

# **Whole body vibration training and its application to age-related performance decrements: an exploratory analysis**

Adam Hawkey, Katie Griffiths, Joh Babraj and James N. Cobley

This is a non-final version of an article published in final form in *Journal of Strength & Conditioning Research*.

Hawkey, A., et al. 2015. Whole body vibration training and its application to age-related performance decrements: an exploratory analysis. *Journal of Strength & Conditioning Research*. doi: 10.1519/JSC.0000000000001111

2 Whole body vibration training and its application to age-related performance decrements: an  
3 exploratory analysis

4  
5 Adam Hawkey<sup>1\*</sup>, Katie Griffiths<sup>2</sup>, John Babraj<sup>1</sup>, and James N Cobley<sup>1</sup>.

6  
7 1. Division of Sport and Exercise Sciences, Abertay University, UK.

8 2. Department of Sport and Physical Activity, University of Wolverhampton, UK.

9  
10 **\*Corresponding author:**

11 Adam Hawkey

12 Division of Sport and Exercise Sciences

13 Abertay University

14 Kydd Building

15 Bell Street

16 Dundee

17 DD1 1HG

18 United Kingdom

19 Email: [a.hawkey@abertay.ac.uk](mailto:a.hawkey@abertay.ac.uk)

20 Tel: +44 (0)1382 308465

21

22

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

## ABSTRACT

Middle age is associated with a pronounced decline in power and flexibility. Whilst whole body vibration training (WBVT) improves performance in a range of populations, whether WBVT can improve muscle power and flexibility in a middle-aged population is not known. The present study aimed to determine the influence of 5 weeks progressive WBVT in middle-aged (45-55 yrs.) and younger (20-30 yrs.) recreationally active females. Participants in each age group were randomly allocated to an intervention (WBVT) or control group. The WBVT groups trained for five weeks on a vibration platform, while the control groups performed identical exercises, with no vibration. Prior to, and after, the five-week study vertical countermovement jump (VCMJ) and range of motion (ROM) performance were measured. WBVT significantly ( $P = 0.001$ ) improved VCMJ performance when compared to the control groups. This improvement was significantly ( $P = 0.001$ ) greater in the middle-aged compared with the younger WBVT group. WBVT significantly ( $P = 0.001$ ) improved ROM irrespective of age. Taken together, these results suggest that WBVT can off-set age related performance decrements, which has therapeutic implications for musculoskeletal aging. Therefore, WBVT could be undertaken to minimise age-related performance deterioration in middle-aged female populations.

**Key words: Aging, exercise, sarcopenia, muscle power, flexibility, vibration**

24

25 **INTRODUCTION**

26 Middle age (35-59 yrs.) is associated with physiological decline, as evidenced by reduced  
27 aerobic capacity, insulin sensitivity, muscle strength, flexibility, muscle power, and mass  
28 <sup>[13,17,34]</sup>. In particular, muscle power declines earlier (~40 yrs.) and more precipitously (~10%  
29 per decade) than many of the aforementioned parameters <sup>[29,32]</sup>. The mechanisms  
30 underpinning this loss are complex and not completely understood but might be related to  
31 denervation with attendant fibre atrophy and lower physical activity levels in middle-aged  
32 compared with younger populations <sup>[8-10]</sup>.

33

34 Exercise training is a powerful strategy for improving muscle power and performance <sup>[6]</sup>.  
35 Despite the well-documented benefits of exercise, adherence to exercise training regimes is  
36 low <sup>[12]</sup>. Lack of time to exercise, owing to work or family commitments, is commonly cited  
37 as a reason given for lack of adherence in both the general population <sup>[21]</sup> and middle-aged  
38 females <sup>[22]</sup>. Time-efficient exercise interventions are, therefore, required to increase exercise  
39 adherence in middle-aged populations.

40

41 Whole-body vibration training (WBVT) is a novel time-efficient exercise stimulus, with  
42 beneficial effects being reported with less than 30 minutes exposure per week <sup>[19]</sup>. It is  
43 believed that by stimulating neuromuscular pathways and muscle spindles, WBVT creates a  
44 tonic contraction of the muscle; often referred to as the tonic vibration reflex <sup>[30]</sup>. WBVT has  
45 enhanced proxy markers of muscle power (e.g. vertical jump performance) in sedentary <sup>[14]</sup>  
46 and recreationally active young populations <sup>[19]</sup>. In addition, WBVT has improved sprint

47 performance <sup>[31]</sup> and flexibility <sup>[18]</sup> in young trained populations. Further, there is also  
48 evidence that older populations ( $\geq 60$  yrs.) can benefit from WBVT, with increases in muscle  
49 strength <sup>[6]</sup> bone density <sup>[38]</sup>, and improvements in balance <sup>[4,7]</sup> and quality of life <sup>[33]</sup> being  
50 reported. However, there is a paucity of research examining the effect of WBVT in middle-  
51 aged populations. Given the decrements in power and flexibility during middle age, the  
52 present study aimed to determine the effects of WBVT on two functional endpoints: namely  
53 jump performance (power marker) and range of motion (ROM: flexibility marker) in younger  
54 (20-30 yrs.) and middle-aged (45-55 yrs.) recreationally active females. It was hypothesised  
55 that WBVT would lead to similar performance enhancements in younger and middle-aged  
56 females.

57

## 58 **METHODS**

### 59 **Experimental Approach to the Problem**

60 The current study was designed to investigate the changes in vertical jump performance and  
61 ROM following 5 weeks of progressive WBVT in younger compared to middle-aged  
62 recreationally active females. Limited research has been carried out to compare the effects of  
63 WBVT on the performance of different age groups. To achieve this, a test-retest experimental  
64 design was chosen with intervention (WBVT) and control groups in two separate age groups.

65

### 66 **Subjects**

67 Following institutional ethical approval, 25 females (Table 1) were separated into young (20–  
68 30 yrs.) and middle-aged (45–55 yrs.) groups and were randomly assigned (within each age  
69 group) to WBVT or control groups. By completing both an informed consent form and

70 physical activity readiness questionnaire (PAR-Q), all participants self-reported that they  
71 were recreationally active (<5 hrs of moderate intensity exercise per week), were not taking  
72 any medication, and reported no lower or upper extremity injuries in the previous 12 months  
73 that could have affected their ability to participate in the study. All middle-aged participants  
74 were post-menopausal.

75

## 76 **Procedures**

77 Participants completed a five min warm-up on a Monark Ergomedic Bike, maintaining their  
78 heart rate between 120- 140 b-min<sup>-1</sup> in accordance with American College of Sports  
79 Medicine (ACSM) guidelines [3]. All participants were required to perform 3 vertical  
80 countermovement jumps (VCMJ) on a Probotics Just Jump Mat (Probotics Inc. USA), which  
81 has been reported to be a reliable measure of assessing muscular performance [26].  
82 Participants were instructed to keep their hands on their hips throughout the VCMJ, as arm  
83 movement can influence jump performance [23]. Participants also performed 3 range of  
84 motion (ROM) tests using the traditional sit-and-reach box [3,24,27]. For both tests, the mean of  
85 all 3 trials was used for subsequent statistical analysis. Participants were tested twice; pre and  
86 post the 5-week intervention period.

87

## 88 **Interventions**

89 Following a familiarisation session and a demonstration of correct positioning, participants  
90 performed a static squat (90°) and a lunge on each leg on a Power Plate Pro5 vibration  
91 platform (Figure 1). While the WBVT group followed the overload training principal (Figure  
92 2), the control group performed the identical isometric exercises, following the same itinerary

93 as the WBVT group but with no vibration. Both groups trained once per week performing  
94 each exercise for 60s, with a 60s recovery after each exercise; totalling ~3 min exposure time  
95 per training session. During the first and second week, the frequency was pre-set to 30 Hz  
96 and the amplitude controlled at 4 mm. For the third week, the frequency was set to 35 Hz.  
97 During the fourth week the frequency was increased to 40 Hz, and on the fifth week to 45 Hz.  
98 Protocol, including frequency and amplitude settings, exercises and durations, was selected  
99 based on previous research showing improvements in jump performance and ROM <sup>[11,14,18-19]</sup>.  
100 During all trials the participant was required to wear the same rubber soled shoes <sup>[25]</sup>. To  
101 align with recommendations regarding recovery periods following resistance training, VCMJ  
102 performance and ROM were re-assessed 72 hrs following the last training session <sup>[28,39]</sup>. Both  
103 VCMJ and ROM were re-assessed at a similar time of day ( $\pm 1$  hrs) as the first assessment to  
104 avoid the confounding influence of circadian variation <sup>[16]</sup>.

105

106 **Insert Figure 1 near here**

107

108 **Insert Figure 2 near here**

109

110 **Statistical Analyses**

111 A one-way ANOVA was utilised to assess baseline values of age, height, mass and baseline  
112 VCMJ and ROM performance between groups. A 2-way mixed model ANOVA was  
113 employed to assess within (pre vs post) and between (treatment groups) subject main effects.  
114 If any significant F values were observed, Bonferroni post-hoc tests were performed to  
115 determine where any significant differences occurred. An alpha value of  $P \leq 0.05$  was used

116 for all tests. All statistical analysis was performed with the statistical package for social  
117 sciences version 20.0 (SPSS, England). All data in text, tables and figures are presented as  
118 mean and standard deviation ( $M \pm SD$ ).

119

## 120 **RESULTS**

### 121 **Baseline participant anthropometrical characteristics**

122 As expected, age significantly differed by group ( $P \leq 0.001$ ). Specifically, the two middle-  
123 aged groups were significantly older than the two younger groups ( $P \leq 0.05$ , see table 1).  
124 However, there were no significant differences ( $P \geq 0.05$ ) between age-matched control and  
125 vibration groups. Height, mass and BMI were not significantly different ( $P \geq 0.05$ ) between  
126 groups at baseline (see table 1). All participants were classified as having a healthy BMI in  
127 accordance with the World Health Organization<sup>[40]</sup>.

128

129 **Insert Table 1 near here**

130

### 131 **Jump performance**

#### 132 *Baseline*

133 VCMJ differed significantly between groups at baseline ( $P \leq 0.001$ ), being significantly  
134 lower in the two middle-aged groups compared to the two younger groups ( $P \leq 0.05$ ; see  
135 table 1). VCMJ did not significantly differ between the two younger groups ( $P \geq 0.05$ ) or  
136 between the two middle-aged groups ( $P \geq 0.05$ ).

137



138 *Training*

139 There was a significant effect of time ( $P \leq 0.001$ ) and a significant time\*group interaction ( $P$   
140  $= 0.001$ ). Post-hoc analysis revealed that there was a significant effect of WBVT, with a  
141 significant improvement in VCMJ performance being observed in the WBVT groups  
142 compared to the control groups ( $P \leq 0.05$ ; see figure 3 and table 2), irrespective of age.  
143 VCMJ performance improved to a greater extent in the middle-aged compared with the  
144 younger WBVT group ( $P = 0.001$ ).

145

146 **Insert Figure 3 near here**

147

148 **Insert Table 2 near here**

149

150 **ROM**151 *Baseline*

152 ROM differed significantly between groups at baseline ( $P = 0.014$ ; see table 1). Post-hoc  
153 analysis revealed that only the middle-aged WBVT group and the young control group  
154 differed significantly ( $P = 0.028$ ).

155

156 *Training*

157 There was a significant effect of time ( $P \leq 0.005$ ) and a significant time\*group interaction ( $P$   
158  $= 0.001$ ). Post-hoc analysis revealed that there was a significant effect of WBVT, with a

159 significant improvement in ROM being observed in the WBVT groups compared with the  
160 control groups ( $P \leq 0.05$ ; see figure 4 and table 2).

161

162 **Insert Figure 4 near here**

163

## 164 **DISCUSSION**

165 To address whether WBVT can attenuate age-related performance decrements during middle  
166 age the present study determined the influence of 5 weeks progressive WBVT on  
167 performance-related markers of power and flexibility in middle-aged compared with young  
168 recreationally active females. In this regard, we show for the first time that WBVT  
169 significantly improves VCMJ performance and flexibility in a middle-aged population.  
170 Indeed, jump performance improved to a greater extent in the middle-aged compared to the  
171 younger WBVT group, probably owing to lower baseline performance. The improvements in  
172 power and ROM support the notion that WBVT can be utilised to offset the age-related  
173 decline in skeletal muscle function.

174

175 In line with previous work <sup>[29,32]</sup>, we observed lower VCMJ, a proxy marker of muscle power,  
176 in middle-aged compared with younger females. Indeed, muscle power begins to decline at  
177 ~40 years of age and declines precipitously thereafter <sup>[29,32]</sup>. The magnitude of several age-  
178 related declines can, however, be attenuated by regular exercise training in elderly <sup>[1,6,8-10]</sup> and  
179 middle-aged populations <sup>[2,20,36]</sup>. In support of this notion, we provide novel data  
180 demonstrating that WBVT significantly improved VCMJ in middle-aged females. Indeed,  
181 middle-aged individuals improved to a greater extent than younger individuals. This likely

182 reflects a greater scope for improvement in the middle-aged group given their lower baseline  
183 level. Nonetheless, WBVT appears to be an effective countermeasure for attenuating age-  
184 related declines in a marker of muscle power.

185

186 It is acknowledged that WBVT did not reverse VCMJ to the level of a younger female; the  
187 middle-aged group recorded a mean post-intervention jump height of 24.9 cm compared to  
188 the younger group improving to 36.6 cm (mean difference = 11.7 cm). This could reflect a  
189 residual age-related deficit that training cannot fully override or simply the short-term nature  
190 of our exercise intervention. The improvements (~13%) in the current study's middle-aged  
191 group are however, similar in magnitude (~10%) to those observed in other short-term<sup>[19]</sup>  
192 and longer duration (~15%) WBVT studies<sup>[14,37]</sup>. We do, however, readily acknowledge that  
193 a limitation of our study is that we did not compare WBVT to any other training modality  
194 (e.g. progressive resistance exercise). Hence, whether WBVT is a more effective training  
195 stimulus than other modalities in this cohort, is an open question.

196

197 The age-related decline in joint flexibility underpins a decreased ROM in older populations  
198 <sup>[35]</sup>. We report significantly lower ROM in the middle-aged WBVT compared to the young  
199 control group at baseline. That this effect is confined to these two groups, not evident  
200 generally between young and middle-aged and thus not attributable to biological age *per se*,  
201 renders this observation difficult to reconcile at first glance. We speculate that this difference  
202 is attributable to differences in innate flexibility between these two groups or perhaps  
203 differences in the type of habitual physical activity undertaken. It could equally reflect our  
204 relatively low sample size ( $n = 6$  and  $n = 7$ ). In any event, 5 weeks of progressive WBVT  
205 significantly improved ROM, irrespective of age. This observation is concordant with

206 previous work, documenting an enhancement of ROM with WBVT <sup>[18]</sup>. Whether WBVT  
207 attenuates the age-related decline in flexibility is not resolved herein, since we did not  
208 observe any age-related deficits in this parameter at baseline. Proof of concept, might be  
209 provided by the favourable response of middle-aged individuals to WBVT and the increase in  
210 flexibility following exercise training in the elderly <sup>[17]</sup>.

211

## 212 PRACTICAL APPLICATIONS

213 From a practical perspective, we have delineated a novel time-efficient WBVT exercise  
214 paradigm that can be utilised to attenuate the age-related performance declines in middle-  
215 aged females. Although, further work is required to elucidate other benefits of WBVT in  
216 middle-aged populations, such as increased maximal oxygen uptake, WBVT might be a time-  
217 efficient countermeasure for certain age-related performance losses in middle-aged females.  
218 Practitioners, therefore, might consider utilising WBVT to enhance muscle power and  
219 flexibility in middle-aged females.

220

## 221 REFERENCES

222

- 223 1. Adamson, S., Cobley, J.N., Lorimer R. and Babraj, J. Extremely short duration high  
224 intensity training substantially improves the physical function and self-reported health  
225 status of an elderly population. *J Am Ger Soc.* 62: 1380-1381, 2014.

226

- 227 2. Adamson, S., Cobley, J.N., Lorimer R. and Babraj, J. Twice weekly high intensity  
228 training substantially improves cardio-metabolic health and physical function in  
229 untrained middle-aged adults. *Biol. 3*: 333-344., 2014
- 230
- 231 3. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and*  
232 *Prescription, (7th edition)*. Philadelphia: Lippincott, Williams and Wilkins, 2006.
- 233
- 234 4. Bautmans, I., Van Hees, E., Lemper, J-C., and Mets, T. The feasibility of whole body  
235 vibration in institutionalised elderly persons and its influence on muscle performance,  
236 balance and mobility: a randomised controlled trial. *BMC Geriatrics*, 5:17. 2005.
- 237
- 238 5. Bogaerts, A.N., Delecluse, C., Claessens, A.L., Coudyzer, W., Boonen, S. and  
239 Verschueren, S.M.P. Impact of whole-body vibration training versus fitness training  
240 on muscle strength and muscle mass in older men: a 1-year randomized controlled  
241 trial. *J Ger: Med Sci*, 62(6), 630–635, 2007.
- 242
- 243 6. Booth, F.W., Laye, M.J. and Roberts, M.D. Lifetime sedentary living accelerates  
244 some aspects of secondary aging. *J Appl Phys*, **111**: 1497-1504, 2011.
- 245
- 246 7. Cheung, W-H., Mok, H.W., Qin, L., Sze, P-C., Lee, K-M., and Leung, K-S. High-  
247 frequency whole-body vibration improves balancing ability in elderly women. *Arch*  
248 *Phys Med Rehabil* 88: 852-857, 2007.
- 249

- 250 8. Cobley, J.N., Sakellariou, G.K., Owens, D.J., Murray, S., Waldron, S., Gregson, W. *et*  
251 *al.* Lifelong training preserves some redox-regulated adaptive responses following an  
252 acute exercise stimulus in aged human skeletal muscle. *Fr Rad Biol Med.* 70: 23-32,  
253 2014.
- 254
- 255 9. Cobley, J.N., Sakellariou, G.K., Waldron, S., Murray, S., Burniston, J.G., Morton,  
256 J.P. *et al.* Life-long training attenuates residual genotoxic stress in the elderly.  
257 *Longevity and Healthspan.* 2:11, 2013.
- 258
- 259 10. Cobley, J.N., Bartlett, J.D., Kayani, A.C., Murray, S.W., Louhelainen, J., Donovan, T.  
260 *et al.* PGC-1 $\alpha$  transcriptional response and mitochondrial adaptation to acute exercise  
261 is maintained in skeletal muscle of sedentary elderly males. *Biogerontology.* 13: 621-  
262 631, 2012.
- 263
- 264 11. DaSilva, M.E., Nunez, V.M., Vaamonde, D., Fernandez, J.M., Poblador, M.S.,  
265 Garcia-Manso, J.M. and Lancho, J.L. Effects of different frequencies of whole body  
266 vibration on muscular performance. *Biol Sp,* 23: 267-282, 2006.
- 267
- 268 12. Davies, D.S.; Burns, H.; Jewell, T.; and McBride, M. *Start active, stay active: A*  
269 *report on physical activity from the four home countries' Chief Medical Officers;*  
270 *16306.* Department of Health: London, UK, pp. 1–62, 2011.
- 271

- 272 13. Deschenes, M.R. Effects of aging on muscle fibre type and size. *Sp Med*, 34, 809-824,  
273 2004.
- 274
- 275 14. Delecluse, C., Roelants, M., & Verschueren, S. Strength increases after whole-body  
276 vibration compared with resistance training. *Med Sci Sp Ex*, 35, 1003–1041, 2003.
- 277
- 278 15. Doherty, T.J. Invited review: Aging and sarcopenia. *J Appl Phys*, 111, 1717-1727,  
279 2003.
- 280
- 281 16. Drust, B., Waterhouse, J., Atkinson, G., Edwards, B. and Reilly, T. Circadian rhythms  
282 in sports performance: An update. *Chr Int*, 22: 21-44, 2005.
- 283
- 284 17. Fatouros, I.G., Taxildaris, K., Tokmakidis, S. P., Kalapotharakos, V., Aggelousis, N.  
285 Athanasopoulos, S. Zeeris, I. and Katrabasas, I. The effects of strength training,  
286 cardiovascular training and their combination on flexibility of inactive older adults.  
287 *Int J Sp Med*, 23: 112–119, 2002.
- 288
- 289 18. Hawkey, A., Lau, Y., and Nevill, A. Effect of six-week whole body vibration training  
290 on vertical jump and flexibility performance in male national league basketball  
291 players. *J Sp Sci*, 27(4), S138–S139, 2009.
- 292
- 293 19. Hawkey, A. Whole body vibration training improves muscular power in a  
294 recreationally active population. *SportLogia*, 8(2), 116–122, 2012.

295

296 20. Holviala, J.H., Sallinen, J.M., Kraemer, W.J., Alen, M.J. and Häkkinen, K.K. Effects  
297 of strength training on muscle strength characteristics, functional capabilities, and  
298 balance in middle-aged and older women. *J Str Cond Res*, **20**(2): 336-44, 2006.

299

300 21. Korhakangas, E., Alahuhta, M.; &Laitinen, J. Barriers to regular exercise among  
301 adults at high risk or diagnosed with type 2 diabetes: A systematic review. *Health Pro*  
302 *Int*, 24, 416–427, 2009.

303

304 22. Kowal, J.; Fortier, M.S. Physical activity behaviour change in middle aged and older  
305 women: The role of barriers and of environmental characteristics. *J Behav Med.* 30,  
306 233–242, 2007.

307

308 23. Linthorne, N. Analysis of standing vertical jumps using a force platform. *Am J Phy*,  
309 69(11): 1198-1204, 2001.

310

311

312

313 24. López-Miñarro, P.A., Andújar, P.S., and Rodríguez-García, P.L. A comparison of  
314 the sit-and-reach test and the back-saver sit-and-reach test in university students. *J Sp*  
315 *Sci Med.* 8(1): 116-22. 2009.

316



- 317 25. Marín, P., Bunker, D., Rhea, M. and Ayllóin, F. Neuromuscular activity during  
318 whole-body vibration of different amplitudes and footwear conditions: implications  
319 for prescription of vibratory stimulation. *J Str Cond Res*, 23 (8): 2311-2316, 2009.
- 320
- 321 26. Markovic, G. and Jaric, S. Is vertical jump height a body size-independent measure of  
322 muscle power? *J Sp Sci*, 25(12): 1355–1363, 2007.
- 323
- 324 27. Mayorga-Vega, D., Merino-Marban, R., and Viciano, J. Criterion-Related Validity of  
325 Sit-and-Reach Tests for Estimating Hamstring and Lumbar Extensibility: a Meta-  
326 Analysis. *J Sp Sci Med*. 13(1):1-14. 2014.
- 327
- 328 28. McLester, J. R., Bishop, P. A., Smith, J. et al. A series of studies – A practical  
329 protocol for testing muscular endurance recovery. *J Str Cond Res*, 17(2): 259-273,  
330 2003.
- 331
- 332 29. Metter, E.J., Conwit, R., Tobin, J. and Fozard, J. Age-associated loss of power and  
333 strength in the upper extremities in women and men. *J Gerontol A Biol Sci Med Sci*,  
334 52: B267-76, 1997.
- 335
- 336 30. Nordlund, M. M., and Thorstensson, A. Strength training effects of whole-body  
337 vibration? *Scandinavian J Med Sci Sp*, 17: 12–17, 2007.
- 338

- 339 31. Paradisis, G., and Zacharogiannis, E. Effects of whole-body vibration training on  
340 sprint running kinematics and explosive strength performance. *J Sp Sci Med*, 6: 44–  
341 49, 2007.
- 342
- 343 32. Reid, K.F. & Fielding, R.A. Skeletal muscle power: A critical determinant of physical  
344 functioning in older adults. *Ex Sp Sci Rev*, 40, 4-12, 2012.
- 345
- 346 33. Runge, M., Rehfeld, G. and Resnicek, E. Balance training and exercise in geriatric  
347 patients. *J M Neur Int*, 1: 61– 65, 2000.
- 348
- 349 34. Short, K.R., Vittone, J.L., Brigelow, M.L., Proctor, D.N., Rizza, R.A., Coenen-  
350 Schimke J.M. et al. Impact of Aerobic Exercise Training on Age-Related Changes in  
351 Insulin Sensitivity and Muscle Oxidative Capacity. *Diabetes*, 52, 1888-1896, 2003.
- 352
- 353 35. Stathokostas, L., McDonald, M.W., Little, R.M. and Paterson, D. H. Flexibility of  
354 Older Adults Aged 55–86 Years and the Influence of Physical Activity. *J Aging Res*,  
355 vol. 2013, Article ID 743843, 8 pages, 2013. doi:10.1155/2013/743843.
- 356
- 357 36. Surakka, J., Aunola, S., Nordblad, T., Karppi, S-L. and Alanen, E. Feasibility of  
358 power-type strength training for middle-aged men and women: self perception,  
359 musculoskeletal symptoms, and injury rates. *Brit J Sp Med*, 37: 131–136, 2003.
- 360
- 361 37. Torvinen S, Kannus P, Sievanen H, et al. Effect of four- month vertical whole body  
362 vibration on performance and balance. *Med Sci Sp Ex*, 34: 1523–1528, 2002.

363

364 38. Verschueren, S.M.P., Roelants, M., Delecluse, C., Swinnen, S., Vanderschueren and  
365 Boonen, S. Effect of 6-month whole body vibration training on hip density, muscle  
366 strength, and postural control in postmenopausal women: a randomized controlled  
367 pilot study. *J Bone Min Res*, 19 (3): 352-359, 2004.

368

369

370 39. Westcott, W.L. How often should clients perform strength training? *ACSM's Certified*  
371 *News*. 20(2): 10-11, 2010.

372

373 40. World Health Organization. Physical status: the use and interpretation of  
374 anthropometry. Report of a WHO Expert Committee. WHO Technical Report Series  
375 854. Geneva: World Health Organization, 1995.

376

377 **Table 1: Baseline participant characteristics. Data is presented as M and SD ( $\pm$ ). Group P values are**  
378 **derived from the one-way ANOVA analysis.**

379 \*denotes significant difference from young WBVT; #denotes significant difference from young control.

380 <sup>1</sup>: classifications taken from the World Health Organization (WHO) Expert Committee <sup>[40]</sup>.

ACCEPTED

381 **Table 2: Pre- and post- performance (VCMJ and ROM) for younger and middle-aged groups (WBVT**  
382 **and control). Data is presented as M and SD ( $\pm$ ).**

ACCEPTED

383

384 **Figure 1: Exercises performed on the WBV platform**

ACCEPTED

385

386 **Figure 2: 5-week training programme on the WBVT platform**

ACCEPTED

387

388 **Figure 3: Changes in jump performance. Data is presented as percentage changes from baseline**

ACCEPTED



389

390 **Figure 4: Changes in range of motion. Data is presented as percentage changes from baseline**

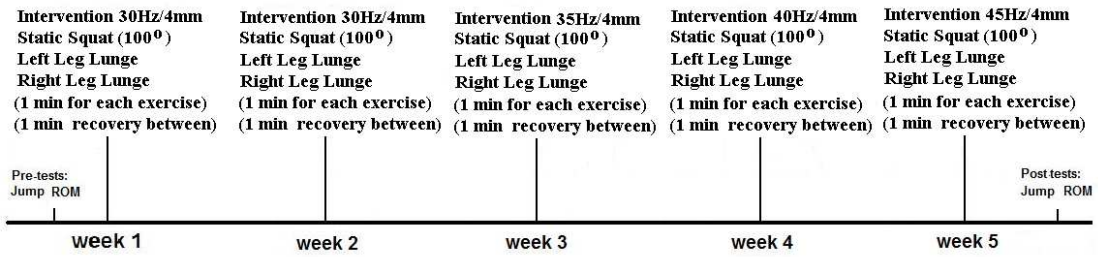
ACCEPTED

Parameter	Young WBVT (n=6)	Young Control (n=7)	Middle-aged WBVT (n=6)	Middle-aged Control (n=6)	Group P value
Age (yrs.)	24.7 ± 2.6	21.0 ± 0.8	52.0 ± 4.4 <sup>*#</sup>	49.5 ± 2.9 <sup>*#</sup>	≤0.001
Mass (kg)	61.7 ± 5.2	56.9 ± 6.6	67.4 ± 12.2	67.8 ± 10.7	0.122
Height (cm)	164.6 ± 1.5	164.5 ± 5.7	164.2 ± 4.7	164.8 ± 5.3	0.761
BMI (kg/m <sup>2</sup> )	22.7 ± 1.8	21 ± 2.2	24.9 ± 2.1	24.9 ± 1.4	0.45
BMI classification <sup>1</sup>	Normal	Normal	Normal	Normal	n/a
Jump performance (cm)	35.1 ± 3.0	36.2 ± 5.4	22.3 ± 4.3 <sup>*#</sup>	24.2 ± 4.8 <sup>*#</sup>	≤0.001
ROM (cm)	30.2 ± 9.4	31.0 ± 6.5	19.4 ± 3.0 <sup>#</sup>	23.5 ± 5.4	0.014

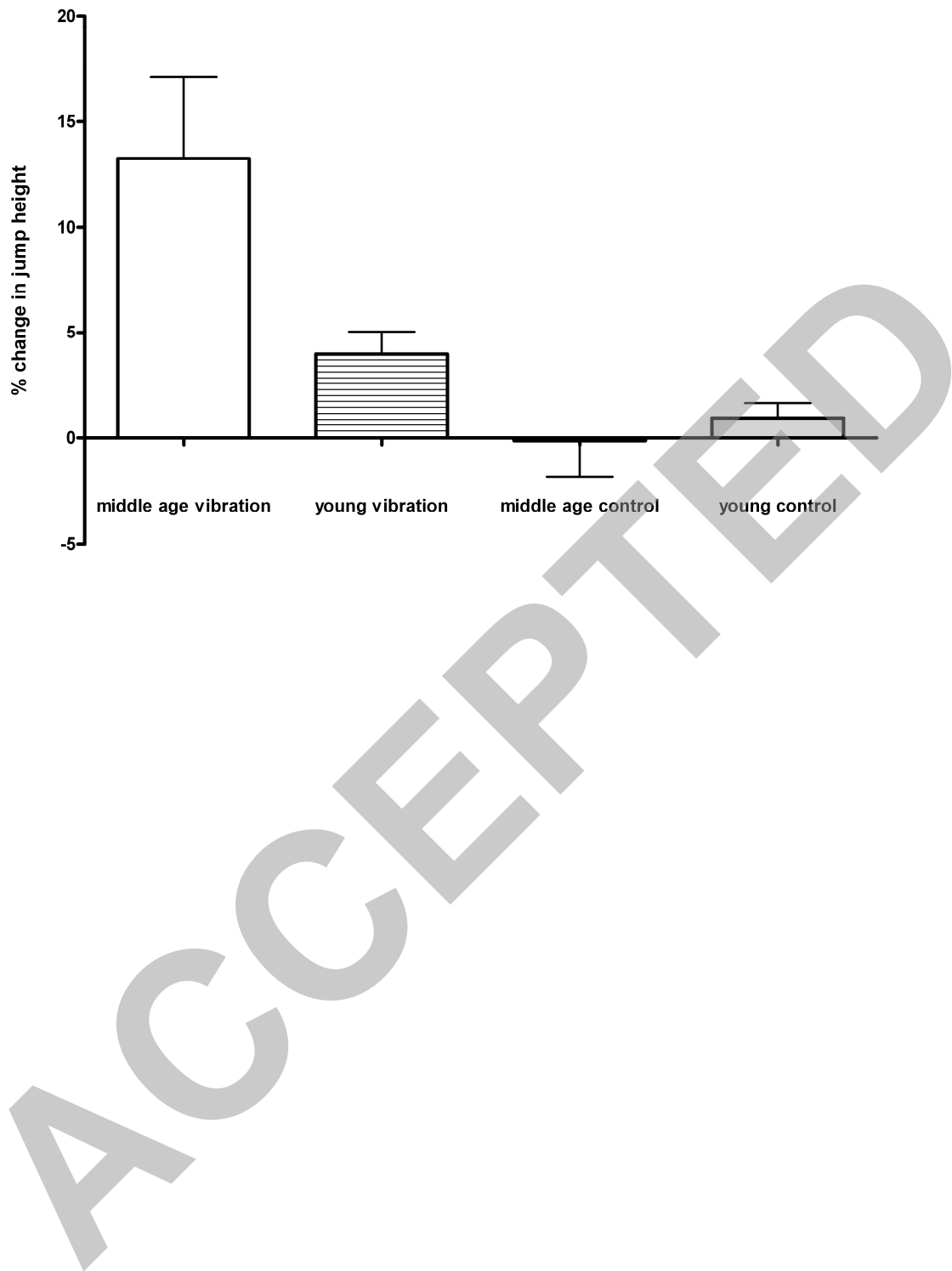
<b>Group:</b>	<b>Pre- VCMJ (cm)</b>	<b>Post- VCMJ (cm)</b>	<b>Pre- ROM (cm)</b>	<b>Post- ROM (cm)</b>
<b>Young WBVT (n=6)</b>	<b>35.1 ± 3.0</b>	<b>36.6 ± 3.5</b>	<b>30.2 ± 9.4</b>	<b>31.9 ± 9.1</b>
<b>Young Control (n=7)</b>	<b>36.2 ± 5.4</b>	<b>36.5 ± 5.0</b>	<b>31.0 ± 6.5</b>	<b>30.4 ± 5.6</b>
<b>Middle-aged WBVT (n=6)</b>	<b>22.3 ± 4.3</b>	<b>24.9 ± 3.3</b>	<b>19.4 ± 3.0</b>	<b>21.3 ± 3.9</b>
<b>Middle-aged Control (n=6)</b>	<b>24.2 ± 4.8</b>	<b>24.1 ± 4.0</b>	<b>23.5 ± 5.4</b>	<b>23.4 ± 4.5</b>

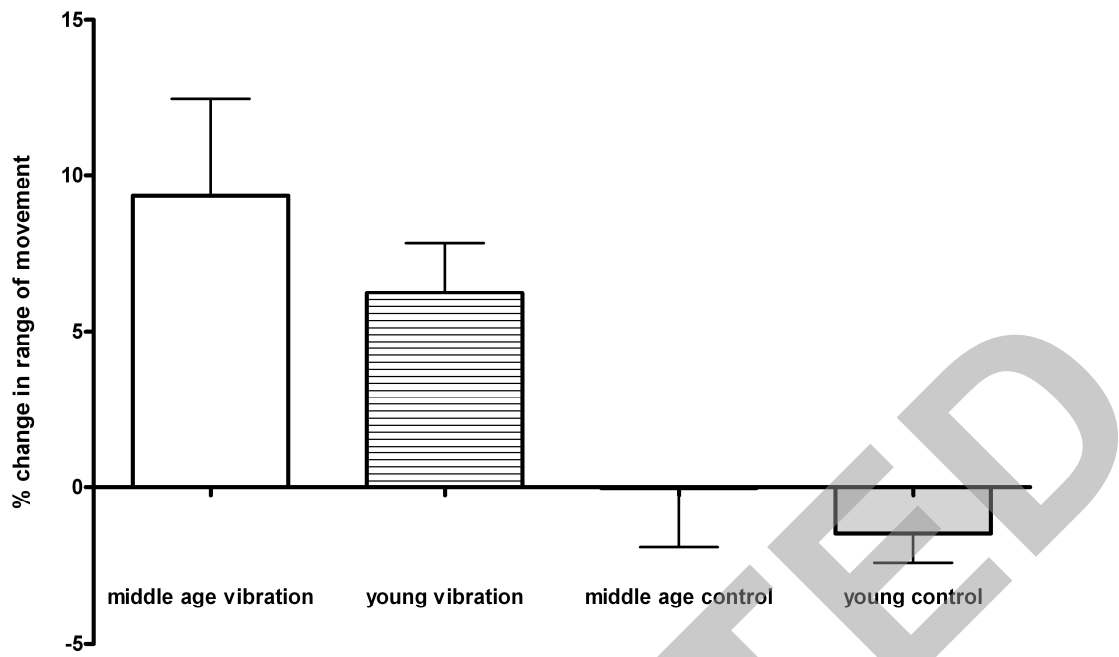


ACCEPTED



ACCEPTED





ACCEPTED