativas como artrite reumatóide (HENDIANI et al., 2003) e Parkinson (PRÄTORIUS; KIMMESKAMP; MILANI, 2003). Pesquisadores (EILS et al., 2002; NURSE; NIGG, 2001) estudaram alteração experimental do limiar de sensibilidade após exposição da planta dos pés ao gelo e tiveram o objetivo de verificar a importância da resposta cutânea na regulação e modificação dos padrões da marcha e concluíram que a resposta sensorial cutânea é importante e deve ser inclusa nos modelos descritos para predição do movimento.

As sensações provenientes do sistema somatossensorial podem informar aos centros superiores se a massa está distribuída igualmente entre os dois pés ou não, senso de posição e velocidade de todos os segmentos corporais (WINTER, 1995). Ainda, a informação exteroceptiva na manutenção do equilíbrio é necessária quando uma pessoa está correndo, pois a pressão do ar contra a frente do corpo indica que uma força está se opondo ao corpo, em direção diferente da causada pela força gravitacional; consequentemente a pessoa se inclina para frente, para neutralizar essa força (ENOKA, 2000; GUYTON, 1988). Com a informação de estímulos externos detectados pelos proprioceptores e exteroceptores, o sistema articular é capaz de organizar uma resposta rápida a uma perturbação, determinar sua posição e distinguir entre movimentos autogerados ou impostos (ENOKA, 2000; WINTER, 1995). Lee e cols. (2004) referem que dentre as informações sensoriais, a entrada do processamento visual proporciona informações sobre a orientação relativa ao ambiente que nos cerca, enquanto a somatossensação capta a entrada de informações relativas às superfícies de suporte.

Informações cutâneas plantares participam, dentre outras fontes sensoriais (TREMBLAY et al., 2005) no controle do equilíbrio (PERRY; MCILROY; MAKI, 2000; NURSE; NIGG, 1999; KAVOUNOUDIAS; ROLL; ROLL, 1998). Prätorius e cols. (2003) salientam que os mecanorreceptores da pele são específicos para diferentes estímulos e a identificação e contribuições destes sensores do pé para o controle postural são de grande interesse. Estudos recentes sobre o efeito da vibração de corpo inteiro na sensibilidade cutânea (SONZA et al., 2013; SCHLEE; RECKMANN; MILANI, 2012; POLLOCK et al., 2011;) têm demonstrado diminuição temporária da sensibilidade de toque-pressão e vibratória. Essa alteração sensorial pode durar até 2,5 h para os receptores de rápida adaptação e dura menos de 1 h para os receptores de tato e pressão após 10 min de exposição (SONZA et al., 2013).

Uma outra questão de interesse está relacionada com a utilização deste equipamento no controle e manuseio de condições dolorosas. Além dos mecanorreceptores, a sensação somática é dependente das terminações nervosas livres, não ou pouco mielinizadas e consequentemente, de pequeno calibre (BEAR; CONNORS; PARADISO, 2002).

Fibras C e fibras Aδ, responsáveis pela condução das informações dolorosas não possuem as mesmas vias de condução de informação ao encéfalo das fibras de largo calibre A_α e A_β que constituem os mecanorreceptores de baixa e rápida adaptação. Assim, uma questão que nos instigou está relacionada se a VCI seria capaz de também influenciar os nociceptores, que possuem pequeno calibre, no controle de condições dolorosas. Sabe-se que a maioria dos nociceptores não responde a estímulos mecânicos e químicos mas podem responder quando tais estímulos são suficientemente intensos. A percepção da dor é variável e a compreensão dessa modulação é importante pois pode oferecer novas estratégias para o tratamento da dor crônica. Na regulação aferente, a dor pode ser reduzida pela atividade simultânea em receptores de baixo limiar (fibras A_β) (MÜNSTER et al., 2012; PRAGER, 2010). Como a VCI afeta os disparos dos mecanorreceptores, gerando diminuição de sensibilidade cutânea, questiona-se sua influência na modulação aferente da dor.

Diminuição no pH tecidual foi observado após inflamação, equimose e exercícios isométricos (SLUKA; KALRA; MOORE, 2001; ISSBERNER; REEH; STEEN, 1996; HOOD et al., 1988). Existe uma correlação positiva entre dor e acidificação local (ISSBERNER; REEH; STEEN, 1996). Nos seres humanos, a diminuição do pH aumenta a atividade de nociceptores e produz a resposta dolorosa (REEH; STEEN, 1996). Como a acidificação muscular local estimula a atividade nociceptora, um modelo de dor dor crônica nesses moldes foi escolhido para ser aplicado em ratos Wistar e o tratamento para modulação de dor, foi realizado através do exercício com VCI.

O exercício é um componente importante no controle de condições dolorosas (BEMENT; SLUKA, 2005). Protocolos de exercícios de baixa intensidade são usados na reabilitação para tratar pacientes com condições crônicas músculo-esqueléticas, como fibromialgia, dor lombar crônica e dor miofascial (BEMENT; SLUKA, 2005; GOWANS; DEHUECK, 2004; WRIGHT; SLUKA, 2001; VAN TULDER; KOES; BOUTER, 1997).

Os estudos em animais mostraram que o exercício físico (corrida) está relacionado com efeitos neuroprotetores, inibição da apoptose, fatores neurotróficos, gerando neurogênese e regeneração, reduzindo a degeneração dos nervos e dos sintomas (ITOH et al., 2011; KIM et al., 2010, 2002; HELFER et al., 2009; DING et al., 2004, 2002; ANG et al., 2003; WANG; YANG; YU, 2001; CHEN et al., 1998). No entanto, em humanos, condições dolorosas geram gasto de energia ou déficits na coordenação do movimento, fazendo com que inúmeras patologias impeçam que os indivíduos afetados possam realizar exercícios de corrida, gerando um potencial reduzido no processo de reabilitação. Assim, outro importante aspecto desta tese se relaciona com a compreensão da influência da VCI sob os receptores sensoriais de dor.

Este conjunto de estudos além de toda a importância e influência da vibração sob os receptores sensoriais cutâneos, influência na sensibilidade dolorosa e no equilíbrio postural, procurou compreender os efeitos gerados pela VCI na temperatura superficial da pele através da utilização da termografia por infravermelho. O maior órgão do corpo é a pele. Ela funciona como um regulador térmico, controlando o fluxo de sangue a poucos milímetros da superfície do corpo. Além disso, a pele é anatomicamente e fisiologicamente simétrica (RANSON, 1933).

Sendo a vasoconstrição um dos grandes fatores negativos gerados pela exposição prolongada à vibração, procurou-se investigar se esta modalidade de exercício poderia afetar a temperatura superficial da pele durante e minutos após a vibração gerada pelo equipamento.

O uso inadequado das frequências de vibração, o tempo de exposição prolongado, e a amplitude podem gerar sérios problemas de saúde pública, considerando o uso doméstico do equipamento com pouca ou nenhuma orientação. Considerando que estímulos vibratórios interagem de forma complexa no corpo humano e causam efeitos fisiológicos. Relata-se principalmente no campo ergonômico que a vibração pode produzir distúrbios motores (BOVENZI et al., 1991) ou doenças, tais como a perda da sensibilidade e diminuição do fluxo sanguíneo presentes na síndrome da mão branca e na síndrome do túnel do carpo (KIHLBERG; HAGBERG, 1997).

Vários fatores de circulação intravascular têm sido implicados na patofisiologia das vibrações que induzem lesão vascular (MAHBUB; HARADA, 2011), relatados principalmente para membros superiores. Estes incluem o aumento plasmático dos níveis de trombomodulina e fator de von Willebrand, estes aumentando a agregação eritrocitária e hipodeformabilidade, ativação plaquetária, elevando os níveis de tromboxano A2 e moléculas de adesão intercelular (STOYNEVA, 2003). Todos esses fatores podem ser seguidos pelo estreitamento do lúmen arterial com hipertrofia do músculo liso medialmente e diminuição da microcirculação digital (HARADA; MAHBUB, 2008).

A vasoconstrição induzida pela vibração pode estar relacionada com mecanismos de ativação locais e centrais. Os limiares de concentração aumentados do vasopeptídeo endotelina-1 (ET1), pode sensibilizar a parede do vaso sanguíneo produzindo os efeitos vasoconstritores de substâncias libertadas a partir dos nervos adrenérgicos (YANG et al., 1990). Revisões de literatura inferem a ocorrência da ativação da via somatossimpática pelos vibrorreceptores de Pacini como o mecanismo reflexo capaz de produzir ativação neural de vasoconstrição (STOYNEVA et al., 2003; SAKAKIBARA; YAMADA, 1995). Como a VCI afeta os disparos dos corpúsculos de Pacini reduzindo sensibilidade, procurou-se investigar se essa modalidade de exercício por vibração não seria capaz de gerar efeitos sobre a circulação periférica.

A transmissibilidade da vibração através do corpo também foi outro foco de interesse desta tese considerando que as máquinas de VCI produzem vibrações de altas magnitudes bem acima dos limiares de detecção. Embora VCI utilize frequências e amplitudes menores que vibração ocupacional (como por exemplo, trabalhadores que precisam manusear uma britadeira em uma construção), um estudo realizado por Abercromby e cols. (2007) estimaram que dentre as configurações das plataformas de VCI em sessões de treinamento de vibração comuns (10 min por dia, 30 Hz e 4 mm de amplitude) excedeu as recomendações da Organização Internacional de Normatização (ISO 2631-1:1997, 1997).

Indivíduos expostos à VCI geralmente reportam desconforto em diferentes regiões do corpo. Órgãos e outros segmentos corporais possuem diversificadas frequências naturais de vibração. Se uma frequência de vibração externa transmitida aproxima-se ou é igual à frequência natural de vibração, ressonância vai ocorrer. Numerosas contrações voluntárias e involuntárias vão ocorrer, contribuindo para fadiga e ou redução do desempenho motor durante ressonância (CHAFIN; ANDERSSON; MARTIN, 2006). A exposição a vibrações verticais, através de um equipamento desenvolvido para o estudo de Rasmussen (1983) cita que o intervalo de 5 - 10 Hz geralmente causa ressonância na região torácico-abdominal, a 10 - 20 Hz na cabeça, mãos e braços e sistema urinário e entre 60 - 90 Hz, no globo ocular.

A transmissão de energia mecânica devido às vibrações é dependente do posicionamento do corpo e se algumas contrações musculares estão sendo mantidas. As máquinas que geram os estímulos vibratórios de corpo inteiro disponíveis comercialmente atingem normalmente faixas de frequências de 5 - 60 Hz, e ressonância de partes do corpo pode ocorrer. Com tais fatos apresentados, o corpo inteiro ou órgãos afetados podem vibrar em amplificadas magnitudes que são maiores que a fonte externa de vibração, especialmente se a vibração que entrar não for amortecida por outras partes do corpo antes de chegar no órgão alvo (BRAUER, 2006; WASSERMAN, 1996).

Acredita-se geralmente que a exposição a longo prazo à alta intensidade de vibração de corpo inteiro pode levar a lesões. Afecções sobre o sistema digestivo com variáveis respostas considerando diferentes frequências de vibração foram encontradas (ISHITAKE et al. 2002). Efeitos no tórax e dor abdominal foram reportados na faixa de frequências entre 4 a 10 Hz, na bexiga e irritação intestinal entre 10 a 20 Hz (KROEMER; GRANDJEAN, 1997).

Desta forma surgiu a preocupação em se estudar um mapa de percepção corporal na detecção de possíveis desconfortos durante a VCI, pois estes podem estar relacionados com o fenômeno da ressonância. Ainda, sugerir um método para se escolher os parâmetros da VCI com intuito de atingir as melhores respostas para o treinamento ou reabilitação. Um mapa de percepção corporal da vibração pode ser estabelecido por meio da avaliação das magnitudes de vibração, como foi detectado pelos sujeitos em regiões específicas do corpo para diferentes frequências.

Considerando que a exposição à vibração afeta vários sistemas do organismo (neuroendócrino, vascular, neurossensorial, musculoesquelético), a seguinte questão problema é apresentada neste trabalho, procurando ser sanada através de três estudos realizados com humanos adultos saudáveis e um estudo com ratos Wistar em um modelo de dor crônica: “A exposição aguda da vibração de corpo inteiro com diferentes parâmetros da plataforma vibratória, gera adaptações/alterações sensoriais, de equilíbrio, de parâmetros fisiológicos e transmissibilidade da vibração em diferentes regiões do corpo?”.

2. OBJETIVOS

2.1 Objetivo geral

Investigar os efeitos da vibração de corpo inteiro, em diferentes parâmetros da plataforma vibratória (modos, frequências e amplitudes) através de estudos em humanos e em ratos Wistar, nas adaptações sensoriais como sensibilidade cutânea vibratória, de toque-pressão e dor, equilíbrio, parâmetros fisiológicos e transmissibilidade da vibração em diferentes regiões do corpo.

2.2 Objetivos específicos

1. Verificar o efeito agudo de diferentes frequências da plataforma vibratória na sensibilidade cutânea dos pés de indivíduos saudáveis;
2. Estudar o tempo de recuperação da sensibilidade tátil (receptores de *Meissner* e *Pacini*), em caso de alteração sensorial;
3. Investigar o efeito agudo em diferentes frequências da plataforma vibratória na temperatura superficial da pele de indivíduos saudáveis, em diferentes regiões da perna;
4. Estudar o efeito agudo em diferentes frequências da plataforma vibratória em parâmetros fisiológicos (pressão arterial, frequência cardíaca, frequência respiratória e temperatura axilar) de indivíduos saudáveis, na comparação antes e depois exposição ao equipamento;
5. Investigar o efeito agudo em diferentes frequências da plataforma vibratória no equilíbrio de indivíduos saudáveis;

6. Estudar o efeito do tratamento da plataforma vibratória em um modelo de dor crônica em ratos Wistar na sensibilidade cutânea dolorosa e de toque-pressão;

7. Verificar a transmissibilidade das vibrações no corpo humano através de acelerometria;

8. Comparar a percepção subjetiva de indivíduos saudáveis expostos à vibração através da escala de Borg com os dados quantitativos da acelerometria;

9. Propor um método de escolha dos diferentes parâmetros da plataforma vibratória, com base na escala de Borg, para maximizar os possíveis efeitos gerados pelo equipamento.

3. RESULTADOS

3.1 Estudo 1

Receptores cutâneos humanos da sola do pé: Sensibilidade alterada e tempo de recuperação após vibração de corpo inteiro

O primeiro estudo realizado procurou compreender os efeitos da VCI nos receptores cutâneos sensoriais de rápida adaptação para baixas (30 Hz) e altas frequências (200 Hz) que correspondem aos corpúsculos de Meissner e Pacini, respectivamente. Ainda, os efeitos sobre os receptores sensoriais de toque-pressão e o tempo de recuperação de todos esses receptores após 10 min de exposição à VCI.

Os objetivos específicos 1 e 2 foram respondidos com este estudo.

Este estudo foi desenvolvido na Universidade de Calgary, com apoio do governo canadense através da bolsa de estudos “Emerging Leaders in the Americas Program – ELAP”, sob supervisão do Prof. Dr. Benno M. Nigg e publicado na revista Neuroscience Letters, aceito em novembro de 2012 e publicado em janeiro de 2013, conforme segue:

Neuroscience Letters 533 (2013) 81–85

Contents lists available at SciVerse ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Human cutaneous sensors on the sole of the foot: Altered sensitivity and recovery time after whole body vibration

Anelise Sonza [a,b,*], Christian Maurer [a], Matilde Achaval [b], Milton A. Zaro [b], Benno M. Nigg [a]

[a] Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Calgary, Alberta, Canada
[b] Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

HIGHLIGHTS

- ► Whole body vibration affects the discharges of fast-adapting skin mechanoreceptors.
- ► Recovery time provides a time window of how long the effects of WBV can last.
- ► Vibration induces a reduction in touch pressure and vibration sensitivity.
- ► No gender differences were found.

ARTICLE INFO

Article history:
Received 11 September 2012
Received in revised form 9 November 2012
Accepted 14 November 2012

Keywords:
Mechanoreceptors
Post vibratory effects
Whole body vibration
Human tactile sensitivity
Exercise

ABSTRACT

The goal of this study was to investigate the effect of whole body vibration (WBV) on human tactile sensitivity, both the immediate effects and the recovery time in the case of altered sensitivity. Twenty adults (25.3 ± 2.6 years, 10 males) participated in a 10-min WBV session, at a frequency of 42 Hz with 2 mm amplitude in a spiral mode. Sensitivity was measured before and four times after WBV exposure. Pressure sensation was determined using Von Frey monofilaments. Vibration perception thresholds for 30 and 200 Hz were measured using a custom built neurothesiometer. The sensation was measured in 5 anatomical regions of the right foot. Sensitivity of measured cutaneous perception was significantly reduced. Fast-adapting mechanoreceptors for 200 Hz and 30 Hz showed 5.2 and 3.8 times lower sensation values immediately after WBV, respectively. Pressure sensation was 2 times lower in comparison to the baseline condition. In general, tactile sensitivity recovery time was between 2 and 3 h. WBV influences the discharge of fast-adapting skin mechanoreceptors. By determining the recovery time, it might be possible to estimate how long the effects of WBV on tactile sensitivity last.

1. Introduction

Whole body vibration (WBV) training platforms have been widely used for rehabilitation and/or performance purposes [19]. The reduced effort required to perform exercises in these machines, especially among patients with disabilities, might explain why this equipment has become so popular. It is important to investigate the responses to WBV in the human system in order to make safe recommendations for its use.

In WBV, the skin is the first tissue that receives the vibration stimulus. The feet have various receptors in the skin that provide feedback to the central nervous system [7,8,11]. The nervous conduction from the mechanoreceptors travels along large diameter afferent A_α/A_β sensory fibers. They are classified as slow (SA) or fast (FA) adapting receptors. The SA receptors produce sustained responses to static stimulation. The FA receptors are sensitive to the rapid application and release of a stimulus [9] and are particularly sensitive to mechanical vibrations [17]. FA mechanoreceptors can be divided into Meissner and Pacinian corpuscles, the former are related to low (30 Hz) and the latter to high (200 Hz) vibration frequencies.

WBV has been shown to influence large diameter fibers, with sensitivity being reduced immediately after its application, as shown by touch-pressure [16] and the vibration perception (200 Hz) threshold (VPT) [20]. Notwithstanding, there are very few studies which report the effects of WBV on foot sensitivity.

Abbreviations: WBV, whole body vibration; SA, slow adapting mechanoreceptors; FA, fast adapting mechanoreceptors; VPT, vibration perception threshold; TENS, transcutaneous electrical nerve stimulation.

* Corresponding author at: Instituto de Ciências Básicas da Saúde, UFRGS, Rua Sarmento Leite, 500, 90046-900 Porto Alegre, RS, Brazil. Tel.: +55 51 33083624; fax: +55 51 3308 3092.
E-mail address: anelise.sonza@gmail.com (A. Sonza).

0304-3940/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neulet.2012.11.036

The post-vibratory disturbances affecting skin mechanoreceptive afferent units were studied by microneurographic recordings after 10 min of local vibration. They showed a decrease in the fiber excitability which may last longer than few minutes [18].

Given that reduced mechanoreceptor sensitivity could increase the risk of falls [11], it is important to know the length of time the reduced sensitivity persists after WBV. However, to the best of our knowledge no study has investigated this subject. Therefore, the purpose of this study was to investigate the effects of WBV on human tactile sensitivity considering the mechanoreceptors for touch-pressure and vibration sensitivity. The specific hypotheses were: (A) sensitivity to touch pressure, 30 Hz and 200 Hz vibration receptors decreases after 10 min exposure to WBV; (B) the effects of WBV last for several hours.

2. Material and methods

2.1. Subjects

Based on the literature [16] the sample size was chosen to include 10 male and 10 female healthy subjects (male: mean (SD in brackets) age 25.9 (±3) years, height 177.2 (±10.2) cm and weight of 73.2 (±12.3) kg; female: mean age 24.7 (±2.3) years, height 167.4 (±6.3) cm and weight of 60.3 (±6.9) kg). All subjects were invited to the Human Performance Laboratory of the University of Calgary (Canada), where the experiment was conducted. Nineteen subjects were physically active with a mean of 5.8 h of exercise per week. None of them had trained on vibration platforms before the intervention. They were free from muscle–skeletal disorders and cognitive dysfunctions. Exclusion criteria were mainly based on contra-indications for WBV [2].

All procedures were approved by the Ethics Committee of the University of Calgary (protocol number 24334) and were in accordance with Declaration of Helsinki.

2.2. Data collection

Data collection included measuring the sensitivity of the foot to touch-pressure and vibration before, immediately after and 1 h, 2 h and 3 h after 10 min exposure to WBV. Each session lasted approximately four and a half hours. WBV training was performed on a vibration platform (TBS100A, Total Image Fitness, Inc., CA). The settings for the WBV exposure (42 Hz, 2 mm amplitude and spiral mode) were chosen based on the results of a prior pilot study because they were found to produce the greatest sensation in the lower legs and feet. The greatest sensation was quantified by the subjects who gave a vibration sensation rating or the highest discomfort level (where they felt the vibration most in their body) to a systematic change of vibration stimuli. The subjects stood, bare foot, on 3 mm of EVA foam with straight legs in an upright position and fixed support base.

Sensitivity to touch-pressure and vibration were measured in 5 anatomical regions of the right foot: heel, the mid-foot (medial arch for touch-pressure sensitivity and lateral for vibration sensitivity), the 1st and 5th metatarsal heads and the hallux. Skin temperatures were monitored using a digital thermometer probe (Fluke Thermometer (50A K/J, John Fluke MGF. Co., Inc., USA) and maintained between 25 °C and 32 °C. The temperature of the foot was taken before each measurement procedure. Subjects whose foot temperature changed more than 2 °C in relation to the control measurement (taken before the WBV exposure) were excluded from the analysis because a significant change in plantar vibration sensitivity was reported for temperature changes of around 5 °C [21].

The tests took place in a quiet environment, with a room temperature of between 20 °C and 23 °C. The subjects spent 10 min without shoes prior to the measurements being taken in order to adjust to the room temperature.

2.3. Touch-pressure sensitivity

To evaluate touch-pressure sensitivity, Semmes–Weinstein monofilaments (Touch-Test™ Sensory Evaluator, 20 piece Kit, 58011, Stoelting Co., USA) were used. Each filament has a specific diameter and a known buckling force. The filaments were numbered in such a way that each number represented the $\log_{10}(F[\text{mN}])$, where the applied force value is in milli-Newtons. The order in which the foot regions were measured was randomized. The subject laid supine with closed eyes. A modified 4, 2, 1 stepping algorithm, proposed by Dyck [5], was used for the protocol procedure. Five repetitive stimuli, including a null stimulus, were given with each tested filament [13].

2.4. Vibration sensitivity

The vibration perception threshold (VPT) is defined as the amplitude of a vibration stimulus that is perceptible to a subject. The VPTs were measured using a custom built device that could alter both the frequency and amplitude of a vibrating metal probe (TACLAB, SJB Research Laboratories, NY, USA). Sinusoidal vibration stimuli were delivered to the skin with the probe connected in series to a magnetic shaker (model V203/32 UNF-CE, LDS, UK). The 9 mm diameter circular probe was introduced through a footrest platform and applied to the plantar surface of the foot. The tip of the probe was initially adjusted to protrude 2 mm above the level surface of the wooden platform. A protocol presented by Nurse and Nigg [15], was used. The experimenter increased the vibration amplitudes slowly at about 1 μm in 5 s [7] and manually. When the subjects announced the stimulus recognition, the values were taken by the experimenter. All measurements were performed by the same researcher to increase the reliability of the collected data.

Skin contact force was set to 1 N (±10%), and monitored with a capacitive sensor (FSR 402 0.5″, Interlink Electronics, USA) mounted between the shaker and the probe. The threshold for the vibration sensitivity was measured in dB and converted to the vibration amplitude in μm using a calibration table that was measured prior to the experiment.

Visual feedback about the force they applied on the probe was provided and subjects were asked to keep the force level constant. Five repetitions of the sensitivity measurement were performed at each anatomical location. Considering the optimal response of the Vater-Pacini corpuscles at frequencies between 200 and 250 Hz [12] and Meissner corpuscles at a frequency of 20–50 Hz [22], thresholds were measured at 200 Hz and 30 Hz.

2.5. Recovery time

It was quantified using the half-life time, which is the time period needed to reduce the changes after WBV exposure by a factor of 2. This time can also be thought of the time it takes for the subject's sensitivity to return to half the normal level.

2.6. Statistical analysis

The mean and the standard error were calculated for the control measurement and between gender, which was the measurement taken before exposure to WBV. All data were normalized to the subject specific control value in order to reduce subject specific differences. Changes in sensitivity in relation to the control condition were tested for normal distribution using the Lilliefors test. Due to the non-parametrical nature of the data, a Wilcoxon signed rank test was used. The level of significance was corrected by means of a Bonferroni correction adjusted for the 5 regions of the foot measured ($\alpha = 0.05$ adjusted to $\alpha_b = 0.05/5 = 0.01$). For the graphical display median and interquartile ranges (25th and 75th) were calculated and displayed.

The recovery time was calculated with an exponential regression line to the amplitude values for all subjects and time points. The base of the exponential function was set to 2, and the recovery time was the inverse of the fitted exponent. The exponential regression was calculated including two, three and four time points and the smallest value was used. Standard deviations (SD) of the recovery time were calculated from the confidence interval of the exponential regression fit.

3. Results

The mean values and the standard error (SE) for all subjects for the initial measured sensitivity thresholds for the 5 anatomical regions are listed in Table 1. The values for the pressure sensation under the normal conditions were between 3.02 and 3.66 of the Monofilament.

The vibration sensitivity, measured at 30 Hz, needed a vibration threshold of about 10 μm for the medial arch, the 1st and 5th metatarsal heads and the hallux. A vibration threshold of 20 μm was necessary for the heel.

For 200 Hz, a vibration threshold between 1.3 μm and 1.9 μm was necessary for the lateral arch, the 1st, the 5th metatarsal heads and the hallux and a vibration threshold of 2.89 μm was needed for the heel.

The effects of WBV on vibration thresholds were analyzed over the whole group ($n = 20$), because no differences in vibration thresholds were found between genders for touch-pressure or vibration sensitivity.

3.1. Touch-pressure sensitivity

A significant loss of sensation after 10 min of WBV was found for touch-pressure sensitivity in all five tested regions of the foot (Fig. 1A). In Fig. 1A and B, the vertical axis represents the increase in force needed to feel the monofilaments. An increase in force is equal to a loss of touch pressure sensitivity. The changes were calculated for every subject individually in order to consider subject specific differences from the baseline condition.

All regions showed a significant decrease in touch pressure sensitivity directly after WBV (Fig. 1A). One hour later, in four regions, except medial arch, sensitivity remained significantly lower than at baseline. Two and three hours after WBV exposure, only the sensitivity of the heel remained significantly lower than at baseline (Fig. 1B).

3.2. Vibration sensitivity

A significant change in vibration sensitivity directly after WBV exposure was found in all the measured regions of the foot at both the tested vibration frequencies, 30 Hz (Fig. 2A) and 200 Hz (Fig. 2B).

One hour after the WBV exposure, in 4 regions, except the heel, sensitivity to 30 Hz vibration remained significantly reduced. After 2 h, the hallux and 1st metatarsal head continued to show a significant decrease in vibration sensitivity to 30 Hz in comparison to the baseline. No region of the foot showed significant differences in vibration sensitivity 3 h after exposure to WBV.

When vibration sensitivity was measured at 200 Hz, the fast adapting afferents for high frequencies (B) showed a significant decrease in sensitivity immediately after and 1 h after the WBV in all tested regions of the foot. After 2 h, 3 regions of the foot presented a significant loss of sensation (5th metatarsal head, lateral arch and hallux). Three hours after WBV exposure the heel and lateral arch were still significantly different from the baseline.

3.3. Recovery time

The recovery time for the touch-pressure sensitivity was less than 1 h for the 1st, 5th metatarsal head and medial arch (Table 2).

The recovery time was 1.8 and 1.5 h for the heel and the hallux, respectively. The recovery times at 30 Hz and 200 Hz of vibration sensitivity were longer than the recovery times for the touch-pressure sensitivity. The recovery time at 30 Hz vibration sensitivity ranged from 1.7 h for the hallux to 2.5 h for the heel. At 200 Hz, the range was from 1.5 h for the hallux to 2.5 h for the medial arch.

4. Discussion

This study shows that for young healthy people a single 10-min session of exposure to WBV decreased the touch-pressure and vibration sensitivity of the foot and the sensory system needs up to 2.5 h to recover the normal condition.

No gender differences were found in this study at baseline or after WBV exposure. For the plantar locations, Hennig and Sterzing [7], with a cohort of 20–35 year-old subjects, found gender had no influence on touch sensitivity and only a slight influence on vibration sensitivity. However, for the dorsal aspect of the foot, the same authors found significant gender differences.

For 200 Hz vibration sensitivity, our data are in agreement with a recent study [20] in which different vibration platform settings were used. In their study 3 anatomical regions were evaluated (1st, 5th metatarsal heads and heel). They found a significant decrease in the vibration sensitivity at 200 Hz directly after a 4 min WBV exposure. Our study extends their results, as we have included two further anatomical regions (lateral arch and hallux). Foot arch characteristics and foot sensitivity are important variables for the comfort rating of shoe insoles [14]. The hallux, by contrast, provides essential mechanical and proprioceptive feedback for gait, which is necessary for normal propulsion during gait [3].

In order for the vibration to be perceived, lower amplitude was necessary for the 200 Hz vibration than for the 30 Hz vibration, which corroborates findings reported in the literature [12].

In our study, in the control condition, it was necessary for the vibration amplitude of the probe to be about 5 times higher for the 30 Hz vibration than for the 200 Hz vibration in order to be perceived by the subjects. Physiological messages are transformed because the cutaneous receptors, particularly the fast adapting (FA) type, are highly sensitive to vibration and linked to the frequency of the vibratory stimulus [17]. We have shown that the FA sensors for high frequencies had a higher response to the WBV increasing the amplitude thresholds than the sensors for low frequencies. The experiment showed an increase in the amplitude for receptors sensitive at 200 Hz of about 5.2 times and for receptors sensitive at 30 Hz of about 3.8 times. The increase in amplitude is related to a reduction in sensitivity. Furthermore, the recovery time was shorter for the Pacinian corpuscles than for the Meissner corpuscles.

A reduction in touch-pressure sensitivity was found directly after WBV. The force applied in order that the subject perceived the monofilaments had to be doubled after the WBV exposure. Using different WBV settings from those used in the present study, Pollock et al. [16] found a decrease in touch-pressure sensitivity immediately after WBV in the 1st metatarsal head. They measured sensitivity 15 and 30 min after 5 min exposure. With 4 mm of amplitude on the WBV device, sensitivity was found to be restored after 15 min. Our findings support their results, as the recovery time for

Table 1
Mean and SE for all 20 subjects in the normal condition. The values are the baseline measurements ("Before WBV") for each site on the tested foot (1 – heel, 2 – mid-foot, 3 – 5th metatarsal head, 4 – 1st metatarsal head, 5 – hallux). Touch-pressure sensitivity (Touch) and the amplitude of the test probe for vibration sensitivity at 30 and 200 Hz were measured.

	Touch [$\log_{10}(1000F[N])$]		30 Hz amplitude [μm]		200 Hz amplitude [μm]	
	Mean	SE	Mean	SE	Mean	SE
	3.66	0.09	19.90	3.13	2.89	0.39
	3.02	0.06	09.11	1.16	1.35	0.16
	3.31	0.11	10.76	2.05	1.78	0.25
	3.32	0.09	09.00	1.60	1.60	0.21
	3.41	0.09	11.22	1.93	1.92	0.30

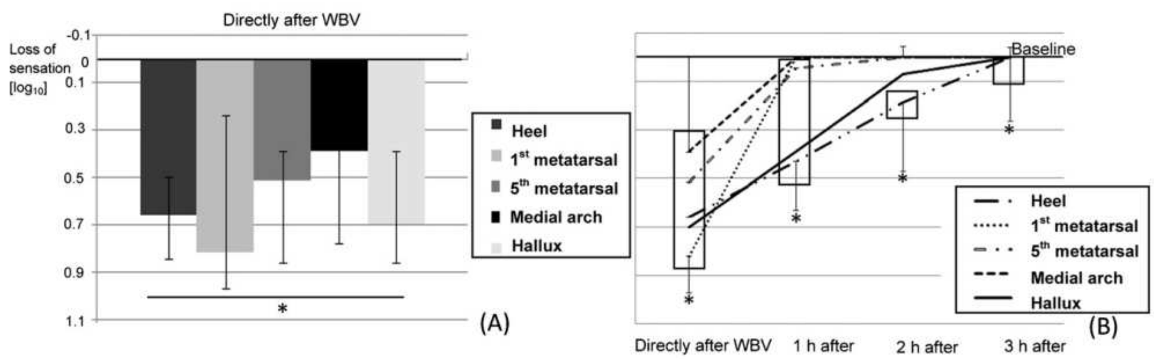

Fig. 1. Loss of sensation in touch pressure after WBV exposure with respect to the control condition. (A) Median and interquartile range (25th–75th) for the change in touch pressure force directly after WBV exposure and (B) 4 times after WBV exposure. Lines in (B) represent the median value and bars represent the interquartile range (25th–75th) for the 5 regions of the foot measured (Bonferroni corrected significance level of $^*\alpha_b = 0.01$).

the medial arch, 1st and 5th metatarsal heads was less than 1 h. In order to determine the time dependent recovery of the touch pressure sensitivity in these regions it will be necessary to use shorter time intervals between the measurements.

High levels of sensory information are part of the sensory feedback system that provides balance [7,8,11] and reflect a combination of factors. Balance is required for safe functional mobility, and any reduction in sensitivity might increase the likelihood of falling. However, interestingly, some studies involving young healthy showed acute enhancement in neuromuscular performance such as balance control [1,20] and muscle strength [4] or non significant results [16] after WBV.

The FA mechanoreceptors are highly affected by vibrations [18]. The nerve fibers that transmit touch pressure and vibration sensitivity are similar to muscle spindle single afferent A_α/A_β fibers [23]. They carry mechanical signals and form a synaptic contact on inhibitory interneurons, competing with the pain stimuli reaching projection neurons. One can speculate that nerve fibers

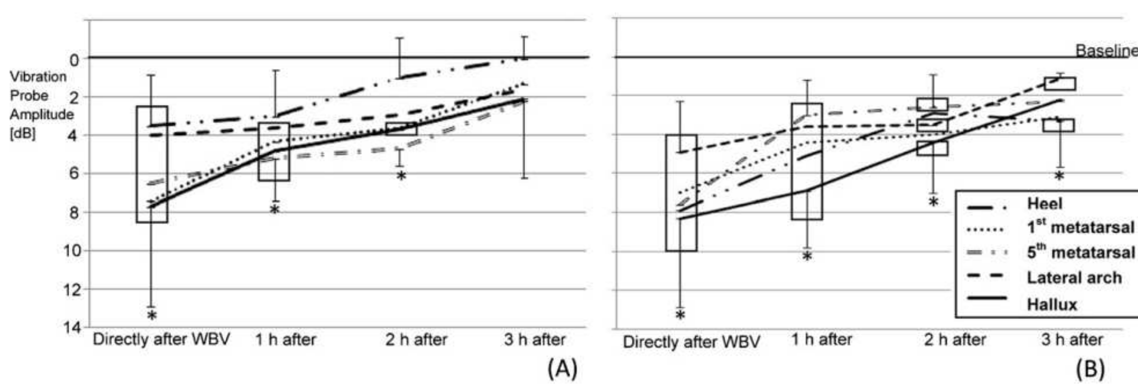

Fig. 2. Time dependent change in vibration sensitivity in relation to the baseline measurement ($^*\alpha_b = 0.01$) at 30 Hz (A) and 200 Hz (B). Lines represent the median value for all 20 subjects and bars represent the interquartile range (25th–75th).

Table 2
Recovery time [h] and standard deviation (SD) after 10 min WBV for the 5 different anatomical regions of the foot (1 – heel, 2 – mid-foot, 3 – 5th metatarsal head, 4 – 1st metatarsal head, 5 – hallux). The recovery time was calculated using the regression line of all measured subjects for touch-pressure sensitivity (Touch) and vibration sensitivity at 30 Hz and 200 Hz.

	Touch		30 Hz		200 Hz	
	Recovery time [h]	SD [h]	Recovery time [h]	SD [h]	Recovery time [h]	SD [h]
	1.8	0.3	2.5	0.8	2.1	0.6
	1.0	0.3	2.0	1.2	2.5	0.7
	0.8	0.2	2.5	1.1	1.7	0.4
	0.7	0.2	2.2	0.7	1.7	0.6
	1.5	0.4	1.7	0.5	1.5	0.5

for touch-pressure and vibration sensitivity may also contribute to the normal perception of stimulus quality, although they do not respond directly to noxious stimuli.

For future studies, it will be interesting to investigate the effects of WBV on pain reduction considering that it can be used in a similar manner as transcutaneous electrical nerve stimulation (TENS) [6]. A possible explanation for this phenomenon might be that vibration activates synchronously large numbers of A_β fibers and therefore stimulates the dorsal column [10].

5. Conclusion

The afferent discharges from fast adapting mechanoreceptors are strongly affected by vibration. Sensitivity to touch-pressure and vibration is impaired after WBV exercise. After a single 10-min exposure to WBV, the time required to recover baseline tactile sensitivity in the feet was between 2 and 3 h.

With the recovery time as a guide, it would be possible to estimate the time window in which the effects of WBV can last. Knowledge of the correct settings for the parameters of the exposure to WBV could therefore be used for suitable rehabilitation interventions.

Conflicts of interest

None.

Acknowledgements

The authors gratefully acknowledge Government of Canada – Emerging Leaders in the Americas Program Scholarship (ELAP) and Government of Brazil – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

References

[1] H. Amano, K. Nakata, T. Mae, H. Kohda, K. Shimomura, M. Satoh, K. Shino, H. Yoshikawa, Effects of whole body vibration training on dynamic balance in healthy adults volunteers, British Journal of Sports Medicine 45 (2011) 334.
[2] I. Bautmans, E. Van Hees, J. Lemper, T. Mets, The feasibility of whole body vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial, BMC Geriatrics 5 (2005) 1–8.
[3] W. Boissonnault, R. Donatelli, The influence of hallux extension on the foot during ambulation, Journal of Orthopaedic & Sports Physical Therapy 5 (5) (1984) 240–242.
[4] M. Cardinale, J. Lim, The acute effects of two different whole body vibration frequencies on vertical jump performance, Sport Medicine (Roma) 56 (4) (2003) 287–292.
[5] P.J. Dyck, A 4, 2 and 1 stepping algorithm for quick and accurate estimation of cutaneous sensation threshold, Neurology 43 (1993) 1508–1515.
[6] R. Guieu, M.F. Tardy-Gervet, J.P. Roll, Analgesic effects of vibration and transcutaneous electrical nerve stimulation applied separately and simultaneously to patients with chronic pain, The Canadian Journal of Neurological Sciences 18 (1991) 113–119.
[7] E.M. Hennig, T. Sterzing, Sensitivity mapping of the human foot: thresholds at 30 skin locations, Foot and Ankle International 30 (10) (2009) 986–991.
[8] J.T. Inglis, F.B. Horak, C.L. Shupert, C. Jones-Rycewicz, The importance of somatosensory information in triggering and scaling automatic postural responses in humans, Experimental Brain Research 101 (1) (1994) 159–164.
[9] M. Knibestöl, A.B. Vallbo, Single unit analysis of mechanoreceptor activity from the human glabrous skin, Acta Physiol Scandinavica 80 (1970) 178–195.
[10] R. Melzack, P.D. Wall, Pain mechanisms: a new theory, Science 150 (1965) 971–979.
[11] P.F. Meyer, L.I. Oddsson, C.J. De Luca, The role of plantar cutaneous sensation in unperturbed stance, Experimental Brain Research 156 (4) (2004) 505–512.
[12] V.B. Mountcastle, R.H. Lamotte, G. Carli, Detection thresholds for stimuli in humans and monkeys: comparison with thresholds events in mechanoreceptive afferent nerve fibers innervating the monkey hand, Journal of Neurophysiology 35 (1) (1972) 122–136.
[13] M.J. Mueller, Identifying patients with diabetes mellitus who are at risk for lower-extremity complications: use of Semmes–Weinstein monofilaments, Physical Therapy 76 (1) (1996) 68–71.
[14] A. Mündermann, D.J. Stefanyshyn, B.M. Nigg, Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors, Medicine and Science in Sports and Exercise 33 (11) (2001) 1939–1945.
[15] M.A. Nurse, B.M. Nigg, Quantifying a relationship between tactile and vibration sensitivity of the human foot with plantar pressure distributions during gait, Clinical Biomechanical 14 (9) (1999) 667–672.
[16] R.D. Pollock, S. Provan, F.C. Martin, D.J. Newham, The effects of whole body vibration on balance, joint position sense and cutaneous sensation, European Journal of Applied Physiology 111 (2011) 3069–3077.
[17] E. Ribot-Ciscar, J.P. Vedel, J.P. Roll, Vibration sensitivity of slowly and rapidly adapting cutaneous mechanoreceptors in the human foot and leg, Journal of Neuroscience Letters 104 (1989) 130–135.
[18] E. Ribot-Ciscar, J.P. Roll, M.F. Tardy-Gervet, F. Harlay, Alteration of human cutaneous afferent discharges as the result of long-lasting vibration, Journal of Applied Physiology 80 (1996) 1708.
[19] J. Rittweger, Vibration as an exercise modality: how it may work, and what its potential might be, European Journal of Applied Physiology 108 (2010) 877–904.
[20] G. Schlee, D. Reckmann, T. Milani, Whole body vibration training reduces plantar foot sensitivity but improves balance control of healthy subjects, Neuroscience Letters 506 (1) (2012) 70–73.
[21] G. Schlee, T. Sterzing, T. Milani, Foot sole skin temperature affects plantar foot sensitivity, Clinical Neurophysiology 120 (2009) 1548–1551.
[22] R.F. Schmidt, Fundamentals of Sensory Physiology, Springer Verlag, New York, 1978.
[23] J.A. Vega, O. Garcia-Suarez, J.A. Montaño, P. Berta, J.M. Cobo, The Meissner and Pacinian sensory corpuscles revisited new data from the last decade, Microscopy Research and Technique 72 (2009) 299–309.

3.2 Estudo 2

Vibração de Corpo Inteiro em diferentes frequências de exposição: Termografia por infravermelho e efeitos fisiológicos

O segundo estudo procurou compreender os efeitos agudos da VCI interagindo com várias respostas fisiológicas em 4 diferentes frequências da plataforma vibratória. As variáveis fisiológicas analisadas foram sensibilidade cutânea de toque-pressão, equilíbrio postural, temperatura de membros inferiores através de termografia por infravermelho, pressão arterial, frequências cardíaca e respiratória e temperatura axilar.

Os objetivos específicos 3, 4 e 5 foram respondidos com este estudo.

Este estudo foi desenvolvido no Instituto Brasileiro de Tecnologia em Couros, Calçados e Afins (IBTeC).

Whole Body Vibration at different exposure frequencies: Infrared thermography and physiological effects

Running Title: Physiological effects of WBV exercise

Anelise Sonza[b*], Caroline C. Robinson[c], Matilde Achaval[a,b], Milton A. Zaro[b],

[a] Departamento de Ciências Morfológicas, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite, 500, 90050-170, Porto Alegre, RS, Brasil
[b] Programa de Pós-Graduação em Neurociências, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite, 500, 90050-170, Porto Alegre, RS, Brasil
[c] Programa de Pós-Graduação em Ciências da Saúde, Universidade Federal de Ciências da Saúde, Porto Alegre, RS, Brasil
* Corresponding author, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite,500, 90050-170, Porto Alegre, RS, Brasil. Fax: +55 51 3308-3092
E-mail address:anelise.sonza@gmail.com (A. Sonza)

Abstract

The aim of this study was to investigate the effects of whole body vibration (WBV) on physiological parameters, cutaneous temperature, tactile sensitivity and balance. Twenty four healthy adults (25.3 ± 2.6 years) participated in four WBV sessions. They spent 15 minutes on a vibration platform in the vertical mode at four different frequencies (31, 35, 40, 44 Hz) with 1 mm of amplitude. All variables were measured before and after WBV exposure. Pressure sensation in five anatomical regions and both feet was determined using Von Frey monofilaments. Postural sway was measured using a force plate. Cutaneous temperature was obtained with an infrared camera. Touch-pressure sensitivity decreased for all regions and frequencies ($p \leq 0.05$). Regarding balance, no differences were found after 20 minutes of WBV at frequencies of 31 and 35 Hz. At 40 and 44 Hz, participants showed higher anterior-posterior center of pressure (COP) velocity and length. The cutaneous temperature of the lower limbs decreased during and 10 minutes after WBV. WBV influences the discharge of the skin touch-pressure receptors. Balance was decreased at higher frequencies (40 and 44 Hz) regarding the anterior-posterior COP velocity and length variables. Vasoconstriction might explain the decreased lower limbs temperature.

Key-words: balance; infrared thermography; mechanoreceptors; post vibratory effects; whole body vibration; vasoconstriction.

1 Introduction

Vibration induces physiological effects that are strongly influenced by parameters such as vibration frequency, amplitude, duration and direction of exposure. Vibratory stimuli interact in a complex manner in the human body and cause physiological effects. In the ergonomic field, vibration is widely reported to produce motor disorders (BOVENZI, ZADINI, FRANZINELLI, BORGOGNI, 1991), loss of sensitivity, decreased blood flow and pathologies such as vibration white finger or carpal tunnel syndrome (KIHLBERG, HAGBERG, 1997).

Whole body vibration (WBV) training platforms have been considered an exercise modality and the reduced effort required with their use might explain their popularity (SONZA, MAURER, ACHAVAL, ZARO, NIGG, 2013). The variety of WBV platform settings that have been used in the available studies and the controversial findings may, in part, explain the inexistence of training standards. An understanding of its acute effects and studies with a wider range of the platform settings might help elucidate this question.

The skin is the body’s largest organ. The dermis comprises a dense network of mechanoreceptors in addition to nerve endings which penetrate the epidermis and together provide the senses of touch, pressure, vibration, pain and heat. It works as the body's thermo regulator, controlling blood flow within a few millimeters of the body surface and aids the sense of balance to modulate posture and gait. Furthermore, the skin is anatomically and physiologically symmetrical (RANSON, 1933).

The influence of WBV on large diameter fibers has been shown directly after WBV for touch-pressure sensitivity (POLLOCK, PROVAN, MARTIN, DI NEWHAM, 2011; SONZA et al., 2013) and influences the discharge of the skin's fast adapting receptors at 30 Hz (SONZA et al., 2013) (*Meissner* corpuscles) and 200Hz (SCHLEE, RECKMANN, MILANI, 2012; SONZA et al., 2013) (*Pacinian* corpuscles) causing reduced sensitivity. The presence of post-vibratory disturbances affecting skin mechanoreceptive afferent units seems to be unanimity among studies using different WBV settings. It is well reported that reduced sensitivity in the mechanoreceptors might increase the risk of falls (MAGNUSSON, ENBOM, JOHANSSON, WIKLUND, 1990; MEYER, ODDSSON, LARS, DE LUCA, CARLO, 2004) because they are part of the sensory feedback system that provides balance (HENNIG, STERZING, 2009; MEYER et al., 2004). However, studies involving the acute effects of WBV on balance are controversial and show enhancement (SCHLEE et al., 2012), non-significant results (POLLOCK, PROVAN, MARTIN, DI NEWHAM, 2011; TORVINEN et al., 2003) or a reduction in overall postural stability (DICKIN, MCCLAIN, HUBBLE, DOAN, SESSFORD, 2012). Hence, it is important to confirm the association between balance control and the reduction in sensitivity at different frequencies of exposure after WBV.

Additionally, thermal measurements provide information related to total blood flow function and it is interesting to understand the effects of WBV on skin temperature. A study with thermography showed an increase in temperature of the medial gastrocnemius with short intercalary exposures (GAMES, SEFTON, 2013). However, to the best of our knowledge, as yet no study has demonstrated the periphery thermal effects during the whole WBV session and in the subsequent minutes.

Another important aspect to consider is the fact that no study has investigated the combination between several physiological parameters at different frequencies of exposure. Therefore, the purpose of this study was to investigate the effects of WBV on different physiological variables and at different WBV settings. The specific hypotheses were: (A) cutaneous sensitivity to touch pressure, at different frequencies of exposure decreases after WBV; (B) lower limb temperature might increase after WBV; (C) balance might decrease after WBV.

2 Methods

This was an experimental before and after study investigating the acute effects of 15 minutes of WBV at four different vibration frequencies on healthy young individuals, each individual being their own comparator. The study took place at the Biomechanics Laboratory of the Brazilian Institute of Leather, Shoe and Artefacts Technology (*Instituto Brasileiro de Tecnologia do Couro, Calçados e Artefatos* - IBTeC), Novo Hamburgo, Rio Grande do Sul, Brazil, from May 2012 to May 2013.

2.1 Participants

Participants were invited from the community. Those eligible were healthy young adults of both genders, aged from 18 to 35 years of age. Exclusion criteria were muscle-skeletal disorders, cognitive or physical dysfunction and the contra-indications for WBV previously reported by Bautmans, van Hees, Lemper, & Mets (2005). All measurements were approved by the Ethical Committee of the Federal University of Rio Grande do Sul, Brazil (protocol number 22626) and were in accordance with the Declaration of Helsinki.

2.1.1 Sample size definition

As this study was mainly designed considering the particularities of using thermography to detect a before and after difference in lower limb temperature of 1.5 (0.9)° C (COCHRANE, STANNARD, SARGEANT, RITTWEGER, 2008), with a two-sided 5% significance level and a power of 90%, a minimum sample size of 20 participants was necessary, given an anticipated dropout rate of 10%. As sample determination did not consider the other measured outcomes, a statistical power was calculated and presented for each analysis.

2.2 Procedures

All the procedures were conducted in the same room with controlled air humidity (50 ± 5%) and temperature (21 ± 2 ℃). After assess ing the participants’ characteristics, data collection included the assessment of the foot sensitivity for touch-pressure sensitivity, balance and physiologic and thermographic measurements, before and after exposure to WBV for 15 minutes at each of the four different vibration frequencies. Each session of exposure to a vibration frequency and the respective before and after assessments lasted approximately one hour. They were performed at intervals of 48 hours to avoid vibration cumulative effects. To be included in the analysis, each participant must have attended four visits at the Biomechanics Laboratory. During each session the measurements were taken in the following sequence: a) cutaneous sensitivity; b) balance; c) physiological assessment; d) IR thermography during 15 minutes of WBV exposure and during the 10 minutes immediately following WBV; e) physiological assessment, f) cutaneous sensitivity; e) balance. The sequence of the measurements is presented in the protocol timeline (Figure 1).

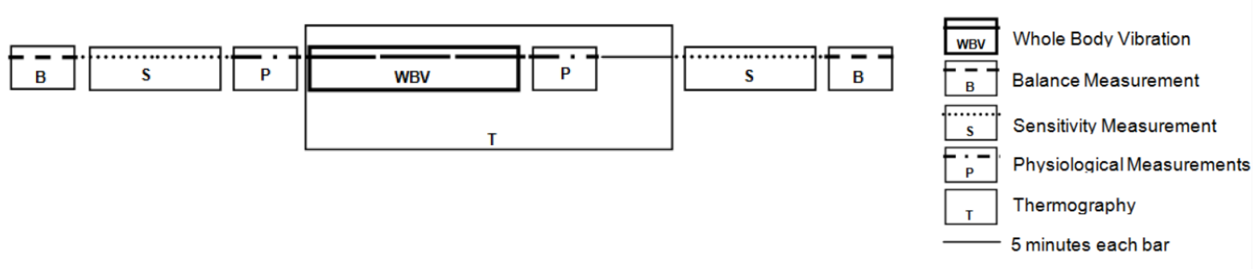

Fig 1: Protocol timeline. Each bar distance corresponds to 5 minutes in the protocol.

WBV exposure was performed on a vibration platform (Pro-form Bio-vibe®, Icon Fitness, Colorado, USA) with allow only four frequency settings (31, 35, 40 and 44Hz, named f1, f2, f3 and f4, respectively) at a fixed vibration displacement of 1 mm peak-to-peak amplitude in a vertical synchronous vibration. Thus, the choice of these vibration parameters was determined due to the limitations of the equipment. The accuracy of the frequencies was measured using a uniaxial piezoelectric accelerometer, model DeltaTron® 4507 B 006A (Brüel & Kjær®, Denmark) and dedicated software. To measure the amplitude and accuracy of the WBV machine, the Spica Tek® kinemetry system (Spica Technologies, New Hampshire, USA) was used with a video camera model IPX VGA 210-L (Imperx®, Florida, USA) and a sample frequency of 200 Hz. As the participants performed one of the four vibration frequencies in each session, the frequency order was selected at random by drawing lots. During WBV exposure, participants were static, standing barefoot on a 3 mm ethylene vinyl acetate (EVA) foam, fixed to the platform base to avoid foot slip, with legs slightly bent (knee flexed approximately 20°, considering a full knee extension of 0°) with feet shoulder-width apart, without upper-limb support. The participants maintained this position for 15 minutes during each WBV exposure. During the 10 minutes following WBV exposure, the participant remained on the platform while maintaining the same position, but was allowed to extend the knees.

2.2.1 Physiological measurements

Physiological measurements such as blood pressure, axillary temperature, and breath and heart rates were taken before and immediately after 15 minutes of WBV exposure. For these measurements, the subjects stood barefoot on the vibration platform, without vibration, with both feet flat on the platform in a quiet environment. The subject should be comfortable and relaxed with a recently emptied bladder. To measure blood pressure, a manually calibrated sphygmomanometer (Premium NML-105, Inmetro, Brazil) and a stethoscope (3M™ Littmann® Classic II S.E. Stethoscope, USA) were used. The left arm was extended and the forearm was supported by the assessor at the level of the subject's heart with the palm of the hand facing up. A digital thermometer OMRON (MC-245, Japan) was used to take the axillary temperature. To measure the heart rate, the pulse was located by lightly pressing the index and middle fingers slightly to the radial side of the subject's wrist (where the radial artery is located). The heart beats were counted in one minute (bpm). One respiratory cycle was considered to include one complete rise and fall of the chest, or the inhalation and exhalation of air. For the breathing rate count, measures were taken to ensure the subject remained unaware their breathing was being monitored in order to obtain a more reliable count. The respiratory rate was registered in one minute of breathing (rpm). All the physiological measurements were performed by the same assessor.

2.2.2 Touch-pressure sensitivity assessment

To obtain the touch-pressure sensitivity, Semmes-Weinstein® monofilaments (Touch-Test™ 20 Piece Kit, Stoelting Co, Wood Dale, USA) were used. Before and 10 minutes after WBV exposure, touch-pressure sensitivity was measured in five anatomical regions of the right and left foot (heel, middle foot, 1^{st} and 5^{th} metatarsal head and hallux), following the same procedures presented by (SONZA, MAURER, ACHAVAL, ZARO, NIGG, 2013). The sequence in which the feet and the respective regions were measured was randomized to avoid any effect of time lags in the feet evaluation. A modified 4, 2, 1 stepping algorithm proposed by Dick et al. (1993) (DYCK, O'BRIEN, KOSANKE, GILLEN, KARNES, 1993), was used for the protocol and the same assessor performed these measurement before and after each WBV exposure. Because temperature influences sensitivity, foot temperature was monitored using a digital thermometer probe HT 208 (Icel®, Manaus, Brazil) and maintained between 25 ℃ and 32 ℃. The temperature of each foot was take n prior to measuring touch-pressure sensitivity. Those participants in whom the temperature of the foot changed more than 2 ℃ from baseline were excluded from the analysis.

2.2.3 Balance assessment

An OR6-5 force plate (AMTI®, Massachusetts, USA) was used to assess balance by center of pressure (COP) sway (displacement, velocity and area). The force platform was embedded in the floor. The balance was measured before WBV exposure and 20 minutes after the end of the 15 minutes of WBV exposure, immediately following the touch-pressure sensitivity assessment. In each trial, the subject stood barefoot, in a single leg stance, with eyes open for one minute. Participants were verbally instructed to look straight ahead with their body erect, hands on the waist and keep balance. Two trials were performed on alternate legs, with a one-minute interval between trials to avoid fatigue. The order of the first foot was sorted at random. Balance assessments were conducted by the same assessor.

A time domain analysis was performed to obtain summary measures of the COP values in both the anterior-posterior (A-P) and medial-lateral (M-L) directions: (a) resultant mean COP velocity; (b) COP length and (c) COP ellipse area. The resultant mean COP velocity was calculated by determining the square root of the sum of the mean velocities in each direction. The COP length was considered the total displacement of the body's COP during data collection. The 95% confidence ellipse area was calculated using the principal component analysis (OLIVEIRA, SIMPSON, NADAL, 1996). COP analysis algorithms (DUARTE, 2013) were implemented in Matlab 7.9 (Mathworks Inc., Natick, USA). The COP data were low-pass filtered at 5 Hz with a fourth-order and zero-lag Butterworth filter (PRIETO, MYKLEBUST, HOFFMANN, LOVETT, MYKLEBUST, 1996), since most of the power of the signal was below 2 Hz (Winter, 1995). The first 10 seconds of data at the beginning of each trial were discarded, and hence not considered in determining the sway measures. Thus the maximum duration of sway was 50 seconds.

2.2.4 Lower limb temperature assessment

The temperature of the lower limbs was assessed using infrared thermography. A PV-320T (Electrophysics, New Jersey, USA) thermal imaging camera (320 X 240 pixel resolution) was used to obtain thermal imagery in the 3 to14 μm spectral range, sensitivity of 0.08 ℃ with a maximum error of 2%. Images were captured and processed using Electrophysics Velocity 2.4 (Electrophysics, New Jersey, USA) image analysis software with automatic calibration and emissivity of 0.971. The camera was placed at an angle of approximately 70° to the surf ace, 0.7 m above the floor and 2.5 m from the vibration platform to provide a full view of the lower limbs. The infrared imaging protocol followed the recommendations of the American Academy of Thermology (BHARARA, COBB, CLAREMONT, 2006). A sequence of images of the dorsal part of the lower limbs was automatically recorded for 25 minutes, 1 frame per second (FPS). The vibration platform was turned on for the first 15 minutes and turned off for the last 10 minutes.

The mean data points within a square drawn in the central area of the thigh, knee, lower leg and foot were analyzed as regions of interest (UEMATSU, EDWIN, JANKEL, KOZIKOWSKI, TRATTNER, 1988) set by the same assessor. Before thermographic assessment, the participants remained with the lower limbs disrobed for 20 minutes in order to equilibrate their body-surface temperature to the room temperature. The lower limbs made no contact with any surface during this period or during the 25 minutes on the platform. The same clothes were used in the four WBV exposures.

2.3 Statistical analysis

The mean values and the standard error (±SE) were calculated for all the participants and all analyzed outcome measurements. The normality of the data distribution was assessed using the Shapiro Wilks test. Despite the non-parametrical nature of the data, differences between the measurements obtained before and after WBV exposure were analysed using the MANOVA multivariate analysis of variance test for multiple dependent variables (frequency, time before vs. after, right and left sides, different regions of the body for the sensitivity and thermographic data and balance variables). To reduce the effects of non-uniformity in the data distribution all values were transformed using a logarithmic (base 10) transformation. With small sample sizes, non-parametric analyses are less likely to detect effects, or the power is reduced, or the confidence intervals are wider. COP data were analysed for 17 participants because of missing data during digital recording. For the thermographic frames sequence, the mean temperature in each frame was used to obtain 25 data points, representing every minute from the sequence. A paired t-test was applied to compare the sequences minute by minute. Adopted level of significance was $\alpha = 0.05$.

3 Results

A total of 24 (26.4 ±4.1 years; 11 male, 13 female) participants, mean height 170.5 (±8.6) cm and weight of 66 (±12.6) kg participated of the study. None of the participants had trained on vibration platforms prior to the experimental interventions.

3.1 Physiological measurements

The MANOVA analysis for all subjects, for the physiological measurements (blood pressure, axillary temperature, respiratory and cardiac rates), including frequency and time (before vs. after), showed effects of time ($p < 0.01$; power = 0.87) on heart rate. No effects were found between the measured frequencies. Heart rate was higher at 31 Hz, comparing before and after WBV ($p<0.01$).

3.2 Touch-pressure sensitivity

Baseline plantar sensitivity presented levels consistent with normality, since, under the normal conditions, the values for pressure sensation were between 3.08 and 3.59 according to the Semmes-Weinstein monofilament (Table 1).

Table 1: Mean and standard error (SE) for all 25 subjects in the normal condition. The values are the baseline measurements (“Before WBV”) for each site on the tested foot (1 – heel, 2 – mid-foot, 3 – 5th metatarsal head, 4 – 1st metatarsal head, 5 – hallux).

	Touch [log10(1000F[N])] Right foot		Touch [log10(1000F[N])] Left foot	
	Mean	**SE**	**Mean**	**SE**
1	3.59	0.05	3.59	0.05
2	3.08	0.07	3.05	0.07
3	3.31	0.08	3.35	0.06
4	3.33	0.08	3.27	0.09
5	3.40	0.08	3.37	0.07

A significant loss of sensation after 15 minutes of WBV exposure compared to baseline (time effect; $p < 0.01$; power = 1.0) was found for touch-pressure sensitivity in all five tested regions of the right and left foot (Table 2).

There were no differences between the right and left foot regarding time or frequency effects.

Table 2: Loss of sensation (LOS) and Standard Error (±SE) in touch pressure sensitivity with respect to the control condition, for both feet, five regions (heel, medial arch, 5th metatarsal head, 1st metatarsal head and hallux). All 25 subjects were measured 10 minutes after WBV exposure, in 4 different frequencies of WBV (f1 = 31, f2 = 35, f3 = 40 and f4 = 44 Hz). (*p < 0.01).

		Right Foot					Left Foot				
		Heel* LOS	MET1* LOS	MET5* LOS	MArch* LOS	Hallux* LOS	Heel* LOS	MET1* LOS	MET5* LOS	MArch* LOS	Hallux* LOS
f1	Log_{10}	0.38	0.24	0.27	0.06	0.18	0.40	0.21	0.22	0.11	0.21
	SE	0.05	0.08	0.07	0.07	0.08	0.06	0.08	0.06	0.07	0.07
f2	Log_{10}	0.52	0.33	0.36	0.20	0.28	0.49	0.28	0.32	0.19	0.27
	SE	0.05	0.08	0.07	0.07	0.08	0.06	0.08	0.06	0.07	0.07
f3	Log_{10}	0.42	0.19	0.31	0.19	0.18	0.31	0.18	0.23	0.08	0.15
	SE	0.05	0.08	0.07	0.07	0.08	0.06	0.08	0.06	0.07	0.07
f4	Log_{10}	0.44	0.31	0.22	0.23	0.30	0.49	0.25	0.28	0.14	0.22
	SE	0.05	0.08	0.07	0.07	0.08	0.06	0.08	0.06	0.07	0.07

3.3 Balance

Considering the postural stability data, the means and standard errors of COP values for each WBV frequency are presented in Fig. 2. The measurements were taken 20 minutes after WBV exposure. In the A-P direction, regarding COP velocity and COP length, there was a significant change in the comparison between before and after WBV for the higher frequencies. For f3 and f4, the participants showed a higher A-P COP velocity (f3 before vs. after: $F = 11.67$, $P < 0.01$; f4 before vs. after: $F= 5.42$, $P = 0.023$) and for A-P COP length (f3 before vs. after: $F = 11.9$, $P < 0.01$; f4 before vs. after: $F= 6.5$, $P = 0.013$). No differences in balance were found within the f1 and f2 frequencies for any of the analyzed COP variables. Regarding the COP area and the M-L COP velocity and length, no differences were found when comparing the conditions before vs. after WBV exposure.

The analysis including frequencies, lower limbs (right vs. left) and time (before vs. after) showed effects for frequency ($p < 0.01$; power = 0.99) and time ($p < 0.01$; power = 0.95). No effect was found between the right and left lower limbs ($p = 0.09$; power = 0.79).

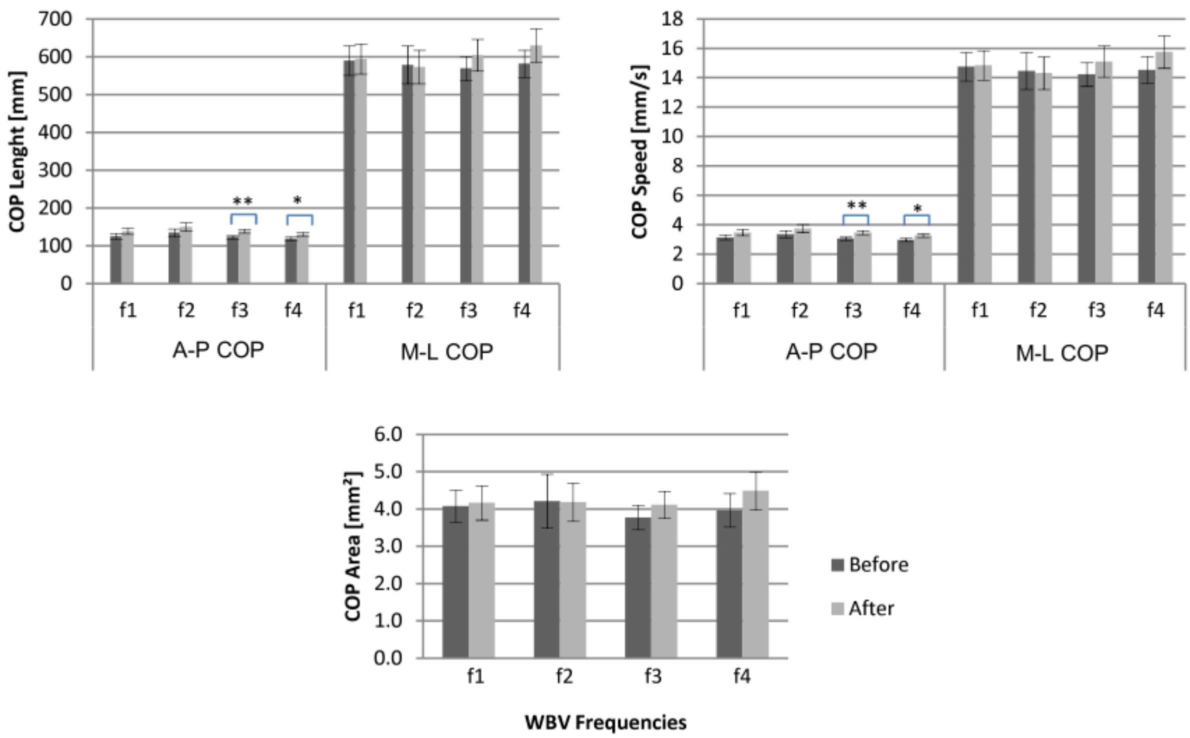

Fig 2: Mean and standard error values of the COP summary measures during the 60-second single-leg stance trials for the different frequency WBV groups, before and 20 minutes after WBV intervention. f1 =31 Hz; f2 = 35 Hz; f3 = 40 Hz; f4 = 44 Hz (n = 17). (*p < 0.05; **p < 0.01).

3.4 Lower limbs temperature

Infrared thermography was used to determine the temperature response to WBV in the lower limbs. The temperature values obtained during the 15 minutes of and 10 minutes following WBV exposure for each frequency vibration are plotted in Fig 3. In general, a decrease was observed in lower limb temperature during the 15 minutes of and 10 minutes following WBV exposure. A slight increase in the temperature was observed at the end of the recovery time, which is an indication that the temperature had started to return to the baseline condition.

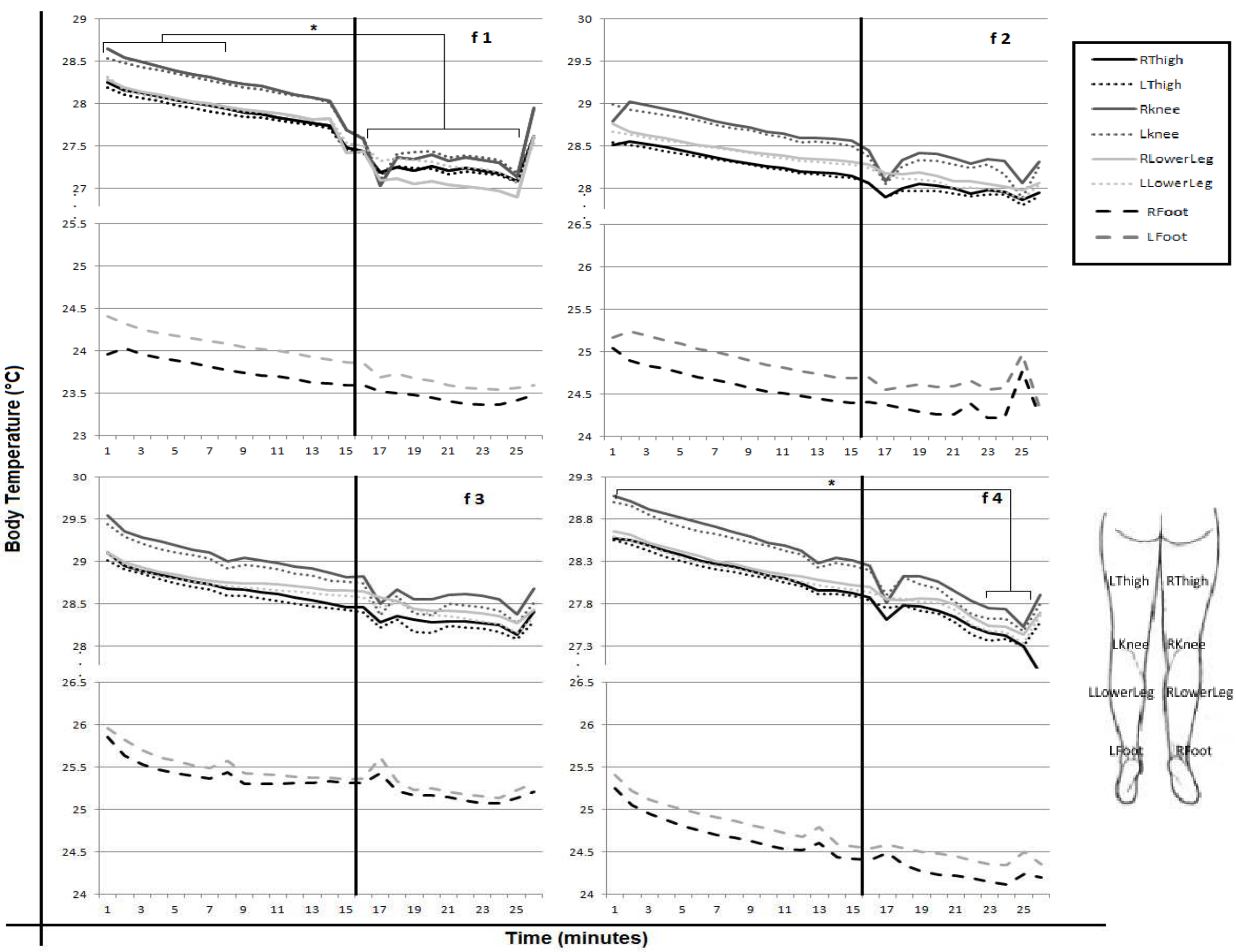

Fig 3: Thermograph curve from the posterior of the lower limbs obtained during 15 minutes of exposure and 10 minutes after exposure to four different WBV frequencies, in four regions of the right and left limbs (thigh, knee, lower leg, foot). f1 = 31Hz; f2 = 35 Hz; f3 = 40 Hz; f = 44 Hz (n = 24). (*p < 0.05).

Comparing lower limb temperature in first minute and minute 25, the MANOVA analysis showed effects for frequency ($p < 0.01$; power = 1.0) and time ($p < 0.01$; power = 1.0). The pairwise comparison showed a significant difference ($p < 0.01$) for the regions of the thigh, knee and lower leg between time and frequencies. For the foot region, there was no difference between the first minute and minute 25 ($p = 0.87$). However, there were differences between the frequencies.

The comparison between f1 and f3 showed differences in skin temperature between all the regions of the lower limbs ($p < 0.01$). Comparing f3 vs. f4 there were differences in the regions of the thigh ($p = 0.001$) and lower leg ($p = 0.013$). For the region of the foot, f1 presented differences between the first minute and minute 25 in comparison to the other three analyzed frequencies. Comparing f2 vs. f3, there were also differences in the same region (foot) ($p = 0.005$).

A *t*-test was applied to compare the minute by minute mean temperatures in the posterior region of lower limbs (Fig 3). A significant decrease in temperature was found between the initial 7 minutes in comparison to the last minutes (from 16 to 24) for the regions of the thigh, knee and lower limbs at f1. At f4, a significant decrease in lower limbs temperature was found between minute 1 and minutes 22 to 24 for the regions of the thigh and knee and compared to the last minute for the lower leg. In the region of the foot in general, at frequencies of 35 and 40 Hz, there was no significant decrease in the temperature ($p < 0.05$).

4 Discussion

The results of this study support the understanding that for young healthy people, in general, a single 15-minute session of WBV does not affect physiological variables such as blood pressure, axillary temperature or the respiratory and heart rates. These findings are in agreement with a study (RITTWEGER, BELLER, & FELSENBERG, 2000; RITTWEGER et al., 2000) that showed the cardiovascular effects of WBV performed to exhaustion are mild compared to those of bicycle ergometry. Although WBV exercise has been considered as an exercise modality, its characteristics in comparison to traditional aerobic exercises such as cycling, walking, dancing, etc. are different in relation to responses to the same variables. This indicates the cardiovascular system is not being trained.

A reduction in touch-pressure sensitivity of the feet at different frequencies of the vibration platform was found 10 minutes after the use of the device. Using different WBV settings from those used in the present study, authors (POLLOCK et al., 2011; SCHLEE et al., 2012; SONZA et al., 2013) found the same results for cutaneous sensitivity immediately after WBV. Sonza et al. (2013) found the recovery time for the right foot and the same foot locations for touch-pressure sensitivity was less than 1 hour. For vibration sensitivity, the recovery time was about 2.5 hours after a single WBV session. Considering studies with different frequencies, vibration modes and amplitudes, cutaneous sensitivity always seems to decrease immediately after WBV.

The central nervous system uses plantar cutaneo-muscular and ankle spindle afferent inputs that influence balance control during quiet and perturbed stance (THOMPSON, BÉLANGER, & FUNG, 2011). Balance is required for safe functional mobility, and any reduction in sensitivity might increase the likelihood of falling (SONZA et al., 2013). However, interestingly, some studies involving young healthy subjects showed acute enhancement in neuromuscular performance such as balance control (SCHLEE et al., 2012) and muscle strength (CARDINALE & LIM, 2003) or non-significant results (POLLOCK et al., 2011; TORVINEN et al., 2003) after WBV. A study modulating lower limb somatosensory information by tendon and plantar cutaneo-muscular vibrations showed altered postural responses that increased COP displacement (THOMPSON et al., 2011). Regarding the balance control variables, A-P COP velocity and length, when measured 20 minutes after WBV, this study shows there is a significant decrease in balance control at the highest analyzed frequencies (40 and 44 Hz). Impaired balance may be due to decreased sensitivity resulting from disturbances in the discharge of the skin mechanoreceptors (sensory feedback system). No significant results were found for either the COP ellipse area or at the lowest frequencies. Dickin et al. (2012) measured balance on a stable support surface and opened eyes after 4 minutes of WBV during separate trials at frequencies of 10, 30 and 50 Hz. They found an increase in COP sway immediately after WBV that returned to baseline 10 and 20-minute post vibration assessments. Two major differences between the current study and that of Dickin et. al. (2012) is the length of exposure and the postural assessment, in the former case it was 15 minutes and unipodal balance assessment, while in the latter it was 4 minutes and bipodal balance assessment. The study involving healthy subjects conducted by Schlee et al. (2012) measured balance at a frequency of 27 Hz and 2mm horizontal amplitude after 4 minutes WBV and found an improvement in balance control immediately after WBV. The present study, in agreement with Dickin et al. (2012), found no differences in balance control with the vibration platform set at 30 Hz, measured 20 minutes post vibration.

It is well documented that thermal measurements provide information related to total blood flow function. Although an increase in lower limb temperature was expected at all the studied frequencies, a decrease in lower limb temperature was found during the 15 minutes of exposure.

A delay was observed in the recovery of lower leg temperature to the baseline condition. At all frequencies, recovery began to occur at around 10 minutes post vibration, this is particularly clear at 31 Hz. This finding is consistent with those of previous investigations (BOVENZI, LINDSELL, & GRIFFIN, 1998; YANG ET AL., 1990; YE, MAURO, BOVENZI, & GRIFFIN, 2012) inducing hand-arm vibration. In 12 healthy participants, Olsen (1993) studied the cold-induced vasoconstrictor response in the digital arteries exposed to unilateral vibration at a frequency of 31.5 Hz. It was observed that 30 minutes of exposure to such vibration caused a significant increase in cold-induced arterial responsiveness in both the vibrated and non-vibrated fingers 60 minutes after the end of the vibration exposure. Some authors (BOVENZI, LINDSELL, & GRIFFIN, 2000; YE ET AL., 2012) conclude that the higher the magnitudes of vibration, the greater the vasoconstriction will be in both the vibrated and non-vibrated fingers during recovery, which is consistent with a greater sympathetic response.

Vasoconstriction induced by vibration may be related to local and central mechanisms (Fig. 4). It has been reported that threshold concentrations of the vasopeptide endothelin-1 (ET1) can sensitize the blood vessel wall to the vasoconstrictor effects of substances released by the adrenergic nerves (YANG et al., 1990). Literature reviews implicate activation of the somatosympathetic pathway by the pacinian vibroreceptors as the reflex mechanism producing neural activation of vasoconstriction (SAKAKIBARA & YAMADA, 1995; STOYNEVA, LYAPINA, TZVETKOV, & VODENICHAROV, 2003). The nervous conduction from the mechanoreceptors travels along large diameter afferent A_{β} sensory fibers. The significant decrease in touch pressure sensitivity found in the present is evidence of somatosympathetic pathway activation through vibration. A previous study by Sonza et al. (2013) found that after 10 min WBV it takes about 2.5 hours for the pacinian vibroreceptors to recover to normalize their discharge rate. The main pathophysiological mechanism is probably an imbalance between ET1 and the calcitonin-gene-related peptide (CGRP), a powerful vasodilator present in digital cutaneous perivascular nerves (NOËL, 2000).

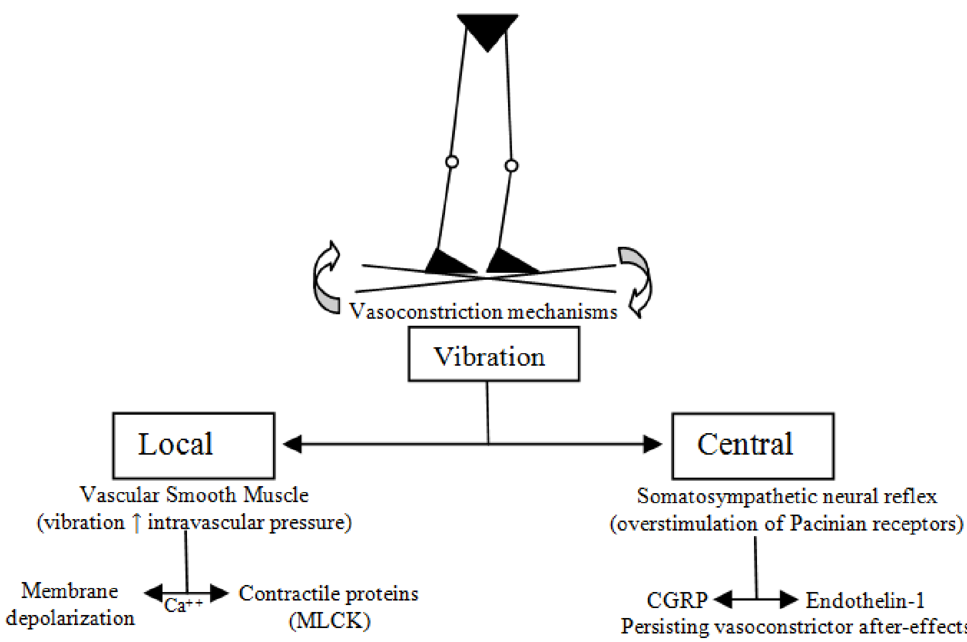

Fig 4: **Putative local and central mechanisms involved in vascular smooth muscle vasoconstriction mediated by vibration stimulation (see text for details).**

Nevertheless, these thermographic results cannot exclude the possibility that local vasoconstrictor mechanisms are acting. Because the resting potential of smooth muscle is determined to a large extent by K^+ (NELSON, PATLAK, WORLEY, & STANDEN, 1990), stretch-induced depolarization could be explained by activation of mechanosensitive ion channels that promote Na^+ or Ca^{+2} influx, Cl^- efflux, or inhibit K^+ efflux (DAVIS & HILL, 1999). Increasing intracellular [Ca^{2+}] via IP_3 (inositol-3-phosphate) gated channels in the sarcoplasmic reticulum sensitizes the smooth muscle apparatus to calcium, activation of myosin light chain kinase, increases phosphorylation of the regulatory myosin light chains and thus leads to contraction (CLARK & PYNE-GEITHMAN, 2005; LAHER & BEVAN, 1987; WOODRUM & BROPHY, 2001). The calcium-dependent enzyme myosin light chain kinase (MLCK) is responsible for initiating physiological contraction in smooth muscle (STULL et al., 1996) and the release of Ca^{2+} increases MLCK activation (CLARK & PYNE-GEITHMAN, 2005).

One implication of these results would suggest that the observed after-effects of vibration may be interpreted as resulting from a vibration-induced vasoconstrictor response observed through the temperature decrease in the vessels of the lower legs. Vasoconstriction was possibly mediated by the sympathetic nervous system and locally amplified by smooth muscle membrane depolarization and endothelium-derived contracting factors (BOVENZI et al., 1998) in response to various chemical and physical stimuli (BURNSTOCK, 1993).

Controversially, a study using IR thermography and different parameter settings on a vibration platform showed an increase in temperature of the medial head of the gastrocnemius (GAMES & SEFTON, 2013). In that case, as the exposure was short and intercalary, the central vasoconstriction mechanisms may not have interacted.

5 Conclusion

A significant loss of touch-pressure sensation was found on the sole of the right and left foot 10 minutes after the WBV session.

At the highest frequencies (40 and 44 Hz) a significant loss of balance was found for the A-P COP velocity and length variables.

During and 10 minutes after WBV exposure, lower limb temperature decreased, probably due to vasoconstriction.

6 Acknowledgements

We gratefully acknowledge the support of the Government of Brazil – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Biomechanics Laboratory of IBTeC and Roberta Detânico for the technical support.

7 References

BOVENZI, M., LINDSELL, C., & GRIFFIN, M. (2000). Acute vascular responses to the frequency of vibration transmitted to the hand. **Occupational and Environmental Medicine**, *57*(6), 422–430.

BOVENZI, M., LINDSELL, C. J., & GRIFFIN, M. J. (1998). Duration of acute exposures to vibration and finger circulation. **Scandinavian journal of work, environment & health**, *24*(2), 130–137.

BOVENZI, M., ZADINI, A., FRANZINELLI, A., & BORGOGNI, F. (1991). Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration. **Ergonomics**, *34*(5), 547–562.

BURNSTOCK, G. (1993). Integration of factors controlling vascular tone. Overview. **Anesthesiology**, *79*(6), 1368–1380.

CARDINALE, M., & LIM, J. (2003). The acute effects of two different whole body vibration frequencies on vertical jump performance. **Med Sport**, *56*, 287–292.

CLARK, J. F., & PYNE-GEITHMAN, G. (2005). Vascular smooth muscle function: The physiology and pathology of vasoconstriction. **Pathophysiology**, *12*(1), 35–45.

COCHRANE, D. J., STANNARD, S. R., SARGEANT, A. J., & RITTWEGER, J. (2008). The rate of muscle temperature increase during acute whole-body vibration exercise. **European Journal of Applied Physiology**, *103*(4), 441–448.

DAVIS, M. J., & HILL, M. A. (1999). Signaling mechanisms underlying the vascular myogenic response. **Physiological reviews**, *79*(2), 387–423.

DICKIN, D. C., MCCLAIN, M. A., HUBBLE, R. P., DOAN, J. B., & SESSFORD, D. (2012). Changes in postural sway frequency and complexity in altered sensory environments following whole body vibrations. **Human movement science**, *31*(5), 1238–1246.

DYCK, P. J., O'BRIEN, P. C., KOSANKE, J. L., GILLEN, D. A., & KARNES, J. L. (1993). A 4, 2, and 1 stepping algorithm for quick and accurate estimation of cutaneous sensation threshold. **Neurology,** *43*(8), 1508.

GAMES, K. E., & SEFTON, J. M. (2013). Whole-body vibration influences lower extremity circulatory and neurological function. **Scandinavian Journal of Medicine & Science in Sports**, *23*(4), 516–523.

HENNIG, E. M., & STERZING, T. (2009). Sensitivity Mapping of The Human Foot: Thresholds at 30 Skin Locations. *Foot & Ankle International*, *30*(10), 986–991.

KIHLBERG, S., & HAGBERG, M. (1997). Hand-arm symptoms related to impact and nonimpact hand-held power tools. **International archives of occupational and environmental health**, *69*(4), 282–288.

LAHER, I., & BEVAN, J. A. (1987). Protein kinase C activation selectively augments a stretch-induced, calcium-dependent tone in vascular smooth muscle. **The Journal of pharmacology and experimental therapeutics,** *242*(2), 566–572.

MAGNUSSON, M., ENBOM, H., JOHANSSON, R., & WIKLUND, J. (1990). Significance of pressor input from the human feet in lateral postural control. The effect of hypothermia on galvanically induced body-sway. **Acta oto-laryngologica**, *110*(5-6), 321–327.

MEYER, P. F., ODDSSON, LARS I E, & DE LUCA, CARLO J. (2004). The role of plantar cutaneous sensation in unperturbed stance. **Experimental brain research.** *156*(4), 505–512.

NELSON, M. T., PATLAK, J. B., WORLEY, J. F., & STANDEN, N. B. (1990). Calcium channels, potassium channels, and voltage dependence of arterial smooth muscle tone. **The American journal of physiology**, *259*(1 Pt 1), C3-18.

NOËL, B. (2000). Pathophysiology and classification of the vibration white finger. **International archives of occupational and environmental health,** *73*(3), 150–155.

POLLOCK, R. D., PROVAN, S., MARTIN, F. C., & DI NEWHAM, J. (2011). The effects of whole body vibration on balance, joint position sense and cutaneous sensation. **European journal of applied physiology**, *111*(12), 3069–3077.

RANSON, S. W. (1933). The anatomy of the autonomic nervous system with special reference to the innervation of the skeletal muscles and blood vessels. **Ann Intern Med,** *6*, 1013–1021.

RITTWEGER, J., BELLER, G., & FELSENBERG, D. (2000). Acute physiological effects of exhaustive whole-body vibration exercise in man. **Clinical physiology** *(Oxford, England)*, *20*(2), 134–142.

SAKAKIBARA, H., & YAMADA, S. (1995). Vibration syndrome and autonomic nervous system. **Central European journal of public health**, *3 Suppl*, 11–14.

SCHLEE, G., RECKMANN, D., & MILANI, T. L. (2012). Whole body vibration training reduces plantar foot sensitivity but improves balance control of healthy subjects. **Neuroscience Letters**, *506*(1), 70–73.

SONZA, A., MAURER, C., ACHAVAL, M., ZARO, M. A., & NIGG, B. M. (2013). Human cutaneous sensors on the sole of the foot: Altered sensitivity and recovery time after whole body vibration. **Neuroscience Letters**, *533*, 81–85.

STOYNEVA, Z., LYAPINA, M., TZVETKOV, D., & VODENICHAROV, E. (2003). Current pathophysiological views on vibration-induced Raynaud's phenomenon. **Cardiovascular research**, *57*(3), 615–624.

STULL, J. T., KREUGER, J. E., KAMM, K. E., GAO, Z.-H., ZHI, G., & PADRE, R. (1996). Myosin light chain kinase. In M. Bárány (Ed.), **Biochemistry of smooth muscle contraction** (pp. 119–130). San Diego: Academic Press.

THOMPSON, C., BÉLANGER, M., & FUNG, J. (2011). Effects of plantar cutaneo-muscular and tendon vibration on posture and balance during quiet and perturbed stance. **Human movement science**, *30*(2), 153–171.

TORVINEN, S., KANNUS, P., SIEVÄNEN, H., JÄRVINEN, TERO A H, PASANEN, M., KONTULAINEN, S., VUORI, I. (2003). Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. **Journal of bone and mineral research***, 18*(5), 876–884.

WOODRUM, D. A., & BROPHY, C. M. (2001). The paradox of smooth muscle physiology. **Molecular and Cellular Endocrinology**, *177*(1-2), 135–143.

YANG, Z. H., RICHARD, V., SEGESSER, L. VON, BAUER, E., STULZ, P., TURINA, M., & LÜSCHER, T. F. (1990). Threshold concentrations of endothelin-1 potentiate contractions to norepinephrine and serotonin in human arteries. A new mechanism of vasospasm? **Circulation**, *82*(1), 188–195.

YE, Y., MAURO, M., BOVENZI, M., & GRIFFIN, M. J. (2012). Association between vasoconstriction during and following exposure to hand-transmitted vibration. **International archives of occupational and environmental health***, 87*, 41–49.

3.3 Estudo 3

Alteração da sensibilidade em um modelo de dor crônica em ratos tratados com esteira e Vibração de Corpo Inteiro: uma perspectiva para redução de dor.

O terceiro estudo desta tese procurou investigar os efeitos do tratamento com VCI e exercício (caminhada) de baixa intensidade no tratamento da dor crônica em um modelo animal com ratos Wistar. Este estudo foi desenvolvido no laboratório de Histofisiologia Comparada, Departamento de Ciências Morfológicas, Instituto de Ciências Básicas da Saúde (ICBS) da Universidade Federal do Rio Grande do Sul (UFRGS). Apresentamos aqui, os dados preliminares desta investigação.

Sensitivity Alteration in a chronic pain model in rats treated with Treadmill and Whole Body Vibration: a Pain Reduction Perspective

Running Title: WBV exercise treatment in a chronic pain model

Anelise Sonza[b*], Milton A. Zaro[b], Matilde Achaval[a,b]

[a] Departamento de Ciências Morfológicas, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite, 500, 90050-170, Porto Alegre, RS, Brasil
[b] Programa de Pós-Graduação em Neurociências, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite, 500, 90050-170, Porto Alegre, RS, Brasil

* Corresponding author, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite,500, 90050-170, Porto Alegre, RS, Brasil. Fax: +55 51 3308-3092
E-mail address:anelise.sonza@gmail.com (A. Sonza)

Abstract: Whole body vibration (WBV), which is widely used as an exercise modality, involves the use of vibratory stimuli that are transmitted to the body through the feet. The goal of this study was to investigate the effect of WBV treatment in a chronic pain model after 10 WBV sessions. Sixty male Wistar rats (±180g, 90 days old) were submitted to a chronic pain model and treated with a low intensity exercise (treadmill), a WBV exercise (vibration platform) and a combined treatment involving both low intensity exercise and WBV. The controls on the platform were set to a frequency of 42 Hz with 2 mm amplitude in a spiral mode. Sensitivity was measured before and after WBV exposure. Pressure sensation was determined using a pressure meter. Pain perception was measured with a hot plate. After each session, WBV influenced the discharge of skin touch-pressure receptors, reducing sensitivity in the WBV groups. Comparing the conditions “before vs. after”, pain perception started to decrease after the third WBV session. Such a decrease in sensitivity may be used to reduce pain perception in patients suffering from painful lower limb conditions without the need to use analgesics.

Key-words: post vibratory effects, whole body vibration, exercise, mechanoreceptors, tactile sensitivity, pain

1 Introduction

Locomotor system dysfunctions are the most common causes of chronic pain (TEIXEIRA; SIQUEIRA, 2009). Epidemiological studies have shown that chronic pain is a major cause of public health problems (BRATTBERG; PARKERB; THORSLUNDB, 1996) and a survey conducted in Europe found its prevalence to be around 20 % (BREIVIK et al., 2006). Sluka, Kalra, & Moore (2001) report that 14 % of U.S. citizens suffer from chronic pain. The lack of predictability in the behavioral response to a noxious stimulus to the development of chronic pain after injury and in pain relief with analgesics has been an important topic of interest and intrigued researchers and clinicians for decades (MØLLER; JENSEN, 2010).

A decrease in pH tissue has been observed following inflammation, bruising and isometric exercises (HOOD et al., 1988; ISSBERNER; REEH; STEEN, 1996; SLUKA; KALRA; MOORE, 2001). There is a positive correlation between pain and local acidification (ISSBERNER; REEH; STEEN, 1996). In humans, the decrease in pH increases the activity of nociceptors and produces a painful response (REEH; STEEN, 1996).

Exercise is an important component in the management of painful conditions (BEMENT; SLUKA, 2005). Protocols including low intensity exercise are used in the rehabilitation of patients with musculoskeletal chronic conditions such as fibromyalgia, chronic low back pain and myofascial pain (BEMENT; SLUKA, 2005; GOWANS; DEHUECK, 2004; VAN TULDER; KOES; BOUTER, 1997; WRIGHT; SLUKA, 2001).

Animal studies have found that physical exercise (running) is related to neuroprotection, apoptosis suppression and neurotrophic factors, which generate neurogenesis and regeneration, thus reducing the nerve degeneration and attenuating symptoms (ANG et al., 2003; CHEN et al., 1998; DING et al., 2002, 2004; HELFER et al., 2009; ITOH et al., 2011; KIM et al., 2010, 2002; WANG; YANG; YU, 2001). However, due to the presence of pain, a limited capacity to expend energy and/or impaired movement coordination, numerous diseases prevent the affected subjects from performing running exercises by themselves, thus hindering the rehabilitation process.

Whole body vibration (WBV) training platforms have been widely used as an exercise modality (SONZA et al., 2013). The reduced effort required to perform exercises on these machines, especially among patients with disabilities, might explain their popularity. It is important to investigate the responses to WBV in order to make safe recommendations for its use. The use of external vibratory mechanical stimuli, which decreases the deficit in voluntary muscle activation by neuromuscular stretch reflex, has been shown to be an effective and easily applied method for patients with severe disability. Considering that reflexes with similar patterns have been identified during running exercise (HAAS, 2008), one can speculate that vibratory stimuli may provide other beneficial effects.

Vibration stimulation can also be used to reduce the perception of pain (LUNDEBERG; NORDEMAR; OTTOSON, 1984; LUNDEBERG, 1984; NISHIYAMA; WATANABE, 1981; RIBOT-CISCAR et al., 1996). It is well reported (BASBAUM; JESSEL, 2000; MELZACK; WALL, 1965) that activity in large-diameter afferents may alter transmission in the central pathways that convey messages ultimately experienced as pain and can attenuate such pain. This interaction is thought to occur in the dorsal horn of the spinal cord and the thalamus (MCMAHON; KOLTZENBURG, 2006). The influence of WBV on large diameter fibers has been shown directly after WBV by touch-pressure (POLLOCK et al., 2011; SONZA et al., 2013) and vibration perception at 30 Hz (SONZA et al., 2013) and 200Hz (SCHLEE; RECKMANN; MILANI, 2012; SONZA et al., 2013) with sensitivity reduction. Following WBV, it has been shown to take between 2 and 3h for sensitivity to return to the baseline condition (SONZA et al., 2013).

Nociceptors are responsible for conducting pain information to the specific central nervous system pathway. Their nerve conduction pathway to the encephalic region is different from that of the myelinated A_α and A_β mechanoreceptors. Thus, a question that arises is whether WBV also influences the role of nociceptors, which are small unmyelinated nerve fibres (C fibres) or thinly myelinated nerve fibres (A_δ fibres), in the control of painful conditions. It is known that the majority of nociceptors only respond to mechanical, thermal or chemical stimuli when such stimuli are sufficiently intense. The perception of pain is variable and it is important to understand how to modulate pain because it may provide new strategies for the treatment of chronic pain. In afferent modulation, pain can be reduced by simultaneous activity in low-threshold receptors (A_β fibers) (MÜNSTER et al., 2012; PRAGER, 2010). Considering that WBV affects the firing of mechanoreceptors, causing decreased skin sensitivity, a question remains regarding the influence of WBV on afferent pain modulation.

The effects of WBV on pain perception (C and A_δ fibres) are of particular interest in therapeutic interventions because no drugs are involved. To the best of our knowledge, the presumed beneficial effect of WBV on pain reduction based on its interaction has not yet been documented. Therefore, the purpose of this study was to use touch-pressure and pain sensitivity to investigate the effects of WBV treatment in a chronic pain model in Wistar rats.

2 Methods

Animals

A total of sixty male Wistar rats (12 weeks old), weighing 180 to 200 g, from a local breeding colony (ICBS, UFRGS) were housed under standard laboratory conditions with food and water available *ad libitum* and a 12:12 h light/dark cycle. All efforts were made to minimize the number of animals studied and their discomfort. The animals were cared for in accordance with the Arouca Brazilian Law (11794/2008) and the recommendations of the Brazilian Society for Neurosciences, the Review Committee of the School of Veterinary Surgery, University of Buenos Aires, and the International Brain Research Organization. Moreover, the methods complied with the National Institute of Health's Guidelines for the Care and Use of Laboratory Animals (publication no. 85-23, revised 1985), and the Ethical Committee of the UFRGS approved the study under protocol number 2012-062.

Experimental Design

The rats were divided into five groups: control saline sedentary (CSS), control chronic pain sedentary (CCS), chronic pain subjected to treadmill training group (GCT), chronic pain treated with whole body vibration group (GCP) and chronic pain treated with treadmill plus vibration training group (GCP+T) during a 15-day protocol (Fig 1).

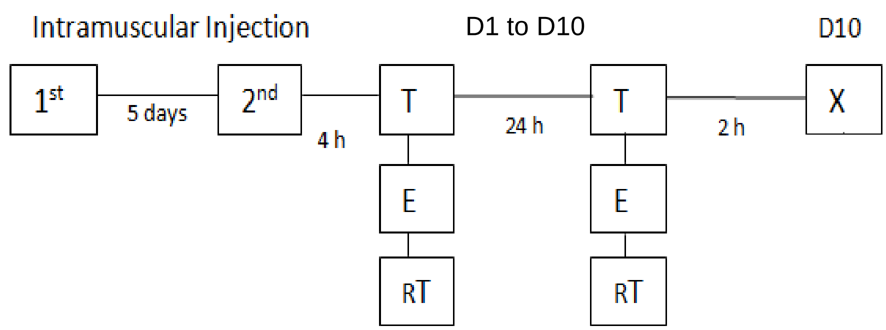

Fig 1: Experimental design. Days 1 to 10 (D); Tests (T); Exercise – WBV and or Treadmill (E); Re-test (RT); animal sacrifice (X).

Animals with chronic pain that were able to walk on the treadmill were included in the experiment and randomly assigned to the experimental groups. Animals that did not develop hyperalgesia after the two low pH saline injections were excluded from the study. The animals were tested 4 h after the second injection.

Chronic Pain Model

Two injections with 100 µl of low pH preservative-free sterile saline (pH 4.0) were administered on separate days in the left gastrocnemius when the animals were anesthetized briefly with halothane (2–4%) (SLUKA; KALRA; MOORE, 2001).

This is a muscular, non-inflammatory pain model that produces long-lasting, widespread mechanical hyperalgesia without motor deficits or significant tissue damage. There was no apparent mechanical hyperalgesia after the first intramuscular injection, therefore a second injection was necessary (SLUKA; KALRA; MOORE, 2001) as shown in Fig 1.

WBV and Treadmill Exercise Training

On the first day, the animals underwent habituation to the training and evaluation instruments. The platform and the treadmill were turned off and each animal was placed inside the specific cages for 10 and 30 minutes respectively. On the following 4 days, to accustom the animal to walking, only the treadmill was turned and set to a speed of 3.05 m/min for 10 min.

The 3 different training groups started training 4 h after the second injection with intramuscular acid. The groups were placed in separate cages.

WBV: The WBV training groups were subjected to whole body vibration on the vibration platform for ten days (TBS100A, Total Image Fitness, Inc., CA), 5 minutes on days 1 to 5 and 10 minutes on the other days. The settings for the WBV exposure (42 Hz, 2 mm amplitude and spiral mode) were chosen based on a study from Sonza et al. (2013) in which, employing the same settings, human subjects showed a significant decrease in touch-pressure and vibration sensitivity after 10 min WBV exposure. The animals stood on a 3 mm ethylene vinyl acetate (EVA) foam pad inside cages firmly attached to the platform.

Treadmill: Four hours after chronic pain induction (second injection), all animals underwent adaptation to a treadmill originally designed for human use (Athletic Runner, Brazil; Model Electronic Athletic) and modified for use by rats. The 10-day exercise protocol consisted of placing the animal to walk on a treadmill set at a speed of 6.1 m/min for 15 minutes on the first 5 consecutive days and for 30 minutes on the other days.

WBV + Treadmill: Four hours after the chronic pain induction (second injection), all animals underwent adaptation to a treadmill. The 10-day exercise protocol consisted of two steps: first, for the first 5 consecutive days, placing the animal to walk on a treadmill set at a speed of 6.1 m/min for 15 minutes and combined with 5 minutes exposure to the WBV; second, for the next 5 days placing the animal to walk on a treadmill set at a speed of 6.1 m/min for 30 minutes combined with 10 minutes of WBV exposure, with the same settings, described above, for both machines.

Control groups were placed on the treadmill or platform, for the same amount of time, however, the devices were turned off. Animals that were unable to walk on the treadmill were excluded from the experiment.

Data collection included measuring the sensitivity of the foot to touch-pressure and pain before vs. after exposure to WBV.

The tests took place in a quiet environment, with a room temperature of between 20-23 ℃.

Touch-pressure sensitivity

To assess mechanical sensitivity, a calibrated pressure-meter, consisting of a hand-held force transducer fitted with a 1 mm^2 polypropylene tip (EFF 301 electronic von Frey anesthesiometer, Insight, Ribeirão Preto, SP, Brazil), was used. The equipment reaction time is 1 ms and the transducer capacity is between 0.1 to 1000 g. The values are given in mV. Vertical elevation of the paw immediately upon removal of the testing tip was considered a positive response. To confirm the response, the test was performed 3 times and the mean of the 3 values was determined. The investigator was trained to apply the polypropylene tip perpendicularly to one of the five distal footpads, while gradually increasing the pressure. A tilted mirror below the grid provided a clear view of the animal's hind-paw (CUNHA et al., 2004). The tests consisted of poking the hind-paw to provoke a flexion reflex followed by a clear flinch response after paw withdrawal. With the electronic pressure-meter, the intensity of the stimulus was automatically recorded when the paw was withdrawn. The stimulation of the paw was repeated until the animal presented three similar measurements (the difference between the highest and the lowest measurement should be less than 10 g) (CUNHA et al., 2004). All sensitivity measurements were performed by the same researcher to increase the reliability of the collected data.

Pain and temperature sensitivity

The Hot Plate (model-DS37, Socrel, Comerio, VA, Italy) is a device that measures the degree of sedation in relation to the time response, where the animal feels heat from the hot plate. This test is widely used to study thermal (anti)nociception in rats and mice (LE BARS; GOZARIU; CADDEN, 2001), since pain cannot be monitored directly in animals but can only be estimated by examining their responses.

Each animal was individually placed on a hot plate with the temperature set at 52 ± 0.5℃ for a maximum of 20 s(LAVICH et al., 2005), o r until it displayed a nocifensive reaction of either hind-paw. The temperature of the hot plate was maintained constant. Each animal was only tested once until a predetermined behavioural endpoint was observed, the typical responses being hind-paw shaking, licking and/or lifting (CARTER, 1991; ESPEJO; MIR, 1993). The latency to the response was recorded manually with a chronometer connected to a device with a pedal. The maximum time allowed on the hot plate was 20 s (LAVICH et al., 2005).

Statistical analysis

The mean and the standard deviation of the measurements taken before exposure to WBV were calculated for use as control measurements. All data were normalized to the each animal's specific control value in order to reduce subject specific differences. Changes in sensitivity in relation to the control condition were tested for normal distribution using the Shapiro-Wilk's test. Due to the parametrical nature of the data, a simple T-test was used to compare the pre and post condition.

3 Results

The sensitivity thresholds and time latencies for each animal were measured prior to any intervention and the mean values and the standard deviation (SD) were calculated.

Touch-pressure sensitivity

Under the normal conditions, the mean values (± SD) for the pressure sensation were 36.4 (± 4.9) mV for the right paw and 36.1 (± 5.4) mV for the left paw.

In Fig. 2, the vertical axis represents the increase in force required to produce a response to the pressure meter. An increase in force is equal to a loss of touch pressure sensitivity. Negative values represent hypersensitivity and positive values hyposensitivity. The changes were calculated for every animal individually in order to consider subject specific differences from the normal condition – the control measurement taken before application of the chronic pain model.

In the control saline sedentary group (CSS), no significant differences were found between the right and left paws nor before and after “training” (Fig. 2, A). In the control chronic pain sedentary group (CCS), significant differences were found between the right and left paws, although no difference was found between before and after “training” (Fig. 2, B).

Observing the chronic pain group treated with a treadmill (GCT), on the second day of treatment, after the treadmill, touch-pressure hypersensitivity was found in the right paw. On the same day, following the same exercise, no such difference was found in cutaneous sensitivity of the left paw. However, following sessions 5 and 6, decreased touch-pressure sensitivity was only found in the left paw.

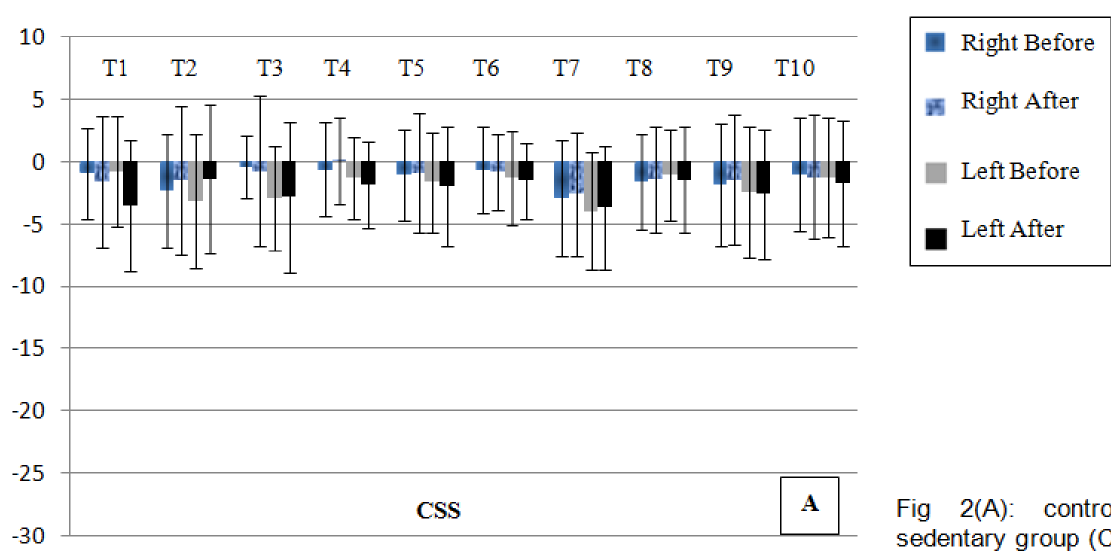

Fig 2(A): control saline sedentary group (CSS).

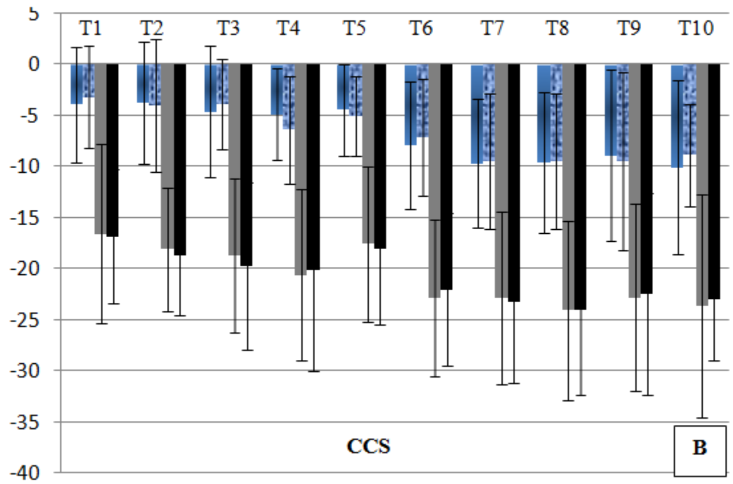

Fig 2(B): control chronic pain sedentary group (CCS),

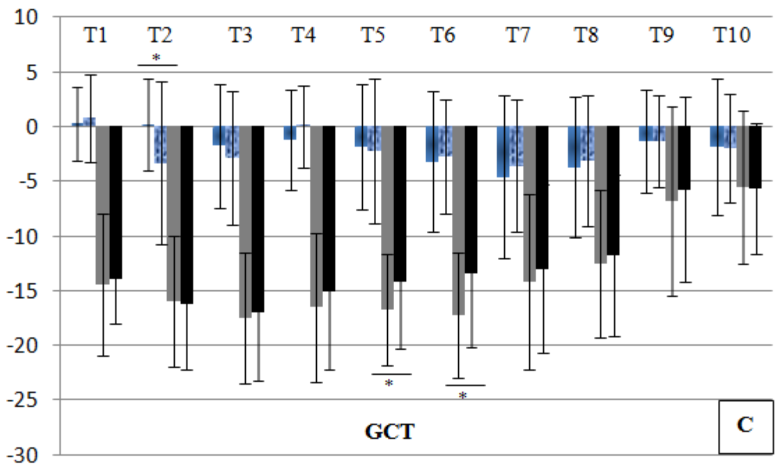

Fig 2(C): chronic pain group treated with treadmill (GCT)

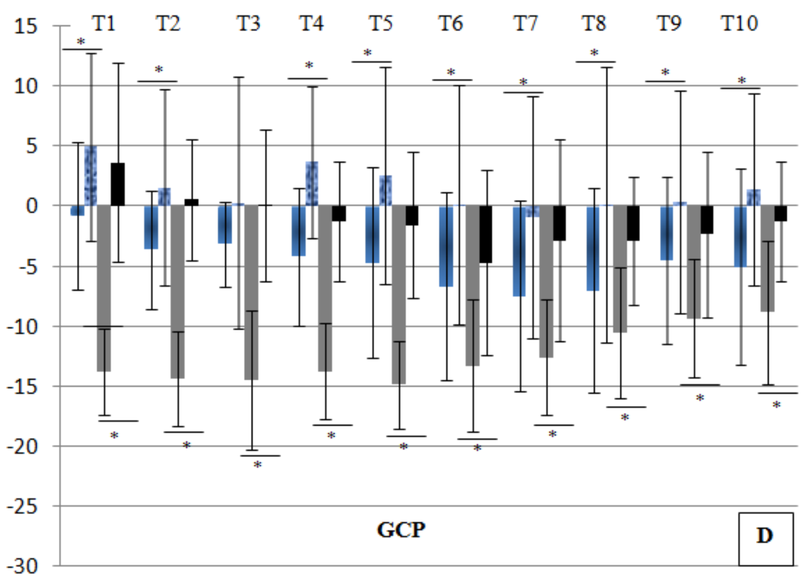

Fig 2(D): chronic pain group treated with whole body vibration (GCP)

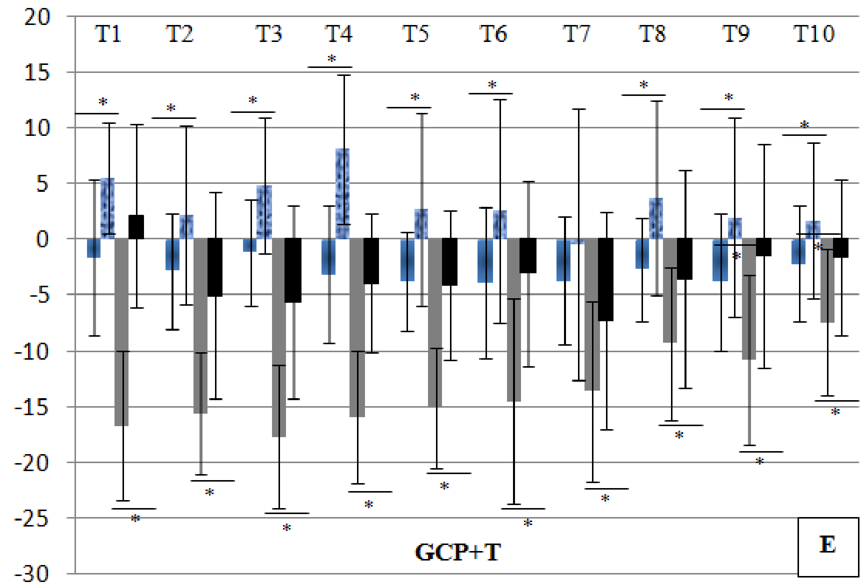

Fig 2(E): chronic pain group treated with whole body vibration plus vibration training (GCP+T)

Fig 2: Mean and SD for the change in touch pressure force for the five groups with respect to the control condition (*p=0.05). The values were normalized by the baseline measurements ("before any procedures") and individually for each animal (n=60). The "x axis" T1 until T10 represents the trainning day 1 until day 10. The "y axis" represents the changes of sensation (mV).

A significant loss of sensation after 5 or 10 minutes of WBV was found for touch-pressure sensitivity in the tested regions of the right and left paw (between "before" and "after" treatment, mainly in the WBV groups. Both paws showed significantly decreased touch pressure sensitivity directly after WBV (Fig 2 D and E). It is interesting to note that, at around the 8th session, sensitivity starts approximate the control condition in all the treated groups.

Pain sensitivity

A significant change in pain perception 40 min after WBV exposure was found mainly in the groups treated with vibration procedures (Fig 3). The control groups showed no differences in time latencies between the 'before' and 'after' measurements (Fig 3, CSS and CCS).

The treadmill group presented increased pain perception (latency time was shorter) in treatment sessions 4, 5 and 7. On the other treatment days, there were no differences in time latency 'before' and 'after' the low-intensity treadmill exercise (Fig 3, GCT).

In the WBV only group, after the third treatment day, the time latency for pain perception was significantly higher (Fig 3, GCP).

In the combined treatment (WBV and Treadmill) group, comparing 'before' and 'after' treatment, the latency was longer after the fourth session, i.e. the pain perception decreased (Fig 3, GCP+T). However, during the first 5 sessions, the animals were exposed to only 5 min of WBV and 15 min of low-intensity exercise on the treadmill.

The hot plate test is intended to measure thermally induced pain. Chronic pain is a negative stimulus ranging from dull to severe persistent pain (GILMAN, 1993). This type of pain often causes supraspinal mechanisms that can be controlled by the animal. The hot plate can be used to assess this type of pain. (SORA et al., 1997).

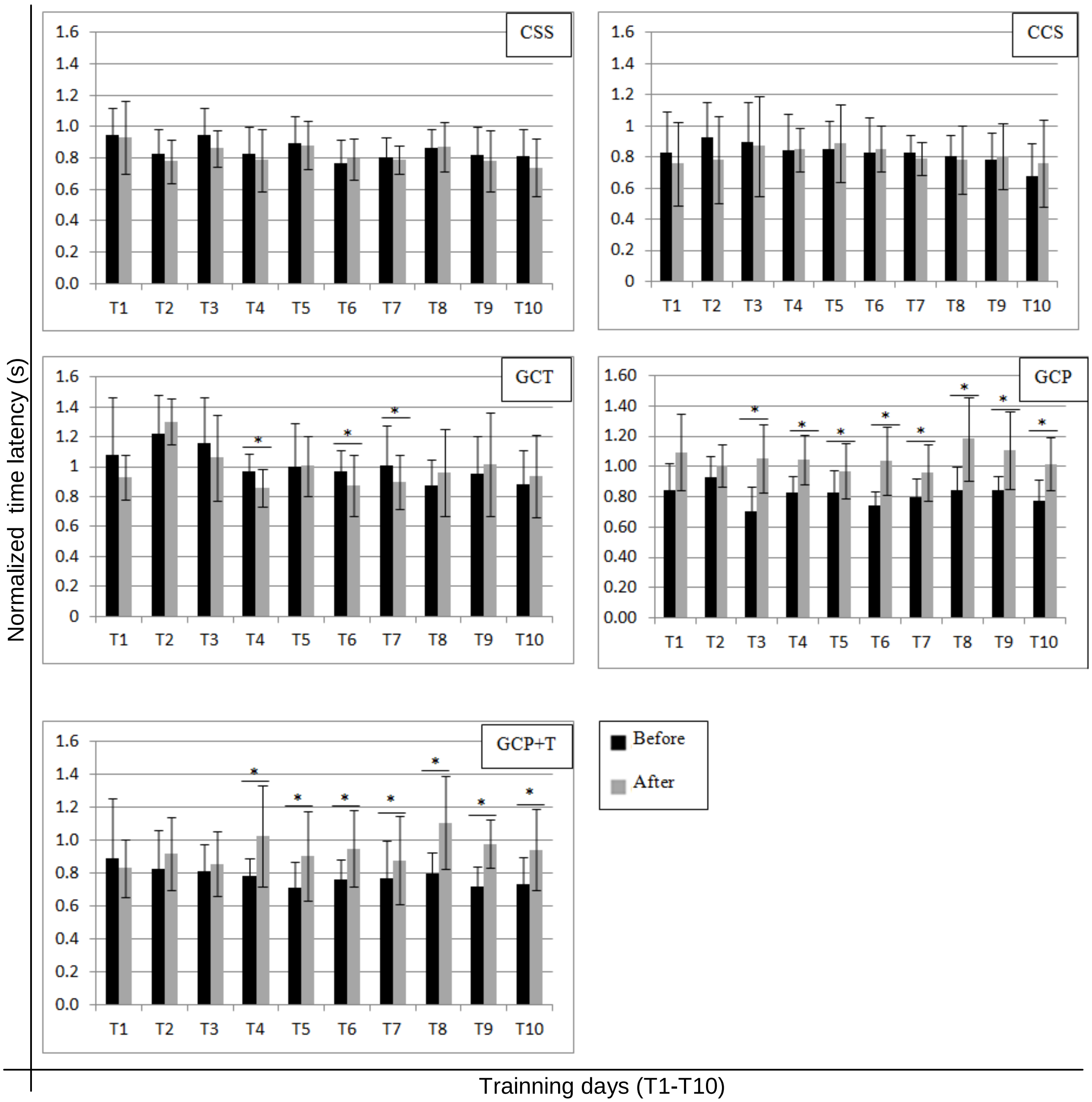

Fig 3: Mean and SD for all five groups. Time latency change in pain sensitivity (*p=0.05). The values were normalized by the baseline measurements ("before any procedures") and individually for each animal (n=40). Hot plate measurement for the 5 different groups: control groups saline sedentary (CSS) and chronic pain sedentary (CCS), chronic pain groups treated with treadmill (GCT), vibration training (GCP) and with treadmill plus vibration training (GCP+T).

4 Discussion

This study shows that for young adult male Wistar rats exposed to a chronic pain model, ten days of treatment sessions with exposure to WBV led to decreased touch-pressure (after all sessions) and pain sensitivity (after the third session). After all the individual sessions, WBV decreased touch-pressure sensitivity and after the third session, the latency to pain perception was longer, mainly in the WBV groups. The exposure time used in this experiment is commonly used for performance enhancement or rehabilitation. Our results for touch-pressure sensitivity reduction are in agreement with studies conducted in humans (POLLOCK et al., 2011; SONZA et al., 2013) where, after a single WBV session, cutaneous sensitivity was significantly and temporarily impaired.

A study by Ribot-Ciscar et al. (1996) indicated that 10 min of local vibration affected the cutaneous mechanoreceptive afferents leading to impaired perceptual and sensorimotor capacity for several minutes post stimulus.

Physiological messages are transformed because the cutaneous receptors, particularly the fast adapting (FA) type, are highly sensitive to vibration. In most cases, according to the microneurographic studies from Ribot-Ciscar et al. (1989), the unit discharge in the mechanoreceptors is directly linked to the frequency of the vibratory stimulus. A reduction in touch-pressure sensitivity was found directly after both 5 and 10-min exposure to WBV. The force applied in order for the animals to perceive the monofilaments was significantly greater after the WBV exposure.

A question arises as to whether loss of sensation might be useful. In this study, we have shown that touch-pressure mechanoreceptors and C fibres are highly affected by vibration. In previous studies, the afferent discharge from fast adapting mechanoreceptors and muscle spindles has been shown to be strongly affected by vibration (POLLOCK et al., 2011; SCHLEE; RECKMANN; MILANI, 2012; SONZA et al., 2013). The nerve fibres that transmit touch pressure and vibration sensitivity are similar to muscle spindle single afferent A_{α}/A_{β} fibres (VEGA et al., 2009). They carry mechanical signals and form a synaptic contact on inhibitory interneurons, competing with the pain stimuli reaching projection neurons. One can speculate that nerve fibres for touch-pressure and vibration sensitivity may also contribute to the normal perception of stimulus quality as they belong to the same category of fibres. Some findings show that Meissner corpuscles are multi-afferented receptor organs that may have nociceptive capabilities in addition to being low threshold mechanoreceptors (BASBAUM; JESSEL, 2000).

Activity, such as vibratory stimuli, in the large-diameter fibre systems not only modifies the perception of pain but also attenuates it (MÜNSTER et al., 2012; PARÉ et al., 2001; PRAGER, 2010). One hypothesis commonly used to explain the vibratory action is based on Melzack and Wall’s “Gate theory of pain” (MELZACK; WALL, 1965), according to which the dorsal horn of the spinal cord governs the transmission of afferent neural signals to the higher centres where the pain is interpreted. A_{β}-fibers and small diameter sensory neurons (C-fibers) form synapses on spinothalamic tract projection neurons in the dorsal horn and from there to the higher centres (PRAGER, 2010). A possible explanation for the pain reduction found to occur with vibration could be that large numbers of A_{α}/A_{β} fibres are activated synchronously and therefore stimulate the dorsal column of the spinal cord. The activation through vibration of low-threshold, large-diameter afferent A_β-fibers (non-nociceptive), which synapse onto inhibitory (GABA-ergic or cholinergic) interneurons in the spinal dorsal horn. These interneurons release inhibitory neurotransmitters (e.g., GABA), thus reducing the excitability of second-order spinal neurons, so that subsequent input from A_δ and C-fibers is attenuated (MÜNSTER et al., 2012; PRAGER, 2010).

Therefore, vibratory stimulation could be used to reduce the perception of pain (NISHIYAMA and WATANABE, 1981; RIBOT-CISCAR et al., 1996) in a similar manner to which transcutaneous electrical nerve stimulation (TENS) is used (GUIEU et al., 1991). In addition, Paré et al. (2001) have demonstrated in mammalians that Meissner corpuscles contain, beside mechanoreceptive fibers, both peptidergic and nonpeptidergic C-fibers that probably serve nociception. Studies using passive vibration in humans (GUIEU; TARDY-GERVET; ROLL, 1991; LUNDEBERG; NORDEMAR; OTTOSON, 1984) showed the application of high frequency vibration directly to the location where the pain was perceived reduced the sensation of pain in about 70% of patients with acute and chronic musculoskeletal pain. Interestingly, Guieu et al. (1991) combined TENS with vibration and found they could enhance the pain reduction effects.

Some authors have suggested that WBV training could be used to reduce the pain perceived by patients with low back pain (IWAMOTO et al., 2005; RIBOT-CISCAR et al., 1996) although this is not a common use for such machines. In randomized controlled trials (IWAMOTO et al., 2005; RITTWEGER et al., 2002), pain relief was achieved following exercise on WBV platforms. It was speculated that eliciting muscles via stretch reflexes due to the generated instability, led to relaxation of the back muscles, thus decreasing pain perception (IWAMOTO et al., 2005). There was no correlation between pain relief and any gains in lumbar extensor force (RITTWEGER et al., 2002). In a study (unpublished data), using a WBV platform with the settings 17Hz, spiral mode, 5mm vibration amplitude, the participants reported feeling most vibration in the lumbar region. The referred settings are similar to those used in previous studies (IWAMOTO et al., 2005; RITTWEGER et al., 2002). We believe that the WBV was acting as local vibration, disturbing large-diameter fibers that reach projection neurons on the dorsal spinal column and, consequently, reducing the pain stimuli.

Patients with acute or chronic lower limb pain may benefit from a temporary reduction in their sensory capacity after WBV, prior to a rehabilitation session, without the use of drugs. This would allow them to perform exercises with less pain and therefore without the restriction of movement due to pain.

5 Conclusion

In rats subjected to a chronic pain model, the afferent discharges from touch-pressure mechanoreceptors were strongly affected by vibration after each treatment session with WBV. Sensitivity to touch-pressure and pain is impaired after WBV exercise.

In therapeutic interventions, when hypersensitivity in the lower legs negatively affects an exercise session because pain prevents the patient from adequately performing the rehabilitation movement, a reduction in sensitivity and the consequent reduction in pain might be helpful. Knowledge of the correct settings for the parameters of the exposure to WBV could therefore be used in rehabilitation interventions.

Further analysis

Calcitonin gene-related peptide (CGRP) and parvalbumin (PV) are highly expressed in selective subpopulations of dorsal root ganglion (DRG) neuronal cells, and are rarely co-localized (CARR; YAMAMOTO; NAGY, 1990). CGRP is a marker of neuronal plasticity in primary sensory neurons and is predominantly expressed by small- to medium-sized primary sensory neurons (VERGE et al., 1989). Most small DRG neurons are involved in nociception (AOKI et al., 2005).

Future studies will focus on CGRP, substance P and serotonin expression after short-duration WBV in the DRGs corresponding to lower lumbar spinal cord segments.

Acknowledgements

We gratefully acknowledge the support of the Government of Brazil – *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) and *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) and Total Image Fitness, Inc., CA for donating the WBV equipment.

Conflict of Interest Statement

There are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

References

ANG, E. T. et al. Neuroprotection associated with running: is it a result of increased endogenous neurotrophic factors? **Neuroscience**, v. 118, n. 2, p. 335–45, jan. 2003.

AOKI, Y. et al. Expression and co-expression of VR1, CGRP, and IB4-binding glycoprotein in dorsal root ganglion neurons in rats: differences between the disc afferents and the cutaneous afferents. **Spine**, v. 30, n. 13, p. 1496–500, 1 jul. 2005.

BASBAUM, A. I.; JESSEL, T. M. The Perception of Pain. In: KANDEL, E. R.; SCHWARTZ, J. H.; JESSELL, T. M. (Eds.). **Principles of Neural Science**. 4. ed. New York: McGraw-Hill, 2000. p. 472–491.

BEMENT, M. K. H.; SLUKA, K. A. Low-intensity exercise reverses chronic muscle pain in the rat in a naloxone-dependent manner. **Archives of Physical Medicine and Rehabilitation**, v. 86, n. 9, p. 1736–40, set. 2005.

BRATTBERG, G.; PARKERB, M. G.; THORSLUNDB, M. Research Reports The prevalence of pain among the oldest old in Sweden. **Pain**, v. 67, p. 29–34, 1996.

BREIVIK, H. et al. Survey of chronic pain in Europe : Prevalence , impact on daily life , and treatment. **European Journal of Pain,** v. 10, p. 287–333, 2006.

CARR, P. A.; YAMAMOTO, T.; NAGY, J. I. Calcitonin gene-related peptide in primary afferent neurons of rat: Co-existence with fluoride-resistant acid phosphatase and depletion by neonatal capsaicin. **Neuroscience**, v. 36, n. 3, p. 751–760, jan. 1990.

CARTER, R. B. Differentiating analgesic and non-analgesic drug activities on rat hot plate: effect of behavioral endpoint. **Pain**, v. 47, n. 2, p. 211–20, nov. 1991.

CHEN, Y. C. et al. Physical training modifies the age-related decrease of GAP-43 and synaptophysin in the hippocampal formation in C57BL/6J mouse. **Brain Research**, v. 806, n. 2, p. 238–45, 28 set. 1998.

CUNHA, T. M. et al. An electronic pressure-meter nociception paw test for mice. **Brazilian Journal of Medical and Biological Research,** v. 37, n. 3, p. 401–7, mar. 2004.

DING, Y. et al. Functional improvement after motor training is correlated with synaptic plasticity in rat thalamus. **Neurological Research**, v. 24, n. 8, p. 829–36, dez. 2002.

DING, Y. et al. Exercise pre-conditioning reduces brain damage in ischemic rats that may be associated with regional angiogenesis and cellular overexpression of neurotrophin. **Neuroscience**, v. 124, n. 3, p. 583–91, jan. 2004.

ESPEJO, E. F.; MIR, D. Structure of the rat ' s behaviour in the hot plate test. **Behavioral Brain Research,** v. 56, p. 171–176, 1993.

GILMAN, A. G. **Goodman and Gilman's The Pharmacological Basis of Therapeutics**. New York: McGraw-Hill, 1993.

GOWANS, S. E.; DEHUECK, A. Effectiveness of exercise in management of fibromyalgia. **Current Opinion in Rheumatology**, v. 16, n. 2, p. 138–42, mar. 2004.

GUIEU, R.; TARDY-GERVET, M. F.; ROLL, J. P. Analgesic effects of vibration and transcutaneous electrical nerve stimulation applied separately and simultaneously to patients with chronic pain. **The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques**, v. 18, n. 2, p. 113–9, maio 1991.

HAAS, C. T. **Vibratory Stimulation and Stochastic Resonance Therapy: Results from studies in Parkinson's disease and spinal cord injury.**Technologies of Globalization Congress Darmstadt. **Anais**...Germany: 2008

HELFER, J. L. et al. The effects of exercise on adolescent hippocampal neurogenesis in a rat model of binge alcohol exposure during the brain growth spurt. **Brain Research**, v. 1294, p. 1–11, 19 out. 2009.

HOOD, V. L. et al. Effect of systemic pH on pHi and lactic acid generation in exhaustive forearm exercise. **The American Journal of Physiology**, v. 255, n. 3 Pt 2, p. F479–85, set. 1988.

ISSBERNER, U.; REEH, P. W.; STEEN, K. H. Pain due to tissue acidosis: a mechanism for inflammatory and ischemic myalgia? **Neuroscience Letters**, v. 208, n. 3, p. 191–4, 26 abr. 1996.

ITOH, T. et al. Exercise inhibits neuronal apoptosis and improves cerebral function following rat traumatic brain injury. **Journal of Neural Transmission (Vienna, Austria : 1996)**, v. 118, n. 9, p. 1263–72, set. 2011.

IWAMOTO, J. et al. Effect of whole-body vibration exercise on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. **Aging Clinical and Experimental Research**, v. 17, n. 2, p. 157–63, abr. 2005.

KIM, S.-E. et al. Treadmill exercise prevents aging-induced failure of memory through an increase in neurogenesis and suppression of apoptosis in rat hippocampus. **Experimental Gerontology**, v. 45, n. 5, p. 357–65, maio 2010.

KIM, S.-H. et al. Treadmill exercise increases cell proliferation without altering of apoptosis in dentate gyrus of Sprague-Dawley rats. **Life Sciences**, v. 71, n. 11, p. 1331–40, 2 ago. 2002.

LAVICH, T. R. et al. A novel hot-plate test sensitive to hyperalgesic stimuli and non-opioid analgesics. **Brazilian Journal of Medical and Biological Research**, v. 38, n. 3, p. 445–451, 2005.

LE BARS, D.; GOZARIU, M.; CADDEN, S. W. Animal models of nociception. **Pharmacological Reviews**, v. 53, n. 4, p. 597–652, dez. 2001.

LUNDEBERG, T. Long-term results of vibratory stimulation as a pain relieving measure for chronic pain. **Pain**, v. 20, n. 1, p. 13–23, set. 1984.

LUNDEBERG, T.; NORDEMAR, R.; OTTOSON, D. Pain alleviation by vibratory stimulation. **Pain**, v. 20, n. 1, p. 25–44, set. 1984.

MCMAHON, S. B.; KOLTZENBURG, M. **Wall and Melzack's textbook of pain**. 5. ed. Philadelphia: Elsevier/Churchill Livingstone, 2006.

MELZACK, R.; WALL, P. D. Pain mechanisms: a new theory. **Science**, v. 150, n. 3699, p. 971–979, 1965.

MØLLER, A. T.; JENSEN, T. S. Pain and genes: Genetic contribution to pain variability, chronic pain and analgesic responses. **European Journal of Pain Supplements**, v. 4, n. S4, p. 197–201, 6 nov. 2010.

MÜNSTER, T. et al. Modulation of somatosensory profiles by spinal cord stimulation in primary Raynaud's syndrome. **Pain Practice : the official journal of World Institute of Pain**, v. 12, n. 6, p. 469–75, jul. 2012.

NISHIYAMA, K.; WATANABE, S. Temporary threshold shift of vibratory sensation after clasping a vibrating handle. **International Archives of Occupational and Environmental Health**, v. 49, n. 1, p. 21–33, jan. 1981.

PARÉ, M. et al. The Meissner corpuscle revised: a multiafferented mechanoreceptor with nociceptor immunochemical properties. **The Journal of Neuroscience : the official journal of the Society for Neuroscience**, v. 21, n. 18, p. 7236–46, 15 set. 2001.

POLLOCK, R. D. et al. The effects of whole body vibration on balance, joint position sense and cutaneous sensation. **European Journal of Applied Physiology**, v. 111, n. 12, p. 3069–77, dez. 2011.

PRAGER, J. P. What does the mechanism of spinal cord stimulation tell us about complex regional pain syndrome? **Pain Medicine**, v. 11, n. 8, p. 1278–83, ago. 2010.

REEH, P. W.; STEEN, K. H. Tissue acidosis in nociception and pain. **Progress in Brain Research**, v. 113, p. 143–51, jan. 1996.

RIBOT-CISCAR, E. et al. Alteration of human cutaneous afferent discharges as the result of long-lasting vibration. **Journal of Applied Physiology (Bethesda, Md. : 1985)**, v. 80, n. 5, p. 1708–1715, maio 1996.

RIBOT-CISCAR, E.; VEDEL, J. P.; ROLL, J. P. Vibration sensitivity of slowly and rapidly adapting cutaneous mechanoreceptors in the human foot and leg. **Neuroscience Letters**, v. 104, n. 1-2, p. 130–5, 25 set. 1989.

RITTWEGER, J. et al. Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. **Spine**, v. 27, n. 17, p. 1829–34, 1 set. 2002.

SCHLEE, G.; RECKMANN, D.; MILANI, T. L. Whole body vibration training reduces plantar foot sensitivity but improves balance control of healthy subjects. **Neuroscience Letters**, v. 506, n. 1, p. 70–3, 6 jan. 2012.

SLUKA, K. A.; KALRA, A.; MOORE, S. A. Unilateral intramuscular injections of acidic saline produce a bilateral, long-lasting hyperalgesia. **Muscle & Nerve**, v. 24, n. 1, p. 37–46, jan. 2001.

SONZA, A. et al. Human cutaneous sensors on the sole of the foot: altered sensitivity and recovery time after whole body vibration. **Neuroscience Letters**, v. 533, p. 81–5, 15 jan. 2013.

SORA, I. et al. Opiate receptor knockout mice define receptor roles in endogenous nociceptive responses and morphine-induced analgesia. **Neurobiology**, v. 94, p. 1544–1549, 1997.

TEIXEIRA, M. J.; SIQUEIRA, J. T. T. Semiologia da dor. In: NETO, O. A. et al. (Eds.). **Dor: Princípios e Prática**. 2. ed. Porto Alegre: Artmed, 2009. p. 1438.

VAN TULDER, M. W.; KOES, B. W.; BOUTER, L. M. Conservative treatment of acute and chronic nonspecific low back pain. A systematic review of randomized controlled trials of the most common interventions. **Spine**, v. 22, n. 18, p. 2128–56, 15 set. 1997.

VEGA, J. A. et al. The Meissner and Pacinian sensory corpuscles revisited new data from the last decade. **Microscopy Research and Technique**, v. 72, n. 4, p. 299–309, abr. 2009.

VERGE, V. M. K. et al. Histochemical characterization of sensory neurons with high-affinity receptors for nerve growth factor. **Journal of Neurocytology**, v. 18, n. 5, p. 583–591, out. 1989.

WANG, R. Y.; YANG, Y. R.; YU, S. M. Protective effects of treadmill training on infarction in rats. **Brain Research**, v. 922, n. 1, p. 140–3, 13 dez. 2001.

WRIGHT, A.; SLUKA, K. A. Nonpharmacological treatments for musculoskeletal pain. **The Clinical Journal of Pain**, v. 17, n. 1, p. 33–46, mar. 2001.

3.4 Estudo 4

Mapa de Percepção Corporal da Vibração de Corpo Inteiro e Cargas de Aceleração Associadas em Membros Inferiores, Quadril e Cabeça

O quarto e último estudo, para tentar responder as hipóteses desta tese, procurou fazer um mapa de percepção corporal combinando dados qualitativos utilizando a escala de Borg e quantitativos através da acelerometria. Este estudo foi desenvolvido no Instituto do Esporte e Ciências do Movimento da Universidade de Duisburg-Essen, Alemanha através do suporte financeiro do Governo do Brasil com o Programa Ciências sem Fronteiras, CAPES. Teve supervisão do Prof. Dr. Ewald M. Hennig.

A Whole Body Vibration Perception Map and Associated Acceleration Loads at the Lower Leg, Hip and Head

Running title: WBV perception map and body accelerometry

Anelise Sonza[a,b*], Nina Völkel [b], Milton A. Zaro[a], Matilde Achaval[a], Ewald M. Hennig[b]

[a] Programa de Pós-Graduação em Neurociências, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite, 500, 90050-170, Porto Alegre, RS, Brazil

[b] Biomechanics Laboratory, Institute of Sport and Movement Sciences, University Duisburg-Essen, Essen, Germany

* Corresponding author, Instituto de Ciências Básicas da Saúde, Universidade Federal do Rio Grande do Sul, Sarmento Leite,500, 90050-170, Porto Alegre, RS, Brazil. Fax: +55 51 3308-3092

E-mail address:anelise.sonza@gmail.com (A. Sonza)

Abstract

The goal of this study was to determine the acceleration magnitudes at tibia, hip, and head for different frequency whole body vibrations. Additionally, vibration sensation ratings by subjects served to create perception vibration magnitude and discomfort maps of the body. Thirty four male and thirty one female young adults at the age of 23.0 (±3.0) years, participated in the experiments. In the first experiment, Whole Body Vibration severity perception ratings, based on a Borg Scale, were recorded for the subjects, standing on a rotational mode vibration platform. Measurements were performed at 12 different frequencies and two intensities of 3 and 5 mm platform displacement amplitudes. On a separate day, a second experiment (n=40) included vertical accelerometry of the head, hip and lower leg with the same WBV settings from the first experiment. The lower limb vibration magnitude perception was between very and extremely hard (17 and 18 on the Borg Scale) for the frequencies between 21-25 Hz; no significant differences were found for the upper limb vibration perception across all frequency conditions. The highest Borg scale values for the trunk region were somewhat hard (11-25 Hz) and for the head 10 - 12 (13-25 Hz). The lower legs had about 4.5 times higher acceleration magnitudes as compared to the hip and 11 times higher than at the head. The highest vertical accelerations were found at a frequency of 23 Hz at the tibia, 9 Hz at the hip and 13 Hz at the head. At the higher intensity (5 mm amplitude), 61.5% of the subjects reported discomfort for the foot region (21 – 25 Hz), 46.2% for the low back region (17, 19 and 21 Hz) and 23% for abdominal region (9 – 13 Hz). Vibration magnitude and discomfort perception ratings corresponded well with the measured acceleration magnitudes at the lower leg, hip, and head. The discomfort ratings might be related to frequency resonance phenomena of body parts. The range from 3 – 7 Hz represents the safest frequency range with magnitudes less than 1g*sec for all studied regions.

Key-words: Whole body vibration, discomfort rate, Borg scale, vibration perception map, accelerometry, vibration transmission

1 Introduction

Vibration is a mechanical wave motion that can cause a transfer of energy from a spring and a mass to interact with one another. A vibration perception map of the body can be established by evaluating the vibration magnitudes, as sensed by the subjects in specific regions of the body for different frequencies. When the body is supported by a vibrating surface, whole-body vibrations (WBV) occur. Since WBV training machines have been largely used for rehabilitation or performance purposes, it is important to understand at which frequencies the whole body or specific regions of the body are affected by the vibrational loads.

Human exposure to vibration includes a wide range of topics from different areas of research, including health sciences and engineering. In this article, emphasis will be placed on discomfort rate, vibration perception mapping of the body and vertical accelerometry for human exposure to a WBV machine. A perception threshold is useful to be reported as the vibration magnitude which results in detection around 50% of occasions (PARSONS, GRIFFIN, 1988). WBV training equipment produces high magnitude vibrations well above threshold detection. Subjects, exposed to WBV, often report discomfort in different parts of the body. For this study, the WBV severity perception was measured. The human body and its individual organs have differing natural frequencies. Resonance will occur if the external vibration frequency transmitted approaches or equals the natural frequency. Numerous voluntary and involuntary contractions of muscles occur, contributing to fatigue and/or a reduction in motor performance ability during resonance (CHAFIN, ANDERSSON, CHAFFIN, ANDERSSON , MARTIN, 2006).

The entire body or affected body organs can vibrate at an amplified magnitude that is greater than the external source vibration, entering the body. Especially if the entering vibration is not dampened by other parts of the body before reaching a target organ (BRAUER, 2006; WASSERMAN, 1996).

Research articles have demonstrated that WBV therapy can bring many benefits as bone remodelling (RUBIN, TURNER, BAIN, MALLINCKRODT, MCLEOD, 2001; JUDEX, DONAHUE, RUBIN, 2002; XIE, JACOBSON, CHOI, BUSA, DONAHUE, MILLER, RUBIN, JUDEX, 2006; FLIEGER, KARACHALIOS, KHALDI, RAPTOU, LYRITIS, 1998), muscle strength (BOGAERTS, DELECLUSE, CLAESSENS, COUDYZER, BOONEN, VERSCHUEREN, 2007; BELAVÝ, HIDES, WILSON, STANTON, DIMEO, RITTWEGER, FELSENBERG, RICHARDSON, 2008; ROELANTS, DELECLUSE, VERSCHUEREN, 2004; BRUYERE, WUIDART, DI PALMA, GOURLAY, ETHGEN, RICHY, REGINSTER, 2005), improved posture and balance control during perturbed stance (VERSCHUEREN, ROELANTS, DELECLUSE, SWINNEN, VANDERSCHUEREN, BOONEN, 2004) and for Parkinson disease (EBERSBACH, EDLER, KAUFHOLD, WISSEL, 2008; HAAS, TURBANSKI, SCHMIDTBLEICHER, 2007), and for reducing low back pain (CHEUNG, ZHANG, CHOW, 2003). As such, it has attracted interest for its potential benefits regarding physical function through vibration effects. However, it can also decrease the sensitivity of the human skin fast adapting mechanoreceptors (SONZA, MAURER, ACHAVAL, ZARO, NIGG, 2013) and can be potentially harmful or with no effects, depending on the selected variables

(CASTILLO, ALAM, TANAKA, LEVENDA, LI, WARDEN, TURNER, 2006; RUBINACCI, MARENZANA, CAVANI, COLASANTE, VILLA, WILLNECKER, MORO, SPREAFICO, FERRETTI, GUIDOBONO, MAROTTI, 2008; FLOYD, BRODERSON, GOODNO, 1973). Although WBV uses frequencies and amplitudes lower than occupation vibration, a study by (ABERCROMBY, AMONETTE, LAYNE, MCFARLIN, HINMAN, PALOSKI, 2007) estimated that the WBV settings in common vibration training sessions (10 minutes per day, 30Hz and 4 mm amplitude) exceeded the recommendations from the International Organization for Standardization (ISO 2631- 1:1:1997, 1997).

Exposure to vertical vibrations in the 5-10 Hz range generally causes resonance in the thoracic-abdominal system, at 10-30 Hz in the head, hand-arm and urinary system, at 60 - 90 Hz in the eyeball (RASMUSSEN, 1983). The mechanical energy transmission due to vibrations is dependent on the body position and muscle contractions. The commercially available WBV machines normally have frequency ranges from 5 - 60 Hz, and resonance of body parts can occurs.

It is commonly believed that long-term exposure to high-intensity whole-body vibration can lead to injuries. Effects on the digestive system with variable effects regarding different vibration frequencies was found to be affected (ISHITAKE, MIYAZAKI, NOGUCHI, ANDO, MATOBA, 2002), chest and abdominal pain between 4 to 10 Hz and bladder and intestinal irritation at 10 to 20 Hz (KROEMER, GRANDJEAN, 1997).

Therefore, the aim of this study was to determine how strong vibrations to various body regions are perceived, whether they are discomfort related and, using accelerometry, how much vibrational loads are present at the lower leg, hip and the head.

2 Material and Methods

Data collection included anthropometrical measurements, body vibration magnitude perception and discomfort at 12 frequencies between 3 and 25 Hz (2 Hz interval) at two intensities (3 and 5 mm amplitude). Measurements were performed on a rotational oscillation mode WBV platform and lasted approximately 25 minutes.

The healthy subjects were free from musculo-skeletal disorders and without cognitive or physical dysfunctions. Exclusion criteria were mainly based on contra-indications for WBV, such as the presence of infectious disease, insulin-dependent diabetes mellitus, endogenous osteosynthethical material, knee or hip prosthesis, pacemaker, and epilepsy interfering with test procedures (BAUTMANS, VAN HEES, LEMPER, METS, 2005). All procedures were approved by the Ethics Committee of the University of Duisburg-Essen (protocol number 13-5652-BO) and were in accordance with Declaration of Helsinki.

2.1 First measurement series: WBV perception map and discomfort rate

Anthropometrical measurements including body mass, height, hip and waist circumferences were performed on 65 subjects.

WBV training was performed on a vibration platform (Qionic-Board-Classic, QIONIC GmbH, Germany). The subjects stood comfortably on the vibration platform, bare foot, with knees lightly bent at approximately 10-15° in an upright position and fixed support base. Two thin ropes were used to control the subjects' alignment; the first one was positioned in front of the participant to avoid forward displacements of the trunk and the second one to achieve the best profile alignment (Fig 1). The equipment screen was remounted from its original to the opposite side to prevent participants from seeing the vibration frequency setting at which the vibration occurs. Prior to the experiment, subjects were exposed to all frequencies which they will experience during the measurements. Thus, they were able to sense all vibration modalities, occurring in the following experiment.

The platform frequency accuracy was determined at 23 different frequency settings (3 to 25 Hz) by a FFT-analysis using the signals of a biaxial miniature capacitive accelerometer model DA 2202-033 (Disynet®, Germany) with a measuring range of ± 33 g. To determine the amplitude of the WBV machine, an ink pen was attached to the platform at the two foot positions on the plate for the two vibration intensities. During these measurements a person stood on the platform, and the ink pen recorded the platform oscillation amplitudes on a paper, fastened to a stand perpendicular to the plate motion.

The frequency range for our experiments was limited to the available range of the chosen WBV equipment. The amplitude of plate displacement during vibration varies from 0 – 6 mm amplitude. All subjects were instructed to position the longitudinal axis of their feet on top of the lines on the plate, indicating either the 3mm or 5mm oscillation amplitude. The frequencies and amplitudes were randomized by intensity (2 amplitudes) and four frequency increase or decrease sequence conditions (3 to 13 Hz up, 13 to 3 Hz down, 15 to 25 Hz up, 25 to 15 Hz down) (Fig 1). Overall, each subject was exposed to vibrations at 12 frequencies (from 3 to 25 Hz, every 2 Hz) at both amplitudes (3 and 5 mm).

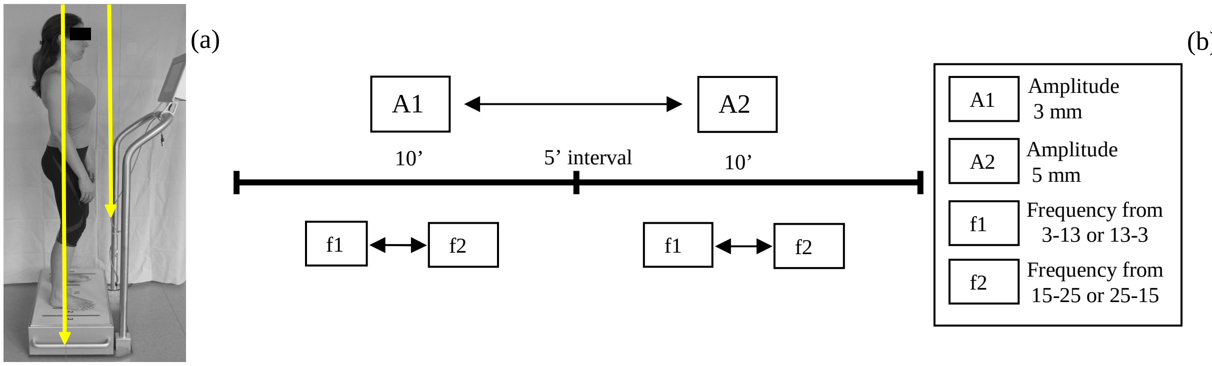

Fig 1: Participants alignment (a) and protocol timeline exemplifying the randomization method (b).

The body map vibration rating perceived exertion was assessed by a modified categorical Borg scale. Using a 21-point rating scale, (BORG, 1962) studied the perception of effort during aerobic exercise. To increase the linearity of the proposed instrument, (BORG, 1970) modified his scale to a 15-point category scale with values in the range from 6 to 20. This 15-point scale has become a standard for rating perceived exertion (Table 1). The validated Borg scale (BORG, 2004), translated into German, was used for the subjects to rate vibration magnitude for different parts of the body (head, trunk, upper limbs and lower limbs).

For each condition subjects were also asked to identify the region of the body where they were feeling most discomfort.

In each condition (24 in total), following 30 seconds of vibration exposure, the subjects had to choose a number from the Borg Scale to define the vibration intensity for 4 regions of the body (head, trunk, upper and lower limbs). After finishing the Borg scale perception ratings for the 4 regions of the body, the subjects answered following questions: 1. Where in your body are you feeling the vibration most intensely? and 2. Where in your body are you feeling discomfort?

Table 1: The 15-grade scale for ratings of perceived exertion (BORG, 1970)**.**

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

After the first 12 vibration exposures the participant had 5 minutes break and then continued the second half of the experiment.

2.2 Second experiment: Acceleration measurements

A second experiment was conducted with 40 subjects to measure the accelerations at the lower leg, hip and at the head. The subjects were measured twice on two different days.

Three uniaxial miniature capacitive accelerometers model DA 1202-033 (Disynet®, Germany), were positioned and fastened at the tibia, spinailiaca anterior superior and head). The participants were instructed to maintain a fixed knee bent position (between 10-15°), head straight and looking forward during the whole procedure. Both vibration intensities (amplitudes of 3 and 5 mm) were applied, resulting in a total of 24 different data sets for each day.

Two accelerometers were fastened above the skin of the midportion of the tibia and the hip on the left side of the body. To decrease skin movement, an elastic rubber band was used to press the tibial accelerometer against the bone. The accelerometer was positioned half way between the lateral malleolus and tibial tuberosity. For reducing skin vibration at the hip an adjustable firm fitting weightlifter belt was used. The accelerometer was on the belt at the anterior superior iliac spine location. The accelerometer for measuring head vibration was placed between the teeth. The subjects had to bite and apply pressure to a thin layer of rubber that covered a metal bite bar on which the accelerometer was fastened. The disposable rubber material served to protect the teeth.

2.3 Statistical analysis

All variables (anthropometrical, subjective perception measurements and accelerometry data) were tested for normal distribution with the Kolmogorov-Smirnov test for the whole group or Shapiro-Wilk for gender comparison. Data were analyzed using Statistical Package for the Social Sciences (version 17.0, SPSS Inc., Chicago, IL, USA) software.

All anthropometrical data were normal for gender stratification; a mean comparison was applied for equal variances between two samples with the level of significance of $\alpha=0.05$.

Despite the non-parametrical nature of the body map vibration rating perceived exertion data and subjective vibration feeling, differences between measurements for different frequencies and amplitudes to WBV exposition were analysed with MANOVA multivariate analysis of variance test for multiple dependent variables, with a level of significance of $\alpha=0.01$. After verification of the effects between the variables, univariate analyses with Tukey's post-hoc test were applied.

The acceleration data were measured in multiples of g and processed for integrated full-wave rectified signals over a period of 2 seconds (g*sec). Since two measurement series were performed on different days, the variable values were averaged across the two days and used for further evaluation.

3 Results

3.1 Subjects

A total of 65 healthy subjects, mean (±SD) age of 23.0 (±3.0) years, mean height 177.3 (±9.1) cm and weight of 73.6 (±11.3) kg were invited to the Biomechanics Laboratory of the University of Duisburg-Essen (Germany), where the experiments were conducted. Table 2 shows the anthropometrical data for the male and female subjects. The subjects were physically active students with a mean of 9 h of exercise per week. Nine percent of them had trained on vibration platforms before. The population was considered normal for all anthropometrical variables, stratified by gender.

Table 2: Mean (±SD) subject data for both gender (n=65).

	Age (years)	Weight (Kg)	Height (m)	BMI (Kg/m^2)	Total
♀	21.7 (±2.2)*	64.8 (±6.6)*	170.6 (±6.1)*	22.29 (±0.3)*	31
♂	24.3 (±3.1)	81.6 (±8.3)	183.5 (±6.6)	24.26 (±0.4)	34

Comparison between gender *p≤0.01

3.2 Vibration magnitude perception map of the body

Throughout the testing subjects were asked to rate the perceived vibration magnitude, for the different regions of the body (head, trunk, upper and lower limbs), the two different intensities and the 12 frequencies. The results are summarized in Figures 2, 3 and 4.

The MANOVA analysis, including frequency and amplitude as independent variables, gender as covariant and parts of the body as dependent variables showed effects between gender for trunk ($p < 0.01$; power = 0.92) and upper limbs ($p < 0.01$; power = 0.99), frequency ($p < 0.01$; power = 1) for all regions except upper limbs ($p = 0.25$; power = 0.69) and amplitude for all regions ($p < 0.01$; power between 0.97 - 1). No interaction effects of amplitude versus frequency were found for the four regions.

The general pattern shows (Figure 2) that the vibrations are felt most in the lower limbs, followed by the trunk and head. Vibration magnitude perception was lowest at the upper limbs.

Figure 3 shows the homogeneous subsets groups stratified by frequencies for the subjective WBV severity perception. The frequencies that do not belong to the specific subset group, show a significant difference for the vibration perception ($p \leq 0.01$).

As expected, in the lower limbs, vibration was felt strongest by the participants. Analysing amplitudes 3 and 5 mm, the univariate analysis is presented in homogeneous subsets (Figure 3). As general results and excluding bigger interpolation frequencies the following frequencies ranges are the same according to the subjects perception: 3 and 5 Hz, from 9 to 15 Hz and between 21 - 25 Hz. The lower frequency range had a Borg scale perception around “fairly light”, for the intermediate (9 – 15 Hz) the perception is “hard” and close to the high frequency range of 21 - 25 Hz the vibration perception was, according to the Borg Scale, between “very hard” and “extremely hard” (Table 1, Figure 2).

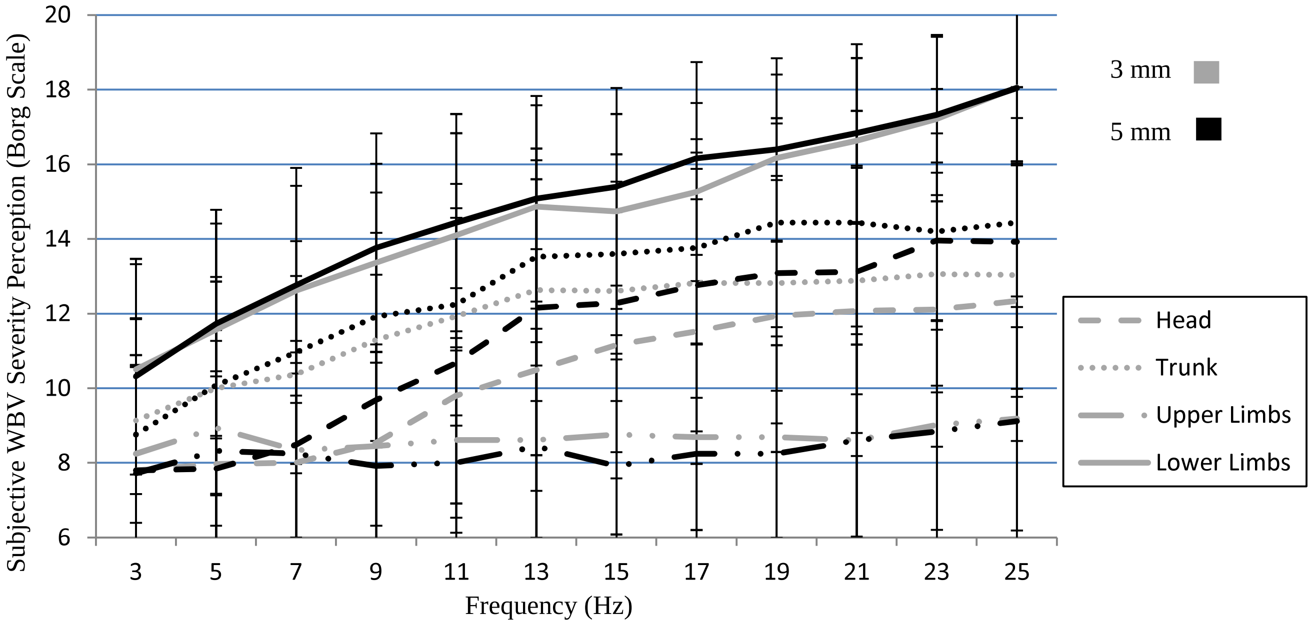

Fig 2: Subjective WBV severity perception (65 subjects) for different body parts during standing on a vibration platform for 12 frequencies (03 to 25 Hz) at 2 intensities (3mm, 5mm).

Summarizing the results for the trunk region at both intensities (3 and 5 mm) the univariate analysis shows ($p \leq 0.01$) that there are two main groups (Table 3). The frequency groups 3 - 5 Hz and 11 - 25 Hz the vibration perception differ inter groups but not intra groups. The vibration perception was “very light” and between “somewhat hard and hard”, respectively (Table 1, Figure 2).

For both intensities no vibration perception differences were found between the frequencies in the upper limbs region, since there is only one homogeneous subset between 3 – 25 Hz (Figure 3). This was the region where the subjects felt only low vibration for all frequencies, judged according to the Borg scale as between “very, very light” and “light” (Table 1, Figure 2).

For the head region at the low intensity condition (3 mm) the univariate analysis shows a significant difference for the vibration perception (p ≤ 0.01) inter groups for the subsets between 3-9 Hz and 13-25 Hz (Figure 3). For frequencies above 13 Hz the subjects started to feel the vibration significantly more in the head in comparison to the smaller frequencies, between “somewhat hard” and “hard”, according to the Borg Scale (Table 1, Figure 2).

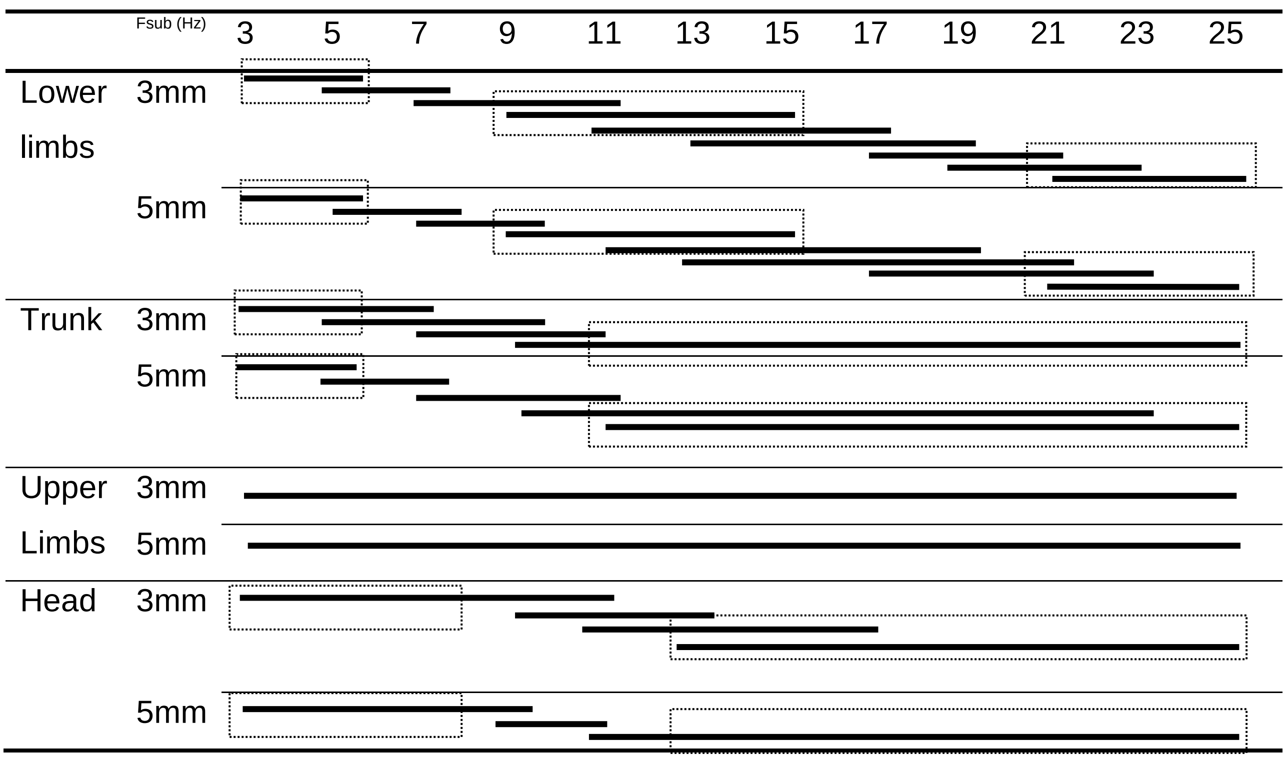

Fig 3: Frequencies subsets (Fsub) for subjective WBV severity perception (65 subjects) for different body parts during standing on a vibration platform for 12 frequencies (3 to 25 Hz) at 2 intensities (3 mm, 5 mm). Bars represent the means for groups in homogeneous subsets are displayed. Inter groups subsets differ between them (p ≤ 0.01). Dotted boxes are the main subsets groups. In general, the frequencies with more interpolations were not considered for the main subsets.

The participants answered two more questions about their vibration perception: Firstly, they reported for each frequency at which body part they felt the highest vibration (Figures 4A, 4B). Secondly, they answered for each frequency, which body part they felt discomfort (Figures 4C, 4D). It was possible to give more than one answer for the second question. The results are presented in figure 3 for both WBV intensities (3 mm - A,C and 5 mm - B,D).

In general, it can be observed from the graphs in figure 3 that the perception of highest vibration in the body and most discomfort differ substantially. Take as an example the vibration at the thigh (yellow line). Although thigh vibrations are felt very much in the lower frequency range from 3 to 15 Hz (Figures 4 A,B), there is very little discomfort associated with it (Figures 4 C,D). However, for the regions of head, lower back, lower legs and foot the frequencies from the responses “feeling most” and “discomfort” are close or coincident.

For the different regions of the body at the 3 mm amplitude, the frequencies at which the majority of the participants felt the vibration most, were (in brackets the frequency where they felt discomfort for at least 4 occurrences): 19 Hz (19 - 21) for the head, 3 Hz for the upper limbs, 15 Hz (17 and 25) for the low back, 17 Hz for the chest, 7 Hz for the abdomen and between 7 – 9 Hz for the waist (13 - 17 for abdominal and waist), 9 Hz for the gluteus, 11 Hz for the thigh (19 - 21), 5 and 11 Hz for the knee, and between 21 – 25 Hz for the lower legs and the foot (23 - 25).

For the 5 mm amplitude, the frequencies at which the majority of the participants felt the vibration most were (in brackets the frequency where they felt discomfort for at least 4 occurrences) were: 13 and 19 Hz for the head (15 and 17), 3 Hz for the upper limbs, 11-

17 Hz for the low back (17 and 23), 3-5 Hz for the chest, 7-9 Hz for the abdomen (9 – 13) and between 7 and 11 Hz for the waist (13 – 17), 7Hz for the gluteus, 9Hz for the thigh (15), 5 Hz for the knee, between 21 – 25 Hz for the lower legs and the foot (21 – 25).

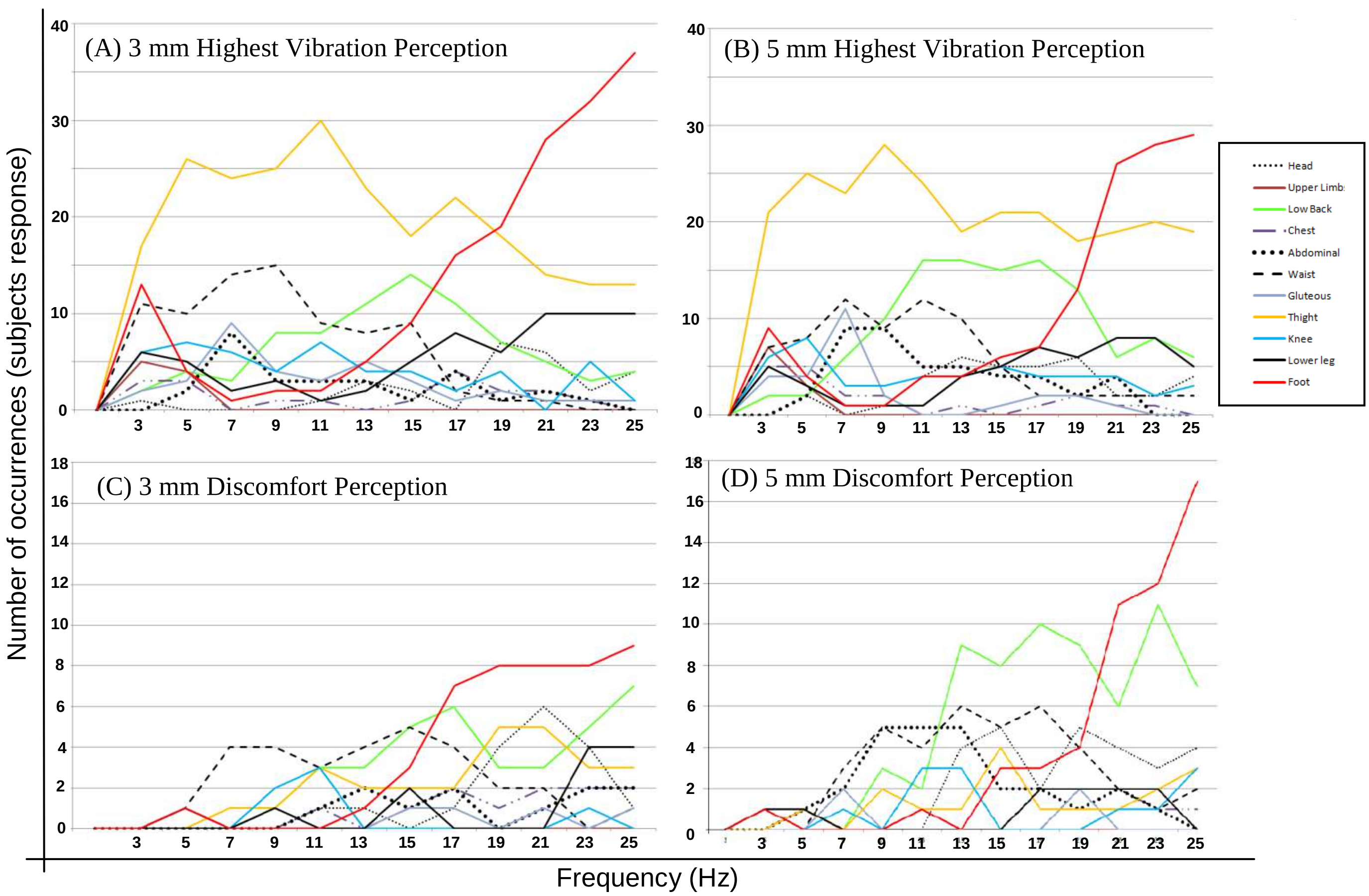

Fig 4: Subjective WBV severity perception based on participant's (n=65) subjective perception for different platform settings. Figures (A) and (B) represent the number of responses by the subjects for which part of the body the subjects felt the vibration most. Figures (C) and (D) represents the number of responses by the subjects for the body parts with vibration discomfort.

3.3 Accelerometry vibration loads at tibia, hip, and head

Accelerations in axial direction were measured at the tibia, hip and head of 40 volunteers who stood in a slight knee bent position. Across the body regions, all frequencies, and both WBV intensities, the peak accelerations, measured by the three accelerometers covered a range from 0.1 to 10.7 g (g = earth's gravitational constant). However, for a better estimation of the mechanical load at the body locations, the rectified and integrated acceleration signal (g * s) for a measuring period of 2 seconds was used for further analyses.

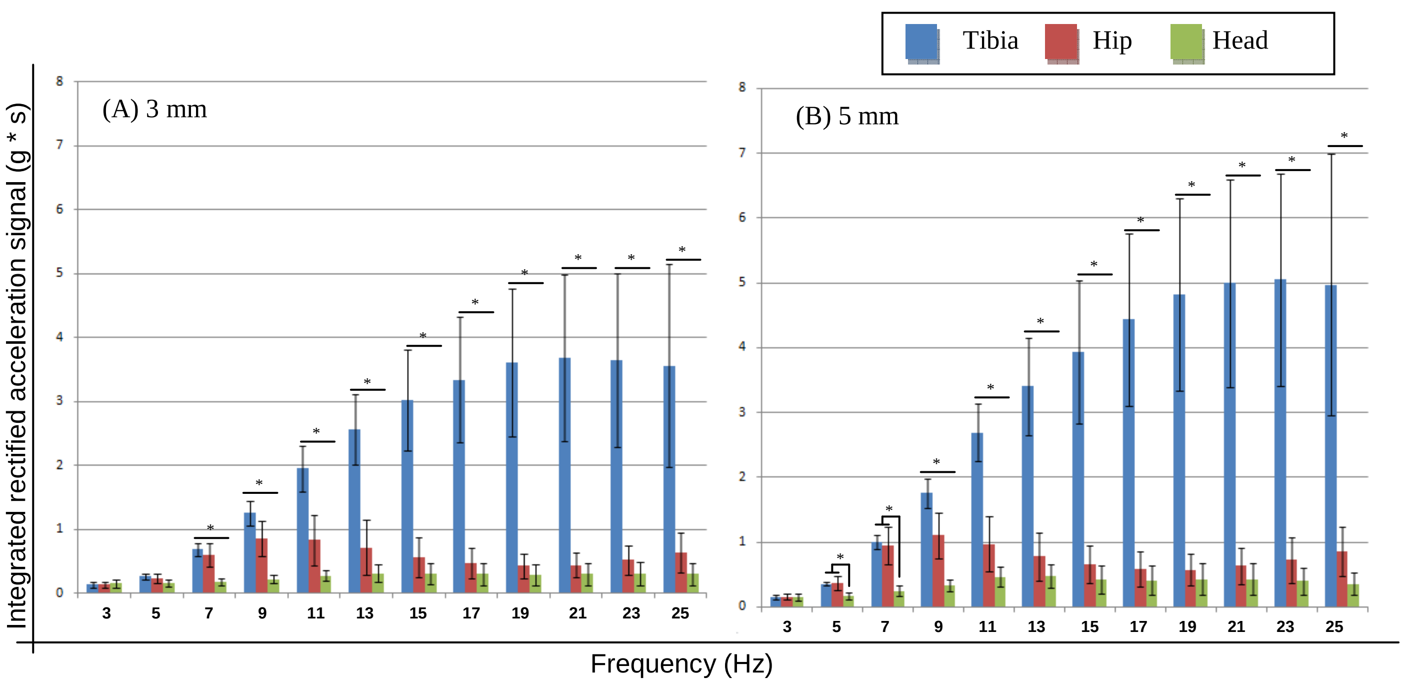

Fig 5: Rectified integrated accelerations (2 second measuring interval) of the axial accelerations to the human body for different WBV platform settings. Figure A represents the low (3 mm) and figure B the high (5 mm) intensity WBV (n=40). Bars represent the comparison between the body regions intra frequencies (p ≤ 0.01).

Figure 5 summarizes the platform accelerations in axial directions transmitted to the regions of tibia, hip and head. Substantial amplification of peak accelerations for these parameters settings occurred between 19 – 25 Hz for the region of tibia, 7 – 13 Hz for the region of hip and between 11 – 25 Hz for the head.

Comparing the regions of the body, except for the 3, 5 and 7 Hz conditions the acceleration integrals for the low intensity (3 mm) vibrations differed between all three body regions. For the high intensity (5 mm) vibrations the acceleration integrals differed between all three body regions for all frequencies between 9 and 25 Hz. For 5 and 7 Hz, the acceleration integrals at the head differed from hip and tibia (Figure 5).

Comparing the acceleration integrals between the two intensities and three body regions, they differ ($p \leq 0.01$) between all frequencies except the frequencies 3 and 5 Hz for the head and 13 and 15 Hz for the Hip.

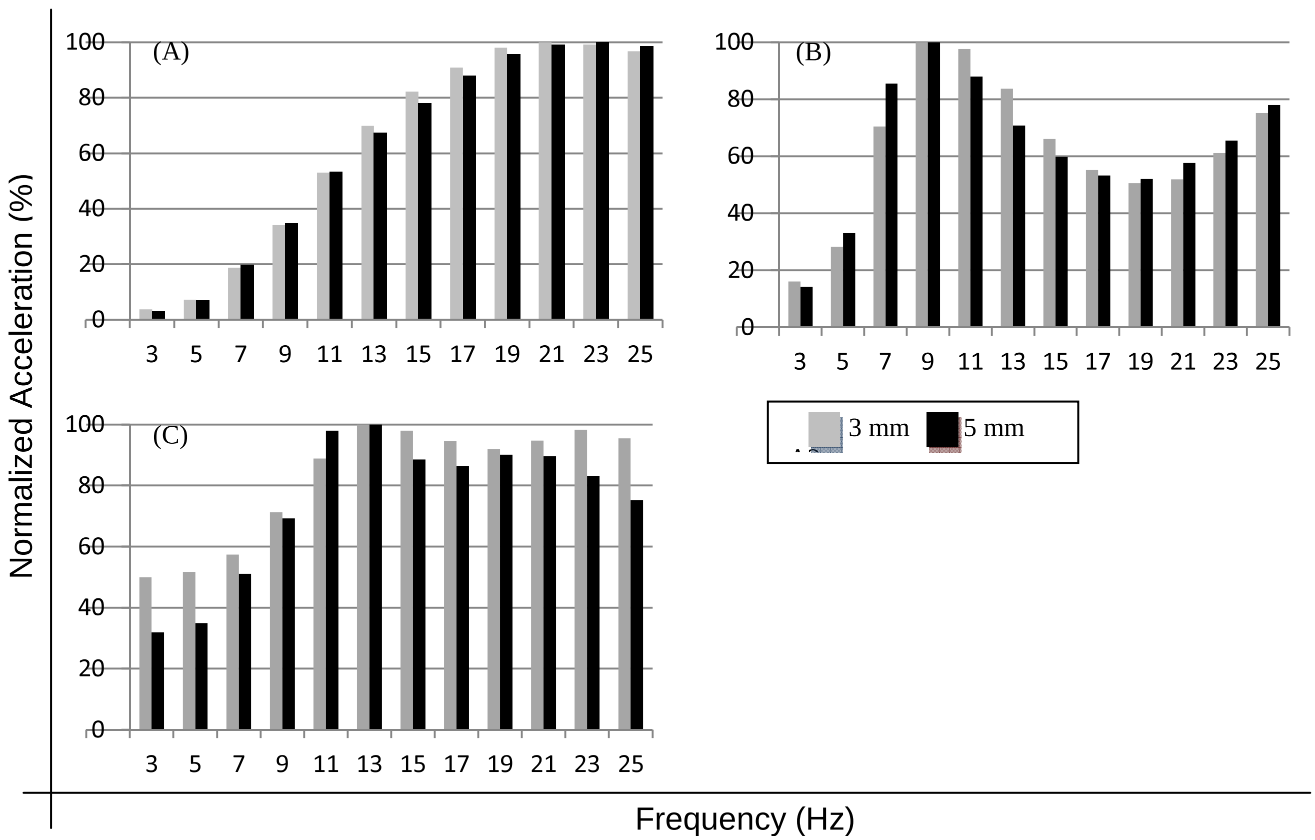

Fig 6: Normalized frequency dependent acceleration loads at the tibia (A), hip (B), and head (C) for two WBV intensities (a percentile load representation against the maximum value (100 %), as found across all frequencies) (n = 40).

A normalized representation of the vibration loads (integrated rectified acceleration signal for 2 seconds) is shown in figure 5. Based on the same data as shown in figure 5, the graphs in figure 6 serve to point out the relative loading within the three body locations. Firstly, the low (3 mm) and high (5 mm) intensity vibration loadings result in a very similar frequency dependent load distribution pattern. There is a clear load increase at the tibia for the higher frequencies. However, the tibial loads remain similarly high from 19 Hz on. At the hip, a loading peak occurs at 9 Hz, becoming smaller until 19 Hz and then increasing again for the highest frequencies. Head acceleration loads slowly increase with frequency and are highest at 11 Hz. Towards the higher frequencies there is only a small decrease for the low intensity WBV, but a more pronounced decrease for the higher intensity WBV.

The homogeneous subsets groups stratified by frequencies for the accelerations values for the regions of tibia, hip and head are presented on Figure 7. The frequencies that do not belong to the specific subset group (individual bars), show a significant difference for the acceleration integrals ($p \le 0.01$).

Acceleration values for the tibia region for both WBV intensities (Figure 3) have the same frequency ranges (excluding bigger interpolation frequencies): 3 and 5 Hz, from 13 to 15 Hz and between 21 - 25 Hz.

Summarizing the results for the hip region at both intensities the univariate analysis shows ($p \le 0.01$) that there are three main homogeneous groups (Figure 7). For the frequency groups 3 - 5 Hz, 9 -11 Hz, and 15 - 23 Hz the acceleration values differ between groups but not within groups. For the head region, two main homogeneous subset groups were found at 3 - 7 Hz and 11 -25 Hz.

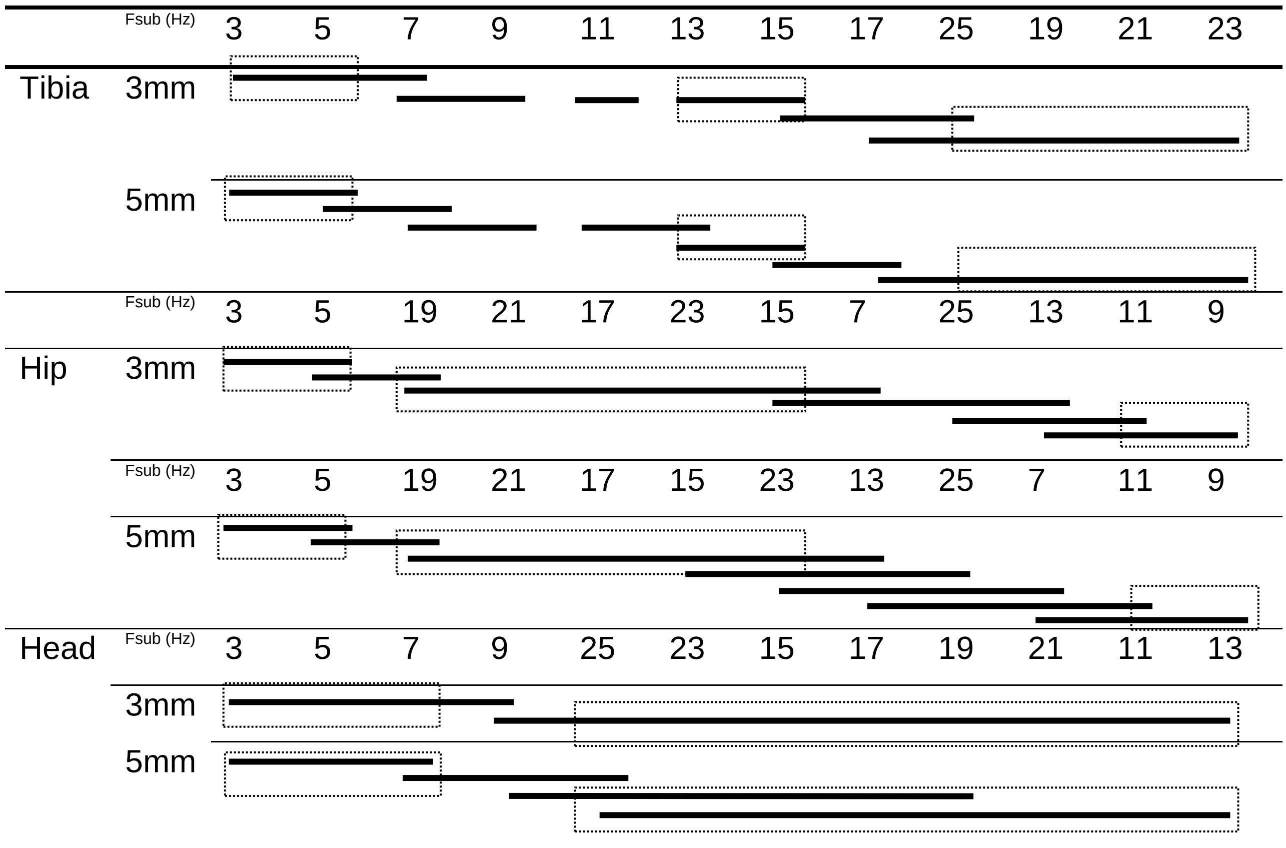

Fig 7: Frequencies subsets (Fsub) for accelerometry (40 subjects) in the regions of tibia, hip and head for 12 frequencies (3 to 25 Hz) at 2 intensities (3 mm, 5 mm). Individual bars represent groups of subsets with no statistically significant differences within the frequencies. Inter groups subsets differ between them ($p \leq 0.01$). Dotted boxes are the main subsets groups. In general, the frequencies with more interpolations were not considered for the main subsets.

Observing Figures 3 and 7, the main homogeneous groups of frequencies for subjective perception and acceleration values are similar, especially for the lower limbs and the head.

Comparing the maximal acceleration integrals among all conditions (regions, amplitudes and frequencies), the lower legs had about 4.5 times higher magnitudes compared to the hip and 11 times higher values than the head. The hip had about 2.5 times higher acceleration magnitudes compared to the head (Figure 8).

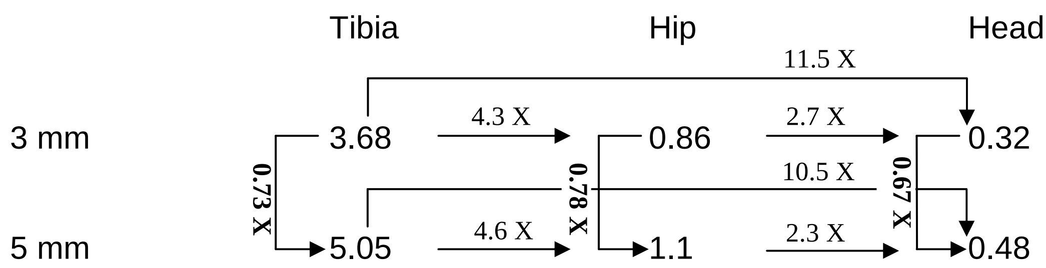

Fig 8: Diagram representing the similar attenuation of the acceleration integral (g*sec) from the tibia to the hip and head for the two WBV intensities 3 and 5 mm.

It is interesting to note, that the attenuation from the lower leg to the hip and head is very similar for both vibration intensities (Figure 8). For the lowest frequency (3 Hz) the vertical acceleration magnitudes were about the same for all 3 measured regions.

Discussion

The complex nature of the human body from a mechanical and biological point of view makes us unique and different from one to another. Nevertheless, mean responses in the perception of vibration magnitude and discomfort are important for judging WBV equipment, used for training and in rehabilitation institutions. The additional determination of acceleration loads at the tibia, hip, and head provides further information on potential risks for the body. The subjective vibration magnitude perception of the body and greatest sensitivities reported may be related to resonance phenomena within the body. This study shows the results for 12 different WBV frequencies and 2 vibration magnitudes on vibration and discomfort perception. For the regions of lower limbs, trunk and head, the subjective WBV severity perception based on the Borg scale increased with higher amplitudes and frequencies. However, for upper limbs it was similar across all frequencies and two intensities (3 and 5 mm).

Thresholds for the perception of whole-body vibrations when sitting, standing or lying vary with the frequency and direction of vibration, with sensitivity generally greater when lying than when sitting or standing (MIWA, 1967; PARSONS, GRIFFIN, 1988). Such findings have influenced standardised frequency weightings for evaluating vibration with respect to the probability of perception (ISO 2631-1: 1997, 1997).

In general, the number of occurrences for discomfort, related to the WBV in our experiments was not very high. However, one should consider that our subjects were healthy sport students and discomfort ratings are likely to be different for patients and/or elderly subjects. However, at 5 mm amplitude, even 61.5% of our healthy sport students felt discomfort for the foot region in the range between 21 – 25 Hz. For the low back region 46.2% felt discomfort for the frequencies of 17, 19 and 21 Hz and 23% felt abdominal discomfort in the frequency range of 9 – 13 Hz. Discomfort can be related to resonance phenomena within the body and must be considered as a possible source of undesirable side effects of using WBV (RUBIN, POPE, FRITTON, MAGNUSSON, HANSSON, MCLEOD, 2003). Our results show that the perception of highest vibration in the body and most discomfort can differ. However, for the regions of head, lower back, lower legs and foot the frequencies from the responses “feeling most” and “discomfort” are close or coincident.

As expected, the highest acceleration loads occured at the tibia with maximal values between 19 and 25 Hz. For the hip, the highest acceleration load was at 9 Hz and for the head at 13 Hz. A study from (KIISKI, HEINONEN, JÄRVINEN, KANNUS, SIEVÄNEN, 2008) measured 4 subjects on a WBV platform at different frequencies and amplitudes. In general, for a WBV platform, operating in vertical mode, they found substantial amplification of peak acceleration between 10-25 Hz for the knee region, 10-20 Hz for the hip, 10-40 Hz for the ankle and 10 Hz for the spine. A study from Abercromby et al. (2007) found that the transmission of vibration mechanical energy at 30 Hz and 4 mm amplitude was 71% to 189% greater during vertical as compared to rotational vibration to the upper body and head. This means that rotational vibrations, as used in this study, are likely to be be less harmful as compared to vertical vibrations. However, the further your feet are apart from the equipment axis (amplitudes can reach 14 mm in some machines) the mechanical loads to the body increase substantially.

The comparison between the maximal acceleration integrals among all conditions demonstrates the attenuation capabilities of the human body from the feet to the head. Considering acceleration transmissibility, the frequency range from 3 – 7 Hz represents the safest frequency range with magnitudes of less than 1g.

There is a good match between subjective perception (Borg scale) and measured acceleration integrals for the lower limbs and the head. This shows that the subjective perception of higher vibration intensities can be related to the regions with higher acceleration peaks.

Conclusion

The subjective WBV severity perception, based on the Borg scale, increased with higher platform oscillation amplitudes and frequencies. However, for the upper limbs it was similar for all frequencies and both vibration intensities. Using Borg's scale, the subjects perception ranged for lower the limbs between "very hard" and "extremely hard" (17 - 18 on the 6 – 20 scale) for the frequencies between 21 – 25 Hz. The vibration perception for the head (13 to 25 Hz) was "fairly light" (10 – 12 on Borg scale) and "somewhat hard" (13 on the scale) for the trunk (11-25 Hz). In general, the subjective magnitude estimation of vibration, using the Borg scale, followed a similar trend as the acceleration integral values, as determined at the lower leg, hip and head. This shows that people are able to estimate the magnitude of vibrations in various parts of their body and it suggests that machine settings should be chosen based on subject's sensation (Borg Scale). However, we also found that body regions where subjects feel high vibrations do not necessarily correspond with body sites where most pain or discomfort is felt. A subjective discomfort or pain perception can be related to hazardous side effects. At 5 mm amplitude, 61.5% of the subjects felt discomfort for the foot region (21 – 25 Hz), 46.2% for the low back region (17, 19 and 21 Hz) and 23% for abdominal region (9 – 13 Hz).

It was found that the human body is capable to substantially attenuate vibration magnitudes from the lower legs to the hip and head. The lower legs had about 4.5 times higher magnitudes compared to the hip and 11 times higher than the head. For the studied platform settings, the frequency range from 3 – 7 Hz represents the safest frequency range with acceleration integrals of less than 1g*sec for all studied regions.

References

ABERCROMBY, AF J; AMONETTE, W E.; LAYNE, CS.; MCFARLIN, B K.; HINMAN, M R.; PALOSKI, W H. Vibration exposure and biodynamic responses during whole-body vibration training. **Medicine and science in sports and exercise**, v. 39, n. 10, p. 1794–1800, 2007.

BAUTMANS, I; VAN HEES, E; LEMPER, J; METS, T. The feasibility of whole body vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility:: a randomised controlled trial. **BMC Geriatrics**, v. 5, 17 // 1, p. 1–8, 2005.

BELAVÝ, D L.; HIDES, JA.; WILSON, S J.; STANTON, W; DIMEO, F C.; RITTWEGER, J; FELSENBERG, D; RICHARDSON, C A. Resistive Simulated Weightbearing Exercise With Whole Body Vibration Reduces Lumbar Spine Deconditioning in Bed-Rest. **Spine**, v. 33, n. 5, p. E121–E131, 2008.

BOGAERTS, A.; DELECLUSE, C; CLAESSENS, A L.; COUDYZER, W; BOONEN, S; VERSCHUEREN, S. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men:: a 1-year randomized controlled trial. **J Gerontol A: Biol Sci Med Sci**, v. 62, n. 6, p. 630–635, 2007.

BORG, G.. Anstrengungsempfinden und körperliche Aktivität. **Dtsch Ärztbl**, v. 101, n. 15, p. 840–845, 2004.

BORG, G.. **Physical performance and perceived exertion**. Copenhagen: CWK Gleerup, 1962.

BORG, G. Perceived exertion as an indicator of somatic stress. **Scandinavian journal of rehabilitation medicine**, v. 2, n. 2, p. 92–98, 1970.

BRAUER, R L. **Safety and health for engineers**. 2. ed. Hoboken, NJ: Wiley-Interscience, 2006. VII, 756. ISBN 0471291897.

BRUYERE, O; WUIDART, M; DI PALMA, E; GOURLAY, M; ETHGEN, Or; RICHY, F; REGINSTER, J. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. **Archives of physical medicine and rehabilitation**, v. 86, n. 2, p. 303–307, 2005.

CASTILLO, A B.; ALAM, I; TANAKA, S.; LEVENDA, J; LI, J; WARDEN, S J.; TURNER, C H. Low-amplitude, broad-frequency vibration effects on cortical bone formation in mice. **Bone**, v. 39, n. 5, p. 1087–1096, 2006.

CHAFIN, D.; ANDERSSON, G.; CHAFFIN, D B.; ANDERSSON, GB. J.; MARTIN, B J. **Occupational biomechanics**. 4. ed. New York: John Wiley & Sons; Wiley, 2006. XV, 360. ISBN 978-0-471-72343-1.

CHEUNG, J; ZHANG, M; CHOW, D. Biomechanical responses of the intervertebral joints to static and vibrational loading: a finite element study. **Clinical biomechanics (Bristol, Avon)**, v. 18, n. 9, p. 790–799, 2003.

EBERSBACH, G; EDLER, D; KAUFHOLD, O; WISSEL, J. Whole Body Vibration Versus Conventional Physiotherapy to Improve Balance and Gait in Parkinson's Disease. **Archives of Physical Medicine and Rehabilitation**, v. 89, n. 3, p. 399–403, 2008.

FLIEGER, J.; KARACHALIOS, T.; KHALDI, L.; RAPTOU, P.; LYRITIS, G. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. **Calcified tissue international**, v. 63, n. 6, p. 510–514, 1998.

FLOYD, W. N.; BRODERSON, A. B.; GOODNO, J. F. Effect of whole-body vibration on peripheral nerve conduction time in the rhesus monkey. **Aerospace medicine**, v. 44, n. 3, p. 281–285, 1973.

HAAS, C. T.; TURBANSKI, S.; SCHMIDTBLEICHER, D. Vibrationstraining in der Rehabilitation von Gang- und Gleichgewichtsstörungen. **focus neurogeriatrie**, v. 1, n. 3, p. 18–19, 2007. doi:10.1007/s12151-007-0049-7.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 2631- 1:1:1997 Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body vibration,: Part 1, General Requirements. **Geneva, Switzerland: International Organization for Standardization.**, 1997.

ISHITAKE, T.; MIYAZAKI, Y.; NOGUCHI, R.; ANDO, H.; MATOBA, T. Evaluation of frequency weighting (ISO 2631-1) for acute effects of whole-body vibration on gastric motility. **Journal of Sound and Vibration**, v. 253, n. 1, p. 31–36, 2002.

JUDEX, S; DONAHUE, L; RUBIN, C. Genetic predisposition to low bone mass is paralleled by an enhanced sensitivity to signals anabolic to the skeleton. **FASEB journal : official publication of the Federation of American Societies for Experimental Biology**, v. 16, n. 10, p. 1280–1282, 2002.

KIISKI, J; HEINONEN, A; JÄRVINEN, T L.; KANNUS, P; SIEVÄNEN, H. Transmission of vertical whole body vibration to the human body. **Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research**, v. 23, n. 8, p. 1318–1325, 2008.

KROEMER, K H. E.; GRANDJEAN, E. **Fitting the task to the human:** A textbook of occupational ergonomics. 5. ed. London [u.a.]: Taylor & Francis, 1997. X, 416. ISBN 0748406654.

MIWA, T. Evaluation methods for vibration effect: Part 3.: Measurements of threshold and equal sensation contours on hand for vertical and horizontal sinusoidal vibrations. **Industrial Health**, v. 6, p. 213–220, 1967.

PARSONS, K. C.; GRIFFIN, M. J. Whole-body vibration perception thresholds. **Journal of Sound and Vibration**, v. 121, n. 2, p. 237–258, 1988.

RASMUSSEN, G. Human Body Vibration Exposure and its Measurement. **The Journal of the Acoustical Society of America**, v. 73, n. 6, p. 22–29, 1983.

ROELANTS, M; DELECLUSE, C; VERSCHUEREN, S M. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. **Journal of the American Geriatrics Society**, v. 52, n. 6, p. 901–908, 2004.

RUBIN, C.; TURNER, A. S.; BAIN, S.; MALLINCKRODT, C.; MCLEOD, K. Anabolism. Low mechanical signals strengthen long bones. **Nature**, v. 412, n. 6847, p. 603–604, 2001.

RUBIN, C; POPE, M; FRITTON, J. C; MAGNUSSON, M; HANSSON, T; MCLEOD, K. 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**, v. 28, n. 23, p. 2621–2627, 2003.

RUBINACCI, A; MARENZANA, M; CAVANI, F; COLASANTE, F; VILLA, I; WILLNECKER, J; MORO, G; SPREAFICO, L; FERRETTI, M; GUIDOBONO, F; MAROTTI, G. Ovariectomy sensitizes rat cortical bone to whole-body vibration. **Calcified tissue international**, v. 82, n. 4, p. 316–326, 2008.

SONZA, A; MAURER, C; ACHAVAL, M; ZARO, M A.; NIGG, B M. Human cutaneous sensors on the sole of the foot: Altered sensitivity and recovery time after whole body vibration. **Neuroscience Letters**, v. 533, p. 81–85, 2013.

VERSCHUEREN, SM P; ROELANTS, M; DELECLUSE, C; SWINNEN, S; VANDERSCHUEREN, D; BOONEN, S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. **Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research**, v. 19, n. 3, p. 352–359, 2004.

WASSERMAN, D E. An Overview of Occupational Whole-Body and Hand-Arm Vibration. **Applied Occupational and Environmental Hygiene**, v. 11, n. 4, p. 266–270, 1996.

XIE, L; JACOBSON, J M.; CHOI, E S.; BUSA, B; DONAHUE, L R; MILLER, L M.; RUBIN, C T.; JUDEX, S. Low-level mechanical vibrations can influence bone resorption and bone formation in the growing skeleton. **Bone**, v. 39, n. 5, p. 1059–1066, 2006.

4. DISCUSSÃO

Este capítulo irá discutir a interação deste conjunto de estudos sobre a vibração de corpo inteiro e seus efeitos em algumas variáveis fisiológicas no corpo humano e também em um modelo de dor crônica em ratos Wistar adultos.

O primeiro estudo investigou os efeitos da VCI na sensibilidade cutânea vibratória, medidos a 30 Hz (corpúsculos de *Meissner)* e 200 Hz (corpúsculos de *Pacini*), e de receptores de toque-pressão dos pés de 20 sujeitos normais. O tempo de duração dos efeitos da vibração nesses receptores sensoriais também foi averiguado assim como diferença entre gêneros. Como principal resultado do primeiro estudo encontrou-se que as descargas aferentes dos mecanorreceptores de adaptação rápida são fortemente afetadas pela vibração e a sensibilidade de toque-pressão também foi afetada. Após 10 minutos de exposição à VCI o tempo de recuperação para a sensibilidade voltar aos limiares basais nos pés foi entre duas e três horas. A sensibilidade de toque-pressão teve seu tempo de recuperação inferior à uma hora.

Neste estudo não foram encontradas diferenças na sensibilidade cutânea de toque-pressão na planta do pé entre gêneros na comparação entre os valores basais (antes) e após a exposição à VCI. Foi observado por Hennig e Sterzing (2009) para a região da planta do pé, avaliando homens e mulheres entre 20 a 35 anos, não encontraram influência sobre a sensibilidade ao toque e pequenas diferenças de sensibilidade vibratória entre gêneros. No entanto, ao avaliarem a sensibilidade no dorso do pé, os mesmos autores encontraram diferenças significativas entre os sexos.

Para a sensibilidade vibratória de alta frequência (200 Hz), nossos dados estão de acordo com um estudo recente (SCHLEE; RECKMANN; MILANI, 2012), em que foram utilizados diferentes parâmetros da plataforma vibratória. Nesse estudo três regiões anatômicas foram avaliadas (cabeças dos 1º e 5º metatarsos e calcanhar). Eles observaram um decréscimo significativo na sensibilidade vibratória de 200 Hz diretamente depois de uma exposição de 4 minutos à VCI. Nosso estudo amplia esses resultados, incluindo mais duas regiões anatômicas (arco lateral e hálux), vibração de 30 Hz e duração dos efeitos da vibração. Características anatômicas do arco do pé e da sensibilidade são variáveis importantes para a classificação de conforto de palmilhas (MÜNDERMANN; STEFANYSHYN; NIGG, 2001). O hálux, por sua vez, fornece *feedback* mecânico e proprioceptivo essencial para a marcha, que é necessária para a propulsão normal durante a marcha (BOISSONNAULT; DONATELLI, 1984).

A fim de que a vibração fosse percebida, menores amplitudes foram necessárias para a vibração de 200 Hz (ou seja, são mais sensíveis para os receptores que detectam altas frequências) comparadas com a vibração 30 Hz, o que corrobora os resultados encontrados por Mountcastle e Lamotte (1972). No nosso estudo, na condição basal, foi necessário que a amplitude de vibração do equipamento fosse 5 vezes superior para a vibração de 30 Hz comparado com a vibração de 200 Hz, a fim de ser percebido pelos participantes.

Mensagens fisiológicas são transduzidas pelos receptores cutâneos, particularmente aqueles de rápida adaptação (RA), são altamente sensíveis à vibração e vinculados à frequência do estímulo vibratório (RIBOT-CISCAR; VEDEL; ROLL, 1989). Demonstramos que os sensores RA para altas frequências foram afetados mais rapidamente pela VCI aumentando os limiares de amplitude comparados aos sensores de baixas frequências.

Com relação à sensibilidade de toque-pressão, Pollock e cols. (2011) verificaram uma diminuição da sensibilidade ao toque-pressão imediatamente após a VCI na cabeça do 1º metatarso. Mediram a sensibilidade através dos filamentos de Von Frey 15 e 30 minutos após 5 minutos de exposição à VCI. Com 4 mm de amplitude no equipamento de VCI, a sensibilidade demorou 15 minutos para voltar ao normal. Nossos resultados mostram como o tempo de recuperação para o arco medial, cabeças dos primeiro e quinto metatarsos foi inferior a 1 hora. A fim de determinar o tempo de recuperação dependente da sensibilidade de tato e pressão nessas regiões irá ser necessária a utilização de intervalos de tempo mais curtos entre as medições. Entretanto, para o hálux encontramos que o tempo recuperação para retorno aos valores basais foi de 1,5 h e 1,8 h para a região do calcanhar.

Como no primeiro estudo foi observada alteração sensorial temporária dos mecanorreceptores da pele e sabe-se que altos níveis de informações sensoriais são parte do sistema de *feedback* sensorial que proporciona equilíbrio (HENNIG; STERZING, 2009; MEYER; ODDSSON; DE LUCA, 2004; INGLIS et al., 1994), questionou-se então se a VCI não afetaria o equilíbrio corporal após sua exposição. O equilíbrio é necessário para a mobilidade funcional, e qualquer redução na sensibilidade pode aumentar a probabilidade de quedas, principalmente em idosos.

Assim, um segundo estudo foi realizado avaliando efeitos pós-vibração e sua interação com variáveis fisiológicas. Foram mensurados a pressão arterial, as frequências cardíaca e respiratória, a temperatura axilar, a temperatura cutânea através de termografia por infravermelho dos membros inferiores e por fim, o equilibro corporal através das análises do centro de pressão (COP), em plataforma de força. Foram avaliados 24 sujeitos neste estudo.

Para os dados de pressão arterial, frequências cardíaca e respiratória e temperatura axilar não foram encontradas diferenças estatisticamente significativas entre as condições basal e pós-vibração corroborando com os dados de Rittweger e cols. (2000). Estes autores estudaram os efeitos da VCI comparado com bicicleta ergométrica sobre o sistema cardiorrespiratório averiguaram que seus efeitos são ínfimos, ou seja, a VCI não incrementa o sistema cardiorrespiratório (RITTWEGER; BELLER; FELSENBERG, 2000).

O segundo estudo também verificou a sensibilidade cutânea de toque-pressão, 10 minutos pós-vibração. Foram avaliados ambos os pés, 5 regiões anatômicas e em 4 diferentes frequências de exposição da plataforma vibratória (30, 35, 40, 44 Hz). Decréscimo significativo da sensibilidade foi encontrado para todas as regiões anatômicas dos pés direito e esquerdo, para todas as frequências da plataforma. Considerando outros estudos que avaliaram sensibilidade cutânea vibratória e ou de toque-pressão (SONZA et al., 2013; SCHLEE; RECKMANN; MILANI, 2012; POLLOCK et al., 2011) com diferentes parâmetros da plataforma (tempo de exposição, amplitudes, frequências e modo de vibração), a VCI de forma geral parece reduzir a sensibilidade após a vibração.

Ainda que a alteração da sensibilidade cutânea seja unanimidade nos estudos até aqui publicados, a sua relação com o equilíbrio postural é controversa. O sistema nervoso central utiliza as informações aferentes cutâneo-musculares e particularmente do fuso muscular do tornozelo para o auxílio no controle do equilíbrio durante a postura estática e perturbada (THOMPSON; BÉLANGER; FUNG, 2011). O equilíbrio é necessário para a mobilidade funcional e qualquer redução na sensibilidade pode aumentar a probabilidade de quedas (SONZA et al., 2013). No entanto, curiosamente, alguns estudos envolvendo indivíduos jovens saudáveis mostraram aumento agudo no desempenho neuromuscular, tais como controle do equilíbrio (SCHLEE; RECKMANN; MILANI, 2012) e da força muscular (CARDINALE; LIM, 2003) ou resultados não significativos (POLLOCK et al., 2011; TORVINEN et al., 2003) depois da VCI. Um estudo que modulou a informação somatossensorial de membro inferior através de vibrações no tendão e plantares cutâneo-muscular mostrou respostas posturais alteradas, aumentando o deslocamento do COP (THOMPSON; BÉLANGER; FUNG, 2011). Nossos resultados mostraram em relação às variáveis de controle de equilíbrio (velocidade e comprimento AP do COP), quando medidos 20 minutos após a VCI, diminuição significativa no controle de equilíbrio nas frequências mais altas analisadas (40 e 44 Hz). A diminuição do equilíbrio pode ser devido à diminuição da sensibilidade cutânea dos mecanorreceptores da pele (sistema de realimentação sensorial). Não foram encontrados resultados significativos para área do COP ou nas frequências mais baixas (30 e 35 Hz). Dickin e cols. (2012) mediram o equilíbrio sobre uma superfície de apoio estável e olhos abertos após 4 minutos de VCI durante os ensaios separados em frequências de 10, 30 e 50 Hz. Eles encontraram um aumento do COP imediatamente após VCI que retornou à linha de base 10 e 20 minutos pós-vibração. Duas grandes diferenças entre o presente estudo e o de Dickin e cols. (2012) foram o tempo de exposição e a avaliação postural, no primeiro caso, que foi de 15 minutos e avaliação do equilíbrio unipodal, enquanto que no segundo foi de 4 minutos e avaliação do equilíbrio bipodal. O estudo envolvendo indivíduos saudáveis conduzidos por Schlee e cols. (2012) mediram o equilíbrio após a VCI (frequência de 27 Hz, amplitude horizontal, 2 mm de amplitude e 4 minutos de exposição) e encontrou uma melhoria no controle de equilíbrio imediatamente após a VCI. O presente estudo, corroborando com Dickin e cols., (2012), não encontrou diferenças no controle do equilíbrio com a plataforma vibratória a 30 Hz, medida 20 minutos após a vibração.

A última variável fisiológica estudada neste segundo artigo foi a temperatura de membros inferiores através da termografia por infravermelho que fornece informações sobre o funcionamento do fluxo sanguíneo. Embora se esperasse um aumento na temperatura do membro inferior em todas as frequências estudadas, pois a VCI é considerada uma modalidade de exercício, foi observada uma diminuição da temperatura do membro inferior durante os 15 minutos de exposição.

Ainda, a temperatura continuou a baixar para todas as frequências, 10 minutos pós-vibração. A recuperação começou a ocorrer ao final dos 10 minutos pós-vibração e isto é particularmente claro aos 30 Hz. Este resultado é consistente com investigações anteriores (YE et al., 2012; BOVENZI; LINDSELL; GRIFFIN, 1998; YANG et al., 1990) induzindo vibrações nos segmentos mão-braço. Em 12 participantes saudáveis, Olsen (1993) estudou a resposta vasoconstritora induzida pelo frio nas artérias digitais expostas a vibração unilateral em uma frequência de 31,5 Hz. Observou-se que 30 minutos de exposição a tal vibração causou um aumento significativo na capacidade de resposta arterial induzida pelo frio em ambos os dedos vibrado e não-vibrado que manteve-se até 60 minutos após o final da exposição à vibração (OLSEN, 1993). Alguns autores (YE et al., 2012; BOVENZI; LINDSELL; GRIFFIN, 2000) concluem que quanto maiores forem as amplitudes de vibração, maior a vasoconstrição será em ambos os dedos vibrado e não vibrado durante a recuperação, o que é consistente com resposta do sistema nervoso simpático.

A vasoconstrição induzida por vibração pode estar relacionada com mecanismos de ação locais e centrais. Concentrações aumentadas do vasopeptideo endotelina-1 (ET1) pode sensibilizar a parede do vaso sanguíneo com efeitos vasoconstritores através de substâncias liberadas pelos nervos adrenérgicos (YANG et al., 1990). Revisões de literatura relatam que a ativação da via somatossimpática pelos vibrorreceptores de *Pacini* como mecanismo reflexo pode produzir ativação neural de vasoconstrição (STOYNEVA, 2003; SAKAKIBARA; YAMADA, 1995). A diminuição significativa da sensibilidade de toque-pressão e vibratória encontrados na presente tese evidencia a ativação da via somatossimpática através de vibração. O principal mecanismo fisiopatológico é provavelmente um desequilíbrio entre ET1 e peptídeo relacionado ao gene da calcitonina (CGRP), um vasodilatador poderoso presente em nervos perivasculares cutâneas digitais (NOËL, 2000).

No entanto, não podemos excluir a possibilidade de que os mecanismos locais de vasoconstrição estão agindo. Uma vez que o potencial de repouso de músculo liso é determinado por grandes quantidades de K^+ (NELSON et al., 1990), a despolarização induzida por estiramento pode ser explicada através da ativação dos canais de íons mecanossensíveis que promovem influxo de Na^+ ou de Ca^{++}, efluxo de Cl^- ou inibição do efluxo de K^+ (DAVIS; HILL, 1999). O aumento intracelular [Ca^{++}], por meio do IP3 (inositol-3-fosfato), gera fechamento dos canais do retículo sarcoplasmático, o músculo liso é sensibilizado ao cálcio, a miosina-cinase de cadeia leve é ativada, a fosforilação dos reguladores das cadeias leves de miosina é aumentada e, então, a contração é desencadeada (CLARK; PYNE-GEITHMAN, 2005; WOODRUM; BROPHY, 2001; LAHER; BEVAN, 1987). Desta forma, a VCI poderia atuar com mecanismo vasoconstritor local e central e por isso a diminuição de temperatura de membros inferiores durante a após a VCI.

Na investigação da variável “dor”, um terceiro estudo foi proposto, tendo em vista que as vias e os receptores de sensibilidade cutânea tátil diferem daqueles relacionados com a sensibilidade dolorosa. Um modelo de dor crônica com ratos Wistar foi realizado e os animais foram tratados com VCI, esteira e a combinação de esteira com VCI. Como principais resultados do terceiro estudo, ratos Wistar submetidos a um modelo de dor crônica, os grupos tratados com VCI mostraram redução significativa da sensibilidade de toque-pressão após todas as sessões em comparação aos demais grupos. Efeitos analgésicos através do tempo de latência medidos com o hot plate foram encontrados após o terceiro dia de tratamento com 5 minutos de exposição por dia à VCI.

Atividades que afetam o disparo nas fibras de grande calibre, tais como estímulos vibratórios, não só modificam a percepção da dor, mas também podem atenuá-la (MÜNSTER et al., 2012; PRAGER, 2010; PARÉ et al., 2001). Uma hipótese comumente usada para explicar a ação de vibração é baseada na "teoria das comportas de dor" de Melzack e Wall (1965). Para os autores, o corno dorsal da medula espinhal, é responsável por regular a transmissão de sinais neurais aferentes aos centros superiores, onde a dor é interpretada como é. As fibras Aβ e fibras C formam sinapses nas lâminas I e V do corno dorsal da medula espinhal, formam parte do feixe espinotalâmico e de lá seguem para os centros superiores (PRAGER, 2010). Uma explicação possível para a redução da dor a partir da vibração pode ser através da ativação de forma sincronizada de um grande número de fibras Aα / Aβ e, portanto, estimulam a coluna dorsal da medula espinhal. A ativação através da vibração das fibras aferentes de grande diâmetro Aβ (não-nociceptivas), aos quais possuem sinapses dos interneurônios inibitórios (gabaérgicos ou colinérgicos), ocorrem no corno dorsal da medula. Estes interneurônios liberam neurotransmissores inibitórios (por exemplo, GABA), reduzindo assim a excitabilidade de neurônios espinhais de segunda ordem, de modo que a subsequente entrada nas fibras delta e C é atenuada (MÜNSTER et al., 2012; PRAGER, 2010).

Assim, a estimulação por meio da vibração poderia ser utilizada para reduzir a percepção da dor (RIBOT-CISCAR et al., 1996; NISHIYAMA; WATANABE, 1981) de uma maneira semelhante que a estimulação elétrica nervosa transcutânea (TENS) é utilizada para a redução da dor (GUIEU; TARDY-GERVET; ROLL, 1991). Somando-se a essas informações, Paré e cols. (2001) demonstraram que em mamíferos, corpúsculos de Meissner contêm além das fibras mecanorreceptivas, fibras-C, tanto peptidérgicas e não-peptidérgicas que provavelmente estão envolvidos na nocicepção. Estudos com vibração passiva (GUIEU; TARDY-GERVET; ROLL, 1991; LUNDEBERG; NORDEMAR; OTTOSON, 1984) observaram redução da dor em cerca de 70% dos pacientes com dor musculoesquelética aguda e crônica. Eles aplicaram a vibração a frequências elevadas diretamente no local onde os pacientes percebiam a dor. Curiosamente, Guieu e cols. (1991) combinaram TENS com vibração e observaram que poderiam aumentar os efeitos de redução de dor. Desta forma, acredita-se que a

VCI pode ser eficaz na alteração temporária de condições dolorosas, entretanto, essa variável de estudo carece de maiores investigações.

Após a investigação da ação da VCI nos receptores cutâneos da pele, equilíbrio e outras variáveis fisiológicas, o último estudo procurou relacionar dados quantitativos advindos da acelerometria (com medições na cabeça, quadril e tíbia) combinados com dados qualitativos provenientes da escala de Borg dos 65 adultos-jovens avaliados. Os dados analisados mostraram que os índices de percepção de severidade da vibração medidos através da escala de Borg corresponderam bem com os dados quantitativos da acelerometria e assim os parâmetros do equipamento podem ser escolhidos com base na sensação subjetiva proveniente da escala de Borg. Os participantes foram questionados sobre qual região do corpo detectavam mais a vibração e se sentiam desconforto. Se o desconforto era presente, questionava-se qual a região específica do corpo estava ocorrendo.

Os níveis de desconforto percebidos através do equipamento podem estar relacionados com a frequência de ressonância das diferentes partes do corpo e devem ser consideradas uma fonte possível de efeitos secundários indesejáveis da utilização da VCI (RUBIN et al., 2003). Os resultados desta tese mostram que a percepção das áreas que mais vibram no corpo e regiões de desconforto através da vibração podem diferir. No entanto, para as regiões da cabeça, lombar, pernas e pé as frequências de respostas "sentir mais" e "desconforto" estão próximas ou coincidentes.

Como esperado, as maiores cargas de aceleração foram encontradas na tíbia com valores máximos entre os 19 e 25 Hz. Para o quadril, a maior carga de aceleração foi de 9 Hz e para a cabeça, 13 Hz. Um estudo de Kiiski e cols. (2008) mediu 4 indivíduos em uma plataforma de VCI em diferentes frequências e amplitudes. Em geral, para uma plataforma de VCI, operando em modo vertical, eles descobriram amplificação substancial do pico de aceleração entre 10-25 Hz para a região do joelho, 10-20 Hz para o quadril, 10-40 Hz para o tornozelo e 10 Hz para a coluna lombar. Abercromby e cols. (2007) verificaram que a transmissão da energia mecânica de vibração a 30 Hz e com 4 mm de amplitude foi de 71% a 189% maior durante o modo de vibração vertical, em relação à vibração de rotação para a parte superior do corpo e da cabeça. Isto significa que as vibrações de rotação, tal como usado neste estudo, é provável que sejam menos prejudiciais em comparação com as vibrações verticais. No entanto, quanto mais distante o posicionamento dos pés dos eixos de equipamentos (amplitudes podem atingir 14 mm em algumas máquinas) as cargas mecânicas sobre o corpo aumentam substancialmente.

Em geral, a percepção subjetiva magnitude de vibração, utilizando a escala de Borg, seguiu uma tendência semelhante à dos valores integrais de aceleração, conforme mensurados na parte inferior da perna, quadril e cabeça. Isso mostra que as pessoas são capazes de estimar a magnitude das vibrações em várias partes do seu corpo. Assim, se sugere que as configurações da máquina devem ser escolhidas com base na sensação do sujeito (Escala de Borg).

5. LIMITAÇÕES

O primeiro estudo traz como limitações:

- A sensibilidade de toque e pressão deveria ter sido mensurada a intervalos mais curtos, pois de forma geral, voltou ao normal em um intervalo menor que uma hora.

- A sensibilidade dolorosa não foi verificada

O segundo estudo traz como limitações:

- Em virtude de problemas técnicos com o salvamento dos dados, apenas 17 sujeitos foram contabilizados nas análises de equilíbrio;

- Ainda que tenham sido observadas alterações significativas na temperatura de membros inferiores durante e após a vibração de corpo interiro, não foram observadas alterações nas respostas fisiológicas como FC e PA. Isto pode ser um indício que os métodos escolhidos para avaliação destas variáveis fisiológicas não tenham sido suficientemente precisos.

-Não foram mensuradas as concentrações do vasopeptídeo ET1 para comprovar os efeitos vasoconstritores relacionados ao sistema nervoso autônomo e também sistema cardiovascular.

O terceiro estudo traz como limitações:

- Não foram realizados até o presente momento análises imunoistoquímicas e histológicas do material biológico colhidos dos animais para correlacionar com os dados comportamentais

- Através do modelo aplicado, não foi possível predizer quanto tempo os animais precisaram para retornar aos valores basais de sensibilidade cutânea de toque-pressão e dolorosa.

O quarto estudo traz como limitações:

- Mais regiões do corpo, como tronco e membros superiores, deveriam ter sido avaliadas com a acelerometria, para que fosse possível realizar uma comparação mais ampla e precisa com os dados subjetivos provenientes da escala de Borg.

6. CONSIDERAÇÕES FINAIS

As descargas aferentes dos mecanorreceptores de rápida de adaptação são fortemente afetadas pela vibração. Sensibilidades de toque-pressão e vibração são prejudicadas após uma sessão com VCI. Após uma única exposição de 10 minutos com VCI, o tempo necessário para recuperar a sensibilidade tátil nos pés dos participantes saudáveis foi entre 2 e 3 horas.

Em intervenções terapêuticas, quando a hipersensibilidade em membros inferiores afeta negativamente uma sessão de exercício, pois a dor atua como fator limitante impedindo que o paciente realize adequadamente o movimento de reabilitação, uma redução da sensibilidade tátil e dolorosa poderia ser útil. Assim, um modelo de dor crônica em ratos Wistar foi aplicado para verificar os efeitos da VCI também sobre a sensibilidade dolorosa.

Em um modelo de dor crônica com ratos Wistar tratados com VCI e ou exercício de baixa intensidade (caminhada em esteira), durante as 10 sessões de VCI aplicadas, a sensibilidade tátil foi reduzida significativamente para os grupos com VCI. Entretanto, no intervalo até a próxima sessão, a sensibilidade voltava aos valores basais. Não se sabe especificar quanto tempo os animais precisaram para retornar aos valores basais de sensibilidade tátil. Redução da sensibilidade dolorosa, avaliados 40 minutos após a exposição à plataforma vibratória, através dos valores de latência do *hot plate* foram encontrados após a terceira sessão com VCI, 5 minutos de exposição nos primeiros 5 dias e 10 minutos de exposição nos dias subsequentes, principalmente para os grupos com VCI. Concluímos que existe uma perspectiva para redução da dor, todavia estudos mais conclusivos através de análises imunoistoquímicas do material coletado devem ser realizados para confirmação desta questão levantada pelo estudo.

Como o sistema somatossensorial interage enviando informações aos centros superiores sobre postura e equilíbrio, e a VCI reduz significativamente a sensibilidade tátil, procurou-se investigar seus efeitos sobre o equilíbrio postural e outras variáveis fisiológicas. Foi encontrado um decréscimo no equilíbrio de sujeitos normais para as maiores frequências de exposição avaliadas (40 e 44 Hz) e modo de vibração vertical, 20 minutos após a exposição à VCI.

Com relação às demais variáveis fisiológicas avaliadas (pressão arterial, frequência cardíaca, frequência respiratória, temperatura axilar), a VCI não incrementa o sistema cardiorrespiratório. A temperatura de membros inferiores avaliada com termografia diminuiu para as 4 frequências avaliadas (30, 35, 40 e 44 Hz) e 10 minutos pós-vibração, provavelmente em virtude da vasoconstrição gerada pela vibração.

O conhecimento das configurações corretas para os diferentes parâmetros das plataformas vibratórias é importante para que uma apropriada abordagem tanto na reabilitação quanto no desempenho esportivo sejam utilizados. Assim se procurou um método foi elaborado cruzando dados quantitativos via acelerometria e qualitativos através da escala de Borg. De forma geral, a estimação subjetiva da magnitude da vibração correspondeu com os valores obtidos com a acelerometria; isso significa que os parâmetros das plataformas vibratórias podem ser selecionados de acordo com a percepção subjetiva dos indivíduos através do uso da escala de Borg, conforme proposto neste estudo. Estudos futuros pretendem avaliar esta metodologia em diferentes condições dolorosas de indivíduos que não possuam contra-indicações ao uso do equipamento, como ferramenta auxiliar no processo de reabilitação.

REFERÊNCIAS BIBLIOGRÁFICAS

ABERCROMBY, A. F. J. et al. Vibration exposure and biodynamic responses during whole-body vibration training. **Medicine and science in sports and exercise**, v. 39, n. 10, p. 1794–800, out. 2007.

ANG, E. T. et al. Neuroprotection associated with running: is it a result of increased endogenous neurotrophic factors? **Neuroscience**, v. 118, n. 2, p. 335–45, jan. 2003.

AOKI, Y. et al. Expression and co-expression of VR1, CGRP, and IB4-binding glycoprotein in dorsal root ganglion neurons in rats: differences between the disc afferents and the cutaneous afferents. **Spine**, v. 30, n. 13, p. 1496–500, 1 jul. 2005.

BASBAUM, A. I.; JESSEL, T. M. The Perception of Pain. In: KANDEL, E. R.; SCHWARTZ, J. H.; JESSELL, T. M. (Eds.). **Principles of Neural Science**. 4. ed. New York: McGraw-Hill, 2000. p. 472–491.

BEAR, M. F.; CONNORS, B. W.; PARADISO, M. A. **Neurociências - desvendando o sistema nervoso.** 2. ed. ed. Porto Alegre: Artmed, 2002. p. 855

BELAVÝ, D. L. et al. Resistive simulated weightbearing exercise with whole body vibration reduces lumbar spine deconditioning in bed-rest. **Spine**, v. 33, n. 5, p. E121–31, 1 mar. 2008.

BEMENT, M. K. H.; SLUKA, K. A. Low-intensity exercise reverses chronic muscle pain in the rat in a naloxone-dependent manner. **Archives of physical medicine and rehabilitation**, v. 86, n. 9, p. 1736–40, set. 2005.

BOGAERTS, A. et al. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. **The journals of gerontology. Series A, Biological sciences and medical sciences**, v. 62, n. 6, p. 630–5, jun. 2007.

BOISSONNAULT, W. G.; DONATELLI, R. A. The influence of hallux extension on the foot during ambulation. **The Journal of orthopaedic and sports physical therapy**, v. 5, n. 5, p. 240–2, jan. 1984.

BOVENZI, M. et al. Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration. **Ergonomics**, v. 34, n. 5, p. 547–62, maio 1991.

BOVENZI, M.; LINDSELL, C.; GRIFFIN, M. Acute vascular responses to the frequency of vibration transmitted to the hand. **Occupational and Environmental Medicine**, v. 57, n. 6, p. 422–430, 1 jun. 2000.

BOVENZI, M.; LINDSELL, C.; GRIFFIN, M. J. Duration of acute exposures to vibration and finger circulation. **Scandinavian Journal of Work, Environment & Health**, v. 24, n. 2, p. 130–137, abr. 1998.

BRATTBERG, G.; PARKERB, M. G.; THORSLUNDB, M. Research Reports The prevalence of pain among the oldest old in Sweden. v. 67, p. 29–34, 1996.

BRAUER, R. L. **Safety and health for engineers**. 2nd. ed. New Jersey: Wiley-Interscience, 2006.

BREIVIK, H. et al. Survey of chronic pain in Europe : Prevalence , impact on daily life , and treatment. v. 10, p. 287–333, 2006.

BRUYERE, O. et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. **Archives of physical medicine and rehabilitation**, v. 86, n. 2, p. 303–7, mar. 2005.

CARDINALE, M.; LIM, J. The acute effects of two different whole body vibration frequencies on vertical jump performance. **Medicine Sport (Roma)**, v. 56, n. 4, p. 287–292, 2003.

CARR, P. A.; YAMAMOTO, T.; NAGY, J. I. Calcitonin gene-related peptide in primary afferent neurons of rat: Co-existence with fluoride-resistant acid phosphatase and depletion by neonatal capsaicin. **Neuroscience**, v. 36, n. 3, p. 751–760, jan. 1990.

CARTER, R. B. Differentiating analgesic and non-analgesic drug activities on rat hot plate: effect of behavioral endpoint. **Pain**, v. 47, n. 2, p. 211–20, nov. 1991.

CASTILLO, A. B. et al. Low-amplitude, broad-frequency vibration effects on cortical bone formation in mice. **Bone**, v. 39, n. 5, p. 1087–96, nov. 2006.

CHAFIN, D. B.; ANDERSSON, G. B. J.; MARTIN, B. J. **Occupational Biomechanics**. 4th. ed. New York: John Wiley & Sons, 2006.

CHEN, Y. C. et al. Physical training modifies the age-related decrease of GAP-43 and synaptophysin in the hippocampal formation in C57BL/6J mouse. **Brain research**, v. 806, n. 2, p. 238–45, 28 set. 1998.

CHEUNG, J. T.-M.; ZHANG, M.; CHOW, D. H.-K. Biomechanical responses of the intervertebral joints to static and vibrational loading: a finite element study. **Clinical biomechanics (Bristol, Avon)**, v. 18, n. 9, p. 790–9, nov. 2003.

CLARK, J. F.; PYNE-GEITHMAN, G. Vascular smooth muscle function: The physiology and pathology of vasoconstriction. **Pathophysiology : the official journal of the International Society for Pathophysiology / ISP**, v. 12, n. 1, p. 35–45, jul. 2005.

CUNHA, T. M. et al. An electronic pressure-meter nociception paw test for mice. **Brazilian journal of medical and biological research = Revista brasileira de pesquisas médicas e biológicas / Sociedade Brasileira de Biofísica ... [et al.]**, v. 37, n. 3, p. 401–7, mar. 2004.

DAVIS, M. J.; HILL, M. A. Signaling mechanisms underlying the vascular myogenic response. **Physiological reviews**, v. 79, n. 2, p. 387–423, abr. 1999.

DICKIN, D. C. et al. Changes in postural sway frequency and complexity in altered sensory environments following whole body vibrations. **Human movement science**, v. 31, n. 5, p. 1238–1246, out. 2012.

DING, Y. et al. Functional improvement after motor training is correlated with synaptic plasticity in rat thalamus. **Neurological research**, v. 24, n. 8, p. 829–36, dez. 2002.

DING, Y. et al. MOTOR BALANCE AND COORDINATION TRAINING ENHANCES FUNCTIONAL OUTCOME IN RAT WITH TRANSIENT MIDDLE CEREBRAL ARTERY OCCLUSION. v. 123, p. 667–674, 2004a.

DING, Y. et al. Exercise pre-conditioning reduces brain damage in ischemic rats that may be associated with regional angiogenesis and cellular overexpression of neurotrophin. **Neuroscience**, v. 124, n. 3, p. 583–91, jan. 2004b.

EILS, E. et al. Modified pressure distribution patterns in walking following reduction of plantar sensation. **Journal of biomechanics**, v. 35, n. 10, p. 1307–13, out. 2002.

ENOKA, R. M. **Bases Neuromecânicas da Cinesiologia**. 2. ed. São Paulo: Manole, 2000. p. 450

ESPEJO, E. F.; MIR, D. Structure of the rat ' s behaviour in the hot plate test. v. 56, p. 171–176, 1993.

FLIEGER, J. et al. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. **Calcified tissue international**, v. 63, n. 6, p. 510–4, dez. 1998.

FLOYD, W. N.; BRODERSON, A. B.; GOODNO, J. F. Effect of whole-body vibration on peripheral nerve conduction time in the rhesus monkey. **Aerospace medicine**, v. 44, n. 3, p. 281–5, mar. 1973.

GILMAN, A. G. **Goodman and Gilman's The Pharmacological Basis of Therapeutics**. New York: McGraw-Hill, 1993.

GOWANS, S. E.; DEHUECK, A. Effectiveness of exercise in management of fibromyalgia. **Current opinion in rheumatology**, v. 16, n. 2, p. 138–42, mar. 2004.

GUIEU, R.; TARDY-GERVET, M. F.; ROLL, J. P. Analgesic effects of vibration and transcutaneous electrical nerve stimulation applied separately and simultaneously to patients with chronic pain. **The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques**, v. 18, n. 2, p. 113–9, maio 1991.

GUYTON, A. C. **Fisiologia Humana**. 6. ed. Rio de Janeiro: Guanabara Koogan, 1988. p. 564

HAAS, C. T. **Vibratory Stimulation and Stochastic Resonance Therapy: Results from studies in Parkinson's disease and spinal cord injury.**Technologies of Globalization Congress Darmstadt. **Anais**...Germany: 2008

HARADA, N.; MAHBUB, M. H. Diagnosis of vascular injuries caused by hand-transmitted vibration. **International archives of occupational and environmental health**, v. 81, n. 5, p. 507–18, abr. 2008.

HELFER, J. L. et al. The effects of exercise on adolescent hippocampal neurogenesis in a rat model of binge alcohol exposure during the brain growth spurt. **Brain research**, v. 1294, p. 1–11, 19 out. 2009.

HENDIANI, J. A. et al. Mechanical sensation and pain thresholds in patients with chronic arthropathies. **The journal of pain : official journal of the American Pain Society**, v. 4, n. 4, p. 203–11, maio 2003.

HENNIG, E. M.; ROSENBAUM, D. Pressure distribution patterns under the feet of children in comparison with adults. **Foot & ankle**, v. 11, n. 5, p. 306–11, abr. 1991.

HENNIG, E. M.; STERZING, T. Sensitivity mapping of the human foot: thresholds at 30 skin locations. **Foot ankle international American Orthopaedic Foot and Ankle Society and Swiss Foot and Ankle Society**, v. 30, n. 10, p. 986–991, 2009a.

HENNIG, E.; STERZING, T. Sensitivity mapping of the human foot: thresholds at 30 skin locations. **Foot & Ankle International**, v. 30, n. 10, p. 986–991, 2009b.

HOOD, V. L. et al. Effect of systemic pH on pHi and lactic acid generation in exhaustive forearm exercise. **The American journal of physiology**, v. 255, n. 3 Pt 2, p. F479–85, set. 1988.

INGLIS, J. T. et al. The importance of somatosensory information in triggering and scaling automatic postural responses in humans. **Experimental brain research**, v. 101, n. 1, p. 159–64, jan. 1994.

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. **ISO 2631- 1:1:1997 Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body vibration,. Part 1, General Requirements.** Geneva: [s.n.].

ISHITAKE, T. et al. EVALUATION OF FREQUENCY WEIGHTING (ISO 2631-1) FOR ACUTE EFFECTS OF WHOLE-BODY VIBRATION ON GASTRIC MOTILITY. **Journal of Sound and Vibration**, v. 253, n. 1, p. 31–36, maio 2002.

ISSBERNER, U.; REEH, P. W.; STEEN, K. H. Pain due to tissue acidosis: a mechanism for inflammatory and ischemic myalgia? **Neuroscience letters**, v. 208, n. 3, p. 191–4, 26 abr. 1996.

ITOH, T. et al. Exercise inhibits neuronal apoptosis and improves cerebral function following rat traumatic brain injury. **Journal of neural transmission (Vienna, Austria : 1996)**, v. 118, n. 9, p. 1263–72, set. 2011.

IWAMOTO, J. et al. Effect of whole-body vibration exercise on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. **Aging clinical and experimental research**, v. 17, n. 2, p. 157–63, abr. 2005.

JUDEX, S.; DONAHUE, L.-R.; RUBIN, C. Genetic predisposition to low bone mass is paralleled by an enhanced sensitivity to signals anabolic to the skeleton. **FASEB journal : official publication of the Federation of American Societies for Experimental Biology**, v. 16, n. 10, p. 1280–2, ago. 2002.

KAVOUNOUDIAS, A.; ROLL, R.; ROLL, J. P. The plantar sole is a “dynamometric map” for human balance control. **Neuroreport**, v. 9, n. 14, p. 3247–52, 5 out. 1998.

KIHLBERG, S.; HAGBERG, M. Hand-arm symptoms related to impact and nonimpact hand-held power tools. **International archives of occupational and environmental health**, v. 69, n. 4, p. 282–8, jan. 1997.

KIISKI, J.; HEINONEN, A.; KANNUS, P. Transmission of Vertical Whole Body Vibration to the Human Body. v. 23, n. 8, p. 1318–1325, 2008.

KIM, S.-E. et al. Treadmill exercise prevents aging-induced failure of memory through an increase in neurogenesis and suppression of apoptosis in rat hippocampus. **Experimental gerontology**, v. 45, n. 5, p. 357–65, maio 2010.

KIM, S.-H. et al. Treadmill exercise increases cell proliferation without altering of apoptosis in dentate gyrus of Sprague-Dawley rats. **Life sciences**, v. 71, n. 11, p. 1331–40, 2 ago. 2002.

KROEMER, K. H. E.; GRANDJEAN, E. **Fitting the task to the human. A textbook of occupational ergonomics**. 5. ed. London : Taylor & Francis, 1997.

LAHER, I.; BEVAN, J. A. Protein kinase C activation selectively augments a stretch-induced, calcium-dependent tone in vascular smooth muscle. **The Journal of pharmacology and experimental therapeutics**, v. 242, n. 2, p. 566–572, ago. 1987.

LAVICH, T. R. et al. A novel hot-plate test sensitive to hyperalgesic stimuli and non-opioid analgesics. **Brazilian Journal of Medical and Biological Research**, v. 38, n. 3, p. 445–451, 2005.

LE BARS, D.; GOZARIU, M.; CADDEN, S. W. Animal models of nociception. **Pharmacological reviews**, v. 53, n. 4, p. 597–652, dez. 2001.

LEE, H.-Y.; CHERNG, R.-J.; LIN, C.-H. Development of a virtual reality environment for somatosensory and perceptual stimulation in the balance assessment of children. **Computers in biology and medicine**, v. 34, n. 8, p. 719–33, dez. 2004.

LUNDEBERG, T. Long-term results of vibratory stimulation as a pain relieving measure for chronic pain. **Pain**, v. 20, n. 1, p. 13–23, set. 1984.

LUNDEBERG, T.; NORDEMAR, R.; OTTOSON, D. Pain alleviation by vibratory stimulation. **Pain**, v. 20, n. 1, p. 25–44, set. 1984.

MAHBUB, M.; HARADA, N. Review of different quantification methods for the diagnosis of digital vascular abnormalities in hand-arm vibration syndrome. **Journal of occupational health**, v. 53, n. 4, p. 241–9, jan. 2011.

MAURER, C. et al. Human balance control during cutaneous stimulation of the plantar soles. **Neuroscience letters**, v. 302, n. 1, p. 45–8, 13 abr. 2001.

MCGILL, M. et al. Possible sources of discrepancies in the use of the Semmes-Weinstein monofilament. Impact on prevalence of insensate foot and workload requirements. **Diabetes care**, v. 22, n. 4, p. 598–602, abr. 1999.

MCMAHON, S. B.; KOLTZENBURG, M. **Wall and Melzack's textbook of pain**. 5. ed. Philadelphia: Elsevier/Churchill Livingstone, 2006.

MELZACK, R.; WALL, P. D. Pain mechanisms: a new theory. **Science**, v. 150, n. 3699, p. 971–979, 1965.

MEYER, P. F.; ODDSSON, L. I. E.; DE LUCA, C. J. The role of plantar cutaneous sensation in unperturbed stance. **Experimental brain research**, v. 156, n. 4, p. 505–12, jun. 2004.

MILANI, T. L.; KIMMESKAMP, S. **Relationship of perception vs. the measurement of plantar pressures –a neurosensory approach** (Nigg. B. M., W. Herzog, Eds.)WORLD BIOMECHANICS CONGRESS IV. **Anais**...Calgary: ISBS, 2002

MIYAZAKI, Y. Adverse effects of whole-body vibration on gastric motility. **The Kurume medical journal**, v. 47, n. 1, p. 79–86, jan. 2000.

MØLLER, A. T.; JENSEN, T. S. Pain and genes: Genetic contribution to pain variability, chronic pain and analgesic responses. **European Journal of Pain Supplements**, v. 4, n. S4, p. 197–201, 6 nov. 2010.

MOUNTCASTLE, R. H.; LAMOTTE, G. C. Detection thresholds for stimuli in humans and monkeys : comparison with thresholds events in mechanoreceptive afferent nerve fibers innervating the monkey hand. **Journal of Neurophysiology**, v. 35, n. 1, p. 122–136, 1972.

MÜNDERMANN, A.; STEFANYSHYN, D. J.; NIGG, B. M. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. **Medicine and science in sports and exercise**, v. 33, n. 11, p. 1939–45, nov. 2001.

MÜNSTER, T. et al. Modulation of somatosensory profiles by spinal cord stimulation in primary Raynaud's syndrome. **Pain practice : the official journal of World Institute of Pain**, v. 12, n. 6, p. 469–75, jul. 2012.

NELSON, M. T. et al. Calcium channels, potassium channels, and voltage dependence of arterial smooth muscle tone. **The American journal of physiology**, v. 259, n. 1 Pt 1, p. C3–18, jul. 1990.

NISHIYAMA, K.; WATANABE, S. Temporary threshold shift of vibratory sensation after clasping a vibrating handle. **International archives of occupational and environmental health**, v. 49, n. 1, p. 21–33, jan. 1981.

NOËL, B. Pathophysiology and classification of the vibration white finger. **International archives of occupational and environmental health**, v. 73, n. 3, p. 150–5, 1 abr. 2000.

NURSE, M. A.; NIGG, B. M. Quantifying a relationship between tactile and vibration sensitivity of the human foot with plantar pressure distributions during gait. **Clinical biomechanics (Bristol, Avon)**, v. 14, n. 9, p. 667–72, nov. 1999.

NURSE, M. A.; NIGG, B. M. The effect of changes in foot sensation on plantar pressure and muscle activity. **Clinical biomechanics (Bristol, Avon)**, v. 16, n. 9, p. 719–27, nov. 2001.

OLSEN, N. Vibration aftereffects on vasoconstrictor response to cold in the normal finger. **European journal of applied physiology and occupational physiology**, v. 66, n. 3, p. 246–8, jan. 1993.

PARÉ, M. et al. The Meissner corpuscle revised: a multiafferented mechanoreceptor with nociceptor immunochemical properties. **The Journal of neuroscience : the official journal of the Society for Neuroscience**, v. 21, n. 18, p. 7236–46, 15 set. 2001.

PAVEL, J. et al. The impact of short-lasting repeated vibrations on retrograde axonal transport, the expression of CGRP and parvalbumin in lower lumbar dorsal root ganglia. **Brain research**, v. 1396, p. 1–10, 17 jun. 2011.

PERRIN, P.; LESTIENNE, F. **Mecanismos do equilíbrio humano: Exploração funcional, aplicação ao esporte e à reeducação**. São Paulo: LIDA, 1998.

PERRY, S. D. Evaluation of age-related plantar-surface insensitivity and onset age of advanced insensitivity in older adults using vibratory and touch sensation tests. **Neuroscience letters**, v. 392, n. 1-2, p. 62–7, 9 jan. 2006.

PERRY, S. D.; MCILROY, W. E.; MAKI, B. E. The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. **Brain research**, v. 877, n. 2, p. 401–6, 22 set. 2000.

POLLOCK, R. D. et al. The effects of whole body vibration on balance, joint position sense and cutaneous sensation. **European journal of applied physiology**, v. 111, n. 12, p. 3069–77, dez. 2011.

PRAGER, J. P. What does the mechanism of spinal cord stimulation tell us about complex regional pain syndrome? **Pain medicine (Malden, Mass.)**, v. 11, n. 8, p. 1278–83, ago. 2010.

PRÄTORIUS, B.; KIMMESKAMP, S.; MILANI, T. L. The sensitivity of the sole of the foot in patients with Morbus Parkinson. **Neuroscience letters**, v. 346, n. 3, p. 173–6, 7 ago. 2003.

RANSON, S. W. The Anatomy of the Autonomic Nervous System With Special Reference to the Innervation of the Skeletal Muscles and Blood Vessels. **Annals of Internal Medicine**, v. 6, n. 8, p. 1013–1021, 1 fev. 1933.

RASMUSSEN, G. Human Body Vibration Exposure and its Measurement. **The Journal of the Acoustical Society of America**, v. 73, n. 6, p. 22–29, 1983.

REEH, P. W.; STEEN, K. H. Tissue acidosis in nociception and pain. **Progress in brain research**, v. 113, p. 143–51, jan. 1996.

RIBOT-CISCAR, E. et al. Alteration of human cutaneous afferent discharges as the result of long-lasting vibration. **Journal of applied physiology (Bethesda, Md. : 1985)**, v. 80, n. 5, p. 1708–1715, maio 1996.

RIBOT-CISCAR, E.; VEDEL, J. P.; ROLL, J. P. Vibration sensitivity of slowly and rapidly adapting cutaneous mechanoreceptors in the human foot and leg. **Neuroscience letters**, v. 104, n. 1-2, p. 130–5, 25 set. 1989.

RITTWEGER, J. et al. Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. **Spine**, v. 27, n. 17, p. 1829–34, 1 set. 2002.

RITTWEGER, J.; BELLER, G.; FELSENBERG, D. Acute physiological effects of exhaustive whole-body vibration exercise in man. **Clinical physiology (Oxford, England)**, v. 20, n. 2, p. 134–142, mar. 2000.

ROELANTS, M.; DELECLUSE, C.; VERSCHUEREN, S. M. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. **Journal of the American Geriatrics Society**, v. 52, n. 6, p. 901–8, jun. 2004.

RUBIN, C. et al. Anabolism. Low mechanical signals strengthen long bones. **Nature**, v. 412, n. 6847, p. 603–4, 9 ago. 2001.

RUBIN, C. et al. 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**, v. 28, n. 23, p. 2621–2627, 1 dez. 2003.

RUBINACCI, A. et al. Ovariectomy sensitizes rat cortical bone to whole-body vibration. **Calcified tissue international**, v. 82, n. 4, p. 316–26, abr. 2008.

SAKAKIBARA, H.; YAMADA, S. Vibration syndrome and autonomic nervous system. **Central European journal of public health**, v. 3 Suppl, p. 11–4, jan. 1995.

SCHLEE, G.; RECKMANN, D.; MILANI, T. L. Whole body vibration training reduces plantar foot sensitivity but improves balance control of healthy subjects. **Neuroscience letters**, v. 506, n. 1, p. 70–3, 6 jan. 2012.

SLUKA, K. A.; KALRA, A.; MOORE, S. A. Unilateral intramuscular injections of acidic saline produce a bilateral, long-lasting hyperalgesia. **Muscle & nerve**, v. 24, n. 1, p. 37–46, jan. 2001.

SONZA, A. et al. Human cutaneous sensors on the sole of the foot: altered sensitivity and recovery time after whole body vibration. **Neuroscience letters**, v. 533, p. 81–5, 15 jan. 2013.

SORA, I. et al. Opiate receptor knockout mice define receptor roles in endogenous nociceptive responses and morphine-induced analgesia. **Neurobiology**, v. 94, p. 1544–1549, 1997.

STOYNEVA, Z. et al. Current pathophysiological views on vibration-induced Raynaud's phenomenon. **Cardiovascular research**, v. 57, n. 3, p. 615–24, mar. 2003.

STOYNEVA, Z. Current pathophysiological views on vibration-induced Raynaud's phenomenon. **Cardiovascular Research**, v. 57, n. 3, p. 615–624, 1 mar. 2003.

TEIXEIRA, M. J.; SIQUEIRA, J. T. T. Semiologia da dor. In: NETO, O. A. et al. (Eds.). **Dor: Princípios e prática**. 2. ed. Porto Alegre: Artmed, 2009. p. 1438.

THOMPSON, C.; BÉLANGER, M.; FUNG, J. Effects of plantar cutaneo-muscular and tendon vibration on posture and balance during quiet and perturbed stance. **Human movement science**, v. 30, n. 2, p. 153–171, abr. 2011.

TORVINEN, S. et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomize controlled study. **Journal of Bone and Mineral Research**, v. 18, n. 5, p. 876–884, 2003.

TREMBLAY, F. et al. Postural stabilization from fingertip contact II. Relationships between age, tactile sensibility and magnitude of contact forces. **Experimental brain research**, v. 164, n. 2, p. 155–64, jul. 2005.

VAN TULDER, M. W.; KOES, B. W.; BOUTER, L. M. Conservative treatment of acute and chronic nonspecific low back pain. A systematic review of randomized controlled trials of the most common interventions. **Spine**, v. 22, n. 18, p. 2128–56, 15 set. 1997.

VEGA, J. A. et al. The Meissner and Pacinian sensory corpuscles revisited new data from the last decade. **Microscopy research and technique**, v. 72, n. 4, p. 299–309, abr. 2009.

VERGE, V. M. K. et al. Histochemical characterization of sensory neurons with high-affinity receptors for nerve growth factor. **Journal of Neurocytology**, v. 18, n. 5, p. 583–591, out. 1989.

VERSCHUEREN, S. M. P. et al. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. **Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research**, v. 19, n. 3, p. 352–9, mar. 2004.

WANG, R. Y.; YANG, Y. R.; YU, S. M. Protective effects of treadmill training on infarction in rats. **Brain research**, v. 922, n. 1, p. 140–3, 13 dez. 2001.

WASSERMAN, D. E. An Overview of Occupational Whole-Body and Hand-Arm Vibration. **Applied Occupational and Environmental Hygiene**, v. 11, n. 4, p. 266–270, abr. 1996.

WINTER, O. Human balance and posture control during standing and walking. **Gait & Posture**, v. 3, p. 193–214, 1995.

WOODRUM, D. A.; BROPHY, C. M. The paradox of smooth muscle physiology. **Molecular and Cellular Endocrinology**, v. 177, n. 1-2, p. 135–143, maio 2001.

WRIGHT, A.; SLUKA, K. A. Nonpharmacological treatments for musculoskeletal pain. **The Clinical journal of pain**, v. 17, n. 1, p. 33–46, mar. 2001.

XIE, L. et al. Low-level mechanical vibrations can influence bone resorption and bone formation in the growing skeleton. **Bone**, v. 39, n. 5, p. 1059–66, nov. 2006.

YAN, J.-G. et al. Vibration-induced disruption of retrograde axoplasmic transport in peripheral nerve. **Muscle & nerve**, v. 32, n. 4, p. 521–6, out. 2005.

YANG, Z. H. et al. Threshold concentrations of endothelin-1 potentiate contractions to norepinephrine and serotonin in human arteries. A new mechanism of vasospasm? **Circulation**, v. 82, n. 1, p. 188–95, jul. 1990.

YE, Y. et al. Association between vasoconstriction during and following exposure to hand-transmitted vibration. **International archives of occupational and environmental health**, v. 87, n. 1, p. 41–9, jan. 2014.