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Characterisation of vertical accelerations experienced by older people attending an aerobics class designed to produce high impacts

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Characterisation of vertical accelerations experienced by older people attending an aerobics class designed to produce high impacts

ABSTRACT

The purpose of this study was to establish the feasibility of using an aerobics class to produce vertical impacts ≥4g in older adults and to determine whether impacts can be predicted by physical function.

Participants recruited from older adult exercise classes completed an SF-12 questionnaire, short physical performance battery and an aerobics class with seven different components, performed at low and high intensity. Maximum g and jerk values were identified for each activity.

41 participants, mean 69 years, were included. Mean maximal values approached or exceeded the 4g threshold for four of the seven exercises. In multivariate analyses, age (-0.53; -0.77, -0.28), and 4m walk time (-0.39; -0.63, -0.16) were inversely related to maximum g (standardised beta coefficient; 95% CI).

Aerobics classes can be used to produce relatively high vertical accelerations in older individuals, although the outcome is strongly dependent on age and physical function.

INTRODUCTION

Hip fracture is a major cause of morbidity and mortality in older people, leading to loss of independence, and a huge economic burden through both direct medical costs and social sequelae (Burge 2001). It is thought that age related declines in the intensity and quantity of PA contribute to this increase in risk of osteoporotic fracture. Promotion of PA in older people is thought to help maintain bone mass: epidemiological studies report that risk of hip fracture is reduced in older adults who remain more physically active (Moayyeri 2008). An important physiological link exists between exercise and bone, as demonstrated by findings from animal studies over 30 years ago that the skeleton is exquisitely responsive to mechanical strain; bone loss caused by immobilization was prevented by only four loading cycles per day (Rubin and Lanyon 1984). There is little evidence that walking interventions improve BMD, as judged by findings of a recent meta-analysis (Martyn-St James and Carroll 2008). In contrast, protocols that combined jogging, walking, and stair climbing consistently improve hip BMD in older people (Martyn-St James and Carroll 2009). Interventions to increase aerobic activities, high impact exercises, "odd-impact" exercise loading, and resistance training (designed to increase bone loading through increased muscle strength) also improve hip BMD in this group (Martyn-St James and Carroll 2009, Nikander, Kannus et al. 2009, Martyn-St James and Carroll 2010, Marques, Wanderley et al. 2011, Allison, Folland et al. 2013).

Therefore, exercise interventions in older people may need to achieve relatively high levels of impact to be effective at increasing BMD. High impact PA produces deformation of lower limb bones, including sites such as the hip, as a consequence of ground reaction forces which occur on landing. Bone strain resulting from a given movement reflects not only ground reaction forces, but also local actions of muscle which serve to amplify externally applied forces due to the short levers they work with (Ireland, Rittweger et al. 2014). Hence, muscle performance also needs to be taken into account when assessing relationships between high impact PA and the skeleton. As well as providing objective measurement of vertical impacts through measurement of Y axis accelerations, accelerometers attached to the centre of mass can also be employed to evaluate other aspects of muscle performance, as in a recent study of training effects on maximum jerk during a sit to stand activity (Regterschot, Folkersma et al. 2014). Jerk is a measure of the rate of change in acceleration, and reflects the rate of force development (also termed rate of joint torque development).

In our previous study based on adolescents from the Avon Longitudinal Study of Parents and Children wearing accelerometers at home for up to seven days, we found that the relationship between habitual levels of PA and hip BMD could be explained by the number of albeit rare vertical accelerations beyond 4.2g, which are typically achieved on jogging at speeds of 10km/hour or more (Deere, Sayers et al. 2012). Similarly, the number of vertical accelerations beyond 3.9g in postmenopausal women, achieved during activities such as jumping in supervised exercise classes, was related to gain in hip BMD (Vainionpaa, Korpelainen et al. 2006). However, there has been little attempt to quantify target levels of impact for preserving bone in older individuals, or the extent to which these are generated by PA interventions in this age group. Therefore, we examined this question in a recent pilot study based on 20 older participants (mean age 67 years), who were asked to wear accelerometers whilst attending a typical aerobics exercise class. Interestingly, no vertical accelerations were recorded beyond 2.1g (Tobias, Gould et al. 2014), suggesting that in older people, it may not be feasible to achieve the level of impacts found to be bone protective in younger individuals.

In this study, we investigated whether higher g levels, similar to those found to be bone protective in younger individuals, can be achieved in older individuals by modifying the content of aerobics classes. We also examined whether the level of impacts achieved in this setting can be predicted by physical and mental function as reflected by the physical and mental components of the SF-12 questionnaire, and the short physical performance battery (SPPB) (Guralnik, Simonsick et al. 1994). In addition, we investigated whether physical and mental function as measured by these instruments are also related to accelerometry-based assessment of muscle function, as reflected by jerk derived from Y-axis accelerations.

METHODS

Study design

We recruited male and female participants from individuals attending a mixed exercise class aimed at older adults, based at the University of Bristol Sports and Exercise Centre. Class members were provided with an explanation of the study along with an invitation pack which included a participant information leaflet, reply slip, consent form, the SF-12 health survey and a freepost envelope. No exclusion criteria were used. On attendance at one of three standardised exercise sessions carried out on consecutive weeks, participants completed a SPPB, which included a test of balance, the time taken to walk 4m and time taken to rise from a chair five times (Guralnik, Simonsick et al. 1994). Each participant was subsequently fitted with an accelerometer, immediately prior to the start of the exercise class. The study protocol was approved by the Faculty of Medicine and Dentistry Research Ethics Committee at the University of Bristol.

Exercise class

The class was designed in collaboration with the exercise instructor (SW) responsible for delivering the sessions, with the aim of including components which produce relatively high impacts that can be reproduced consistently and safely in older individuals. Each class lasted a total of 45 minutes which included a 15 minute warm up and 10 minute cool down. The exercise sequence is shown in Table 1. Each component comprised seven movement repetitions, which were initially performed at low intensity, and then repeated at higher intensity if participants felt able to do this. Consecutive components were interspersed with a holding move of gentle side to side steps for 30 seconds, to aid identification of separate components within the data. External factors were optimised in order to encourage higher impacts including the tempo and genre of the music played, the dimensions, heating and lighting in the exercise room, the delivery style of the instructions provided throughout the class, and the explanation that our study was about the health benefits of high impact exercise.

Accelerometers

At the start of each exercise class, participants were fitted with a triaxial accelerometer (Gulf Coast Data Concepts Series X16-1C). These are small, portable, sealed self-contained units which record movement in three axes of movement at a frequency of 50Hz. The monitors were worn in a secure size specific elasticated belt, horizontally on their right hip so that vertical (Y axis) accelerations of the centre of mass could be identified. Real time clock software installed on each accelerometer enabled the timing of each movement to be recorded. Individual CSV data were converted to a Stata (StataCorp. College station Texas, V.13) datafile and variables derived using custom code. Y axis accelerations were examined for separate exercise components for each participant, and peak g identified. Jerk was obtained by dividing the difference between each acceleration and the acceleration recorded immediately beforehand, by time elapsed. As jerk was used as an estimate of muscle performance working against gravity, these analyses were based on negative Y axis values.

Statistical analysis

Mental component score (MCS) and physical component score (PCS) of the SF-12 were derived separately. The SPPB showed a strong ceiling effect, reflecting the self-selected nature of our study participants, and so separate components (i.e. gait speed and chair rise time) were also analysed. Maximum g (expressed as over and above 1g caused by the earth's gravitational force) for each participant was identified across the exercise class as a whole. Aggregate maximum g, obtained from averaging maximum g across all seven high intensity components, was also derived. Maximum g for each component of the exercise class was obtained by combining the maximal value observed for each participant. Maximum jerk was derived by averaging the top ten jerk values obtained for each exercise component. Aggregate maximum jerk was obtained for each participant, by averaging maximum jerk values across all seven high intensity exercise components. Summary statistics from SF-12 questionnaires, SPPB and accelerometers were reported for males and females separately and combined, expressed as mean and SD. To examine relationships between general function and exercise class performance, regression analyses using standardised variables were performed using the SF-12 mental component score, SF-12 physical component score, gait speed and chair rise time as exposures, and aggregate peak g/jerk as outcomes, in males and females combined. Univariate analyses were performed initially, followed by multivariable analyses adjusted for age, gender and other exposures.

RESULTS

Participant characteristics

A total of 41 participants (7 men and 34 women) were recruited. Table 2 presents the basic characteristics and health assessment scores. Mean age was 69 years (SD: 6 years). The group had a relatively high level of physical function with 80% scoring 12/12 on the SPPB test (mean: 11.7, SD: 0.8) and 78% of participants scoring above the average (based on US population data) score for the physical component of the SF-12 questionnaire. Mental and physical component scores, SPPB score, gait speed and chair rise time were similar in males and females. Aggregate maximum g scores across all seven high intensity components were relatively high at 3.61g, with slightly higher values in males compared to females (see Table 3). Maximum g, based on the highest g value recorded across the whole exercise class, were higher still at 5.30g, again with higher values in males compared to females. Aggregate maximum jerk for high intensity components combined was approximately 40% higher in males compared to females.

Accelerometry readings in different exercise components

Mean maximum g associated with individual components of the aerobics class are shown in males and females in Table 4, and in males and females combined in Figure 1. Low intensity exercise was associated with peak impacts ranging from 1.45g for knee lifts, to 2.81g for mambo. High intensity exercise produced peak g values which were approximately 80% greater on average than those seen in low intensity exercise, ranging from 2.46g for knee lifts to 4.64g for jacks. Mean maximum jerk likewise varied between activities, with high intensity versions of a given activity associated with approximately 66% higher jerk values on average compared to the low intensity version (Table 5). Although there was little overall difference between genders, higher impact activities such as jacks appeared to be associated with higher maximum jerk, and to a lesser extent maximum g, in males as compared with females.

Health status and accelerometer readings

We analysed relationships between age, gender and indicators of health status, and aggregate maximum g and aggregate maximum jerk across all seven high intensity components, in the 41 study participants. Univariate analyses revealed that greater age and slower walk time were associated with lower aggregate maximum g, whereas a positive association was observed for PCS (Table 6). The associations with age and walk time were particularly strong, such that a one SD increase in age and walk time was associated with 0.61 and 0.51 SD decreases in aggregate g respectively. Associations with age and walk time persisted in multivariate analysis, although the beta coefficient for the association with walk time was attenuated by approximately 30%, whereas the association with PCS was no longer present.

Inverse associations were observed between aggregate maximum jerk and not only age and walk time but also chair rise time, whereas a positive association was observed with PCS (Table 7). There was also evidence that maximum jerk was lower in females. These associations all persisted in multivariate analysis, though beta coefficients for the relationships with age and walk time were attenuated by approximately 40%.

Although aggregate maximum g and jerk were strongly correlated (r=0.74), we wished to establish whether either of these are preferentially related to walk time or chair rise time. The association between walk time and aggregate maximum g persisted after adjusting for aggregate maximum jerk, although the beta coefficient was reduced by approximately half (from -0.43 to -0.23 in age and gender adjusted model). In contrast, the association between chair rise time and maximum jerk was only reduced by 12% (beta coefficient from -0.25 to -0.22) after adjusting for aggregate maximum g.

The association between walk time and aggregate maximum jerk was no longer observed after adjusting for aggregate maximum g (beta coefficient from -0.38 to -0.10).

DISCUSSION

We evaluated the level of impacts achieved by older people participating in an aerobics class designed to produce relatively high impacts that are likely to be bone protective, by using accelerometers worn over the hip to measure vertical accelerations. We found that participants generally achieved vertical accelerations in the region of 4g, a level previously suggested to have positive effects on BMD in adolescents (Deere, Sayers et al. 2012) and premenopausal women (Vainionpaa, Korpelainen et al. 2006). This contrasts with results of our previous study based on an equivalent study population, in whom virtually no accelerations were observed exceeding 2g (Tobias, Gould et al. 2014). The success of the present aerobics class in achieving higher impacts is likely to reflect a combination of the types of exercise used, and the intensity with which they were undertaken. For example, vertical accelerations in the region of 4g were only achieved during exercises which involve rapid upwards displacement of the centre of mass ie Spotty dogs, Mambo, jacks, and bench steps. Furthermore, accelerations of this magnitude were only observed when participants were explicitly encouraged by the instructor to exercise at high intensity.

Future studies will be required to determine whether an aerobics class structured along these lines is successful in improving BMD, based on trials where this forms the basis of a PA intervention. That such a strategy is likely to be effective is supported by previous observations that interventions expected to produce high impacts, such as hopping, appear to be effective at increasing hip BMD in older individuals (Allison, Folland et al. 2013). However, the level of impacts produced was not generally recorded in previous interventional studies in this age group, and it is unclear how comparable these were to the present aerobics class in terms of delivery of osteogenic PA.

Participants attending the aerobics class were a self-selected group, and had relatively high levels of function as reflected by baseline SF-12 and SPPB scores. That level of function as reflected by these scores was a strong predictor of performance in these classes was confirmed by our finding that age and walking time were both strong negative predictors of the level of vertical accelerations achieved. Hence, the SPPB, which is widely used clinically to screen for function and frailty in older people, may also prove useful in screening older individuals in terms of how likely they are to benefit from aerobics classes as a means of generating osteogenic PA.

Presumably, the relationship between gait speed and maximum g during the aerobics class reflects the fact that accelerometer recordings whilst performing standardised activities at maximal intensity provide measurements of muscle performance. For example, in jumping mechanography, rate of acceleration while jumping is used to measure peak muscle force, which is in turn related to cortical bone geometry and strength (Hardcastle, Gregson et al. 2013). Although jumping mechanography relies on the use of force plates rather than accelerometers to measure ground reactions forces, a recent study in children observed good agreement between these two methods (Meyer, Ernst et al. 2015).

Accelerometers can also be used to derive jerk, which reflects the rate of force development, and may represent a distinct aspect of muscle function as compared with maximum muscle force or power. A decrease in rate of force development has been reported to be an important contributor to declining muscle function in older men (Thompson, Ryan et al. 2013), and a risk factor for falls in older women (Crozara, Morcelli et al. 2013). Although few previous studies have examined accelerometer-derived measures of jerk, in one recent study maximum jerk was found to show expected improvements in response to training during a sit to stand activity in older people (Regterschot, Folkersma et al. 2014). Since rate of force development appears to be related to the ability to execute movements such as sit to stand, we reasoned that maximum jerk as measured during the aerobics class may be related to chair rise time. Interestingly, chair rise time was found to predict maximum jerk, but not maximum g, providing face validity for the use of accelerometry-based measures of maximum jerk as a measure of rate of force development. More objective validation, based on participants wearing accelerometers during jumping mechanography, is planned as part of future studies.

In terms of limitations, in this exploratory study to examine whether higher impacts are achievable in the setting of an aerobics class directed towards older individuals, several strategies were used concurrently, including alterations in the tempo of music played during the class, and in instructions given. Before wider implementation it would be helpful to evaluate the relative importance of each strategy. Another limitation is that this study was based on a self-selected group; based on the relationship we observed between baseline functional status and maximum level of vertical accelerations achieved, subsequent application of this approach may need to be restricted to older people with similarly high levels of physical function.

In conclusion, aerobics classes can be readily modified to ensure that participating older individuals experience levels of impacts which are likely to be bone protective. However, the success of this strategy in producing high impacts is strongly dependent on pre-existing physical function as reflected by factors such as age and gait speed. Further research is justified to examine whether aerobics classes designed to produce high impacts are effective at improving BMD, and hence have a role as an adjunct to, or possible replacement of, conventional pharmacotherapy.

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Figure Legends

Figure 1: Mean of the maximum g experienced by participants during the low and high impact version of each of the seven aerobics movements (N=41).

TABLE 1: Exercise components of the aerobics class session

Order	Type of movement	Low intensity	High intensity
1	Step-ups on and off bench	No jumping	Jump down
2	Jacks	Half jack	Jumping jack
3	Alternate leg mambo	Heel raise on return	Jump on return
4	Spotty dogs	Back tap (no jump)	Switch legs (with spring)
5	Double hamstring curl	No jumping/hopping	With jump and hop
6	Knee lifts	Low level	With jump and hop
7	March/spring on spot	Marching	Speed sprint on spot

Table shows the seven exercise components with the high and low intensity version of each included in the aerobics class.

TABLE 2: Physical characteristics of PIVOTAL participants

Characteristics	Men	Woman	Total
n	7 (17.1)	34 (82.9)	41 (100)
Age (years)	67.6 ± 3.3	69.6 ± 6.5	69.2 ± 6.1
Mental component score (MCS)	46.9 ± 10.3	54.8 ± 5.8	53.4 ± 7.3
MCS above average reference range[a]	2 (28.6)	26 (76.5)	28 (68.3)
Physical component score (PCS)	52.3 ± 11.1	49.7 ± 8.0	50.1 ± 8.5
PCS above average reference range[a]	6 (85.7)	26 (76.5)	32 (78.1)
SPPB score (max of 12)	11.4 ± 1.1	11.7 ±0.7	11.7 ±0.8
Walk time (sec)	3.2 ±0.4	3.4 ±0.63	3.3 ±0.6
Chair rise time (sec)	9.6 ±3.8	9.3 ±2.30	9.3 ±2.6

Table shows the physical characteristics for the 41 aerobics class participants. SPPB, short performance physical battery.

[a] Based on normative values from US population data(Ware, Kosinski et al. 1996)

Vales are mean ± SD or n(%)

TABLE 3: Physical activity recordings summary in males and females

	Female		Male		All	
	mean	SD	mean	SD	mean	SD
Aggregate g (m/s²)	3.57	1.46	3.80	1.98	3.61	1.53
Maximum g (m/s²)	5.15	1.90	6.01	2.92	5.30	2.09
Aggregate Jerk (m/s³)	24.62	12.03	35.35	19.80	26.45	13.96

Table shows summary statistics for derived accelerometry variables based on all activities during the aerobics session in males (n=7), females (n=34) and all of the cohort (N=41). Maximum g is based on the highest value experienced by participants during the exercise class as a whole, whereas aggregate g and jerk represent maximum values averaged across all seven high intensity components.

*

Table 4: Maximum g experienced during each aerobics activity

		Maximum g							
		Female				Male			
Activity	**Intensity**	**Mean**	**SD**	**p25**	**p75**	**Mean**	**SD**	**p25**	**p75**
Knee lifts	Low	1.47	0.64	0.88	1.94	1.39	0.61	0.88	1.53
	High	2.51	1.26	1.65	3.26	2.19	0.87	1.41	2.91
Hamstring curls	Low	1.82	0.81	1.12	2.43	2.31	1.58	1.38	2.90
	High	3.13	1.85	1.79	3.70	2.87	1.58	1.90	4.54
Spotty dogs	Low	1.98	0.76	1.44	2.38	2.19	1.17	1.52	2.75
	High	3.97	1.77	2.71	5.27	3.56	1.94	2.46	5.74
Jacks	Low	2.63	1.33	1.74	3.07	2.73	2.05	1.34	5.02
	High	4.51	2.13	3.10	5.96	5.31	3.51	1.52	8.22
Mambo	Low	2.93	1.02	2.20	3.57	2.22	1.25	1.18	2.93
	High	3.87	1.57	2.79	5.03	4.13	2.03	2.51	6.29
Marching	Low	1.50	0.52	1.13	1.86	1.53	0.73	0.90	2.03
	High	3.00	1.59	1.79	3.84	3.65	3.02	2.18	4.69

Bench steps	Low	2.25	0.89	1.50	2.99	2.43	1.35	1.38	3.71
	High	4.01	1.54	3.00	5.08	4.88	2.36	3.77	5.73

Table shows summary statistics of the maximum g experienced in the low and high intensity version of each aerobics class movement for the n=7 male and n=34 female participants.

Table 5: Mean of maximum jerk experienced during each aerobics activity

		Maximum jerk											
		Female				Male				All			
Activity	**Intensity**	**Mean**	**SD**	**p25**	**p75**	**Mean**	**SD**	**p25**	**p75**	**Mean**	**SD**	**p25**	**p75**
Knee lifts	Low	22.29	7.85	16.41	27.21	19.93	6.39	15.52	22.34	21.89	7.60	16.41	27.12
	High	29.62	10.42	21.57	35.30	30.24	11.48	15.74	40.62	29.72	10.46	21.57	35.64
Hamstring curls	Low	18.83	8.64	12.38	24.46	19.62	7.98	13.36	23.11	18.96	8.44	12.39	23.11
	High	29.59	10.54	21.09	37.70	30.47	12.11	21.52	43.06	29.74	10.67	21.37	37.70
Spotty dogs	Low	20.00	5.90	16.46	24.31	20.70	5.91	14.95	24.59	20.12	5.83	16.46	24.31
	High	33.51	14.21	22.81	43.33	35.85	17.94	18.08	47.42	33.91	14.68	22.81	43.33
Jacks	Low	26.29	14.53	15.77	30.35	38.39	29.35	16.06	53.23	28.36	18.02	16.06	34.27
	High	46.78	37.54	28.51	50.88	81.19	111.49	17.78	61.52	52.66	56.56	28.51	54.32
Mambo	Low	36.01	16.45	23.78	41.85	27.36	10.86	19.61	39.27	34.53	15.87	22.86	39.36
	High	48.69	23.62	31.95	54.79	45.01	19.89	24.93	54.61	48.06	22.84	31.95	54.61
Marching	Low	33.59	15.09	23.35	44.62	33.42	12.50	25.06	45.20	33.56	14.53	23.68	44.62
	High	81.94	52.19	46.95	99.79	87.39	74.66	28.41	96.76	82.87	55.57	46.95	97.99

Bench steps	Low	32.97	9.99	24.72	39.04	32.90	21.42	18.21	35.68	32.96	12.29	23.96	39.03
	High	43.27	20.20	28.12	51.59	60.62	38.38	36.22	75.62	46.24	24.52	30.57	55.67

Table shows summary statistics of the maximum jerk (based on the mean of the top 10 jerks experienced during the class) in the low and high intensity version of each aerobics class movement for the n=7 male and n=34 female participants.

Table 6: Associations between physical activity impact predictor variables with aggregate maximum g from all aerobics movements

Variable	Aggregate g (m/s²)					
	Univariate regression analysis			Multivariate regression analysis		
	Coef.	95% CI	p	Coef.	95% CI	p
Age (years)	-0.61	-0.87, -0.35	<0.001	-0.53	-0.77, -0.28	<0.001
Gender (female)	0.15	-0.70, 1.00	0.727	0.09	-0.57, 0.74	0.786
SPPB score (full marks)	0.37	-0.43, 1.17	0.355	0.10	-0.52, 0.72	0.746
Walk time (sec)	-0.51	-0.79, -0.23	0.001	-0.39	-0.63, -0.16	0.002
Chair rise time (sec)	-0.21	-0.52, 0.11	0.195	-0.08	-0.33, 0.18	0.539
MCS	0.07	-0.25, 0.39	0.667	0.24	-0.01, 0.38	0.061
PCS	0.33	0.03, 0.64	0.033	0.13	-0.11, 0.38	0.270

Table shows univariate and multivariate associations between aggregate maximum g from all aerobics movements with age, gender and indicators of health status (n=41).

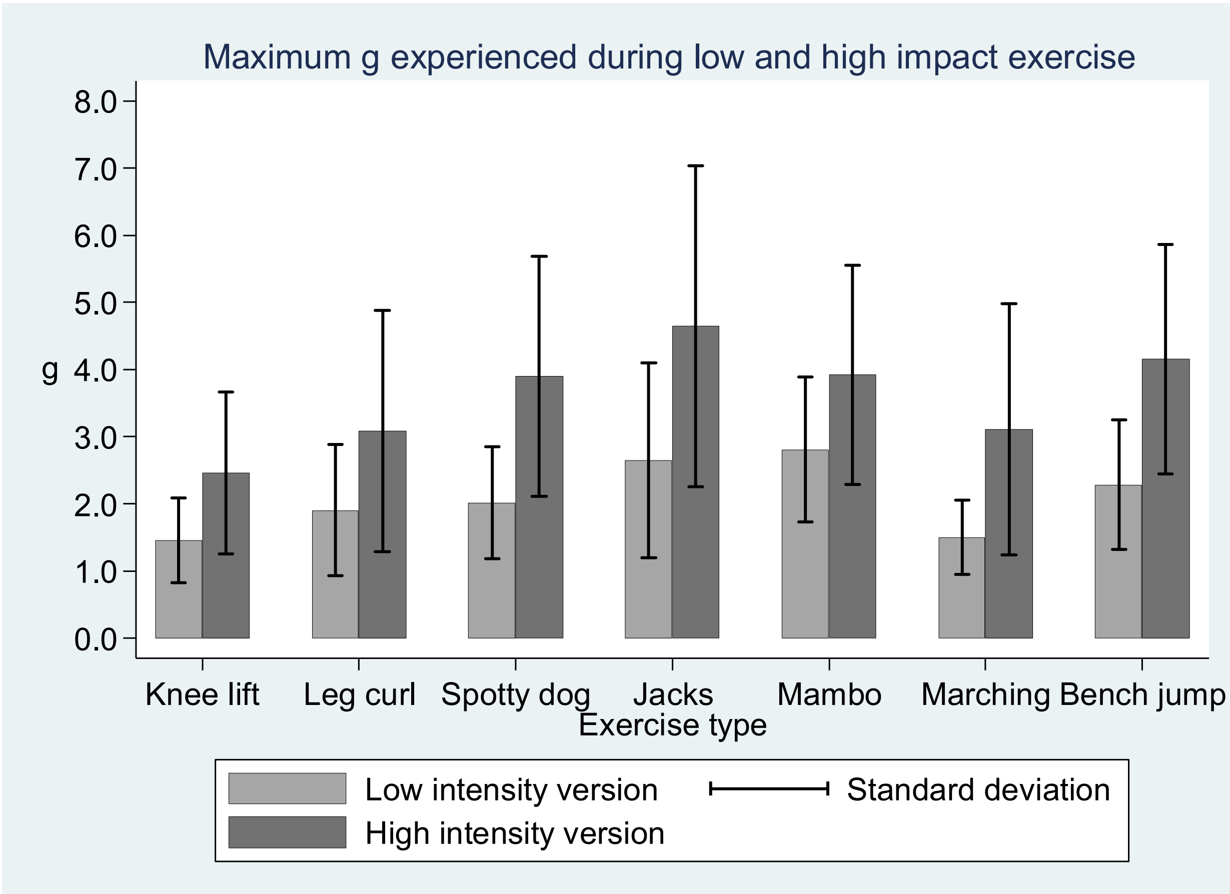
SPPB, short performance physical battery; MCS, Mental Component score; PCS, Physical component score

Table 7: Associations between physical activity impact predictor variables with aggregate maximum jerk from all aerobics movements

	Aggregate Jerk(m/s³)					
	Univariate regression analysis			Multivariate regression analysis		
Variable	Coef.	95% CI	p	Coef.	95% CI	p
Age (years)	-0.48	-0.76, -0.19	0.002	-0.28	-0.54, -0.02	0.036
Gender (female)	0.77	-0.04, 1.58	0.063	0.66	-0.04, 1.35	0.062
SPPB score (full marks)	0.16	-0.65, 0.96	0.698	-0.16	-0.82, 0.50	0.620
Walk time (sec)	-0.47	-0.76, -0.18	0.002	-0.32	-0.57, -0.07	0.014
Chair rise time (sec)	-0.34	-0.64, -0.03	0.030	-0.32	-0.59, -0.05	0.021
MCS	-0.13	-0.45, 0.19	0.418	0.13	-0.13, 0.40	0.315
PCS	0.42	0.13, 0.72	0.006	0.26	0.01, 0.52	0.046

Table shows univariate and multivariate associations between aggregate maximum jerk from all aerobics movements with age, gender and indicators of health status (N=41).
SPPB, short performance physical battery; MCS, Mental Component score; PCS, Physical component score

Figure 1


Maximum g experienced during low and high impact exercise
g
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Knee lift
Leg curl
Spotty dog
Jacks
Mambo
Marching
Bench jump
Exercise type
Low intensity version
High intensity version
Standard deviation

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