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ORIGINAL ARTICLE

Exercise volume and intensity: a dose–response relationship with health benefits

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Abstract
Introduction The health benefits of exercise are well established. However, the relationship between exercise volume and intensity and health benefits remains unclear, particularly the benefits of low-volume and intensity exercise.
Purpose The primary purpose of this investigation was, therefore, to examine the dose–response relationship between exercise volume and intensity with derived health benefits including volumes and intensity of activity well below international recommendations.
Methods Generally healthy, active participants ($n = 72$; age = 44 ± 13 years) were assigned randomly to control ($n = 10$) or one of five 13-week exercise programs: (1) 10-min brisk walking 1×/week ($n = 10$), (2) 10-min brisk walking 3×/week ($n = 10$), (3) 30-min brisk walking 3×/week ($n = 18$), (4) 60-min brisk walking 3×/week ($n = 10$), and (5) 30-min running 3×/week ($n = 14$), in addition to their regular physical activity. Health measures evaluated pre- and post-training including blood pressure, body composition, fasting lipids and glucose, and maximal aerobic power (VO_2max).
Results Health improvements were observed among programs at least 30 min in duration, including body composition and VO_2max: 30-min walking 28.8–34.5 mL kg^{-1} min^{-1}, 60-min walking 25.1–28.9 mL kg^{-1} min^{-1}, and 30-min running 32.4–36.4 mL kg^{-1} min^{-1}. The greater intensity running program also demonstrated improvements in triglycerides.
Conclusion In healthy active individuals, a physical activity program of at least 30 min in duration for three sessions/per week is associated with consistent improvements in health status.

Keywords Aerobic exercise · Body composition · Physical activity · Lipid metabolism · Exercise intensity

Abbreviations

A1C	Glycosylated hemoglobin
BMI	Body mass index
CVD	Cardiovascular disease
HDL	High-Density Lipoprotein
LDL	Low-density lipoprotein
PAR-Q+	Physical activity readiness questionnaire for everyone
SD	Standard deviation
TC	Total cholesterol
VO_2max	Maximal aerobic power

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Introduction

A relationship between physical activity and health benefits has been well established (Blair and Morris 2009; Warburton et al. 2006b; Wen et al. 2011). Regular physical activity has been associated with improved body composition [weight, body mass index (BMI), waist circumference], vascular health (arterial compliance), and blood pressure (Blair and Morris 2009; DeVan et al. 2005; Edwards and Lang 2005; Slentz et al. 2004). In addition, improved lipid lipoprotein profile [total cholesterol (TC), high-density lipoprotein cholesterol (HDL), triglycerides] and glucose homeostasis [glucose tolerance and glycosylated hemoglobin (A1C)] have been observed with increased physical activity (Dengel et al. 1996; Snowling and Hopkins 2006; Warburton et al. 2010; Wen et al. 2011). Exercise training is also known to improve health-related physical fitness measures including maximal aerobic power (VO_2max) and musculoskeletal fitness (Bouchard et al. 1999; Kell et al. 2001; Warburton et al. 2010; Wenger and Bell 1986).

The dose–response nature of this relationship between physical activity and improved health has also been demonstrated with morbidity, overall mortality, and numerous chronic conditions (Kesaniemi et al. 2001; Kohl 3rd 2001; Lee and Skerrett 2001; Wen et al. 2011). Current recommendations promote physical activity/exercise volumes of at least 150 min·week^{-1} (Tremblay et al. 2011; US Department of Health and Human Services 2008; Warburton et al. 2010). However, Wen et al. (2011) showed in their prospective cohort study, with 416,175 individuals that much lower volume physical activity may have some benefits on health; however, more evidence is required before it is possible to generalize. Further, while a linear inverse relationship between physical activity and chronic disease mortality and death has been proposed, the nature of this relationship with lower volumes of exercise is unknown (Kesaniemi et al. 2001; Kohl 3rd 2001; Lee and Skerrett 2001; Warburton et al. 2006b; Wen et al. 2011).

The primary purpose of this investigation was to accurately examine the dose–response relationship between physical activity and health benefits in relation to exercise programs of differing exercise volume and intensity including low-volume and recommended exercise volumes. We hypothesized that minimal health benefits would be attained with low-volume exercise training, while increased exercise volume and intensity would lead to increased health benefits.

Materials and methods

Participants ($n = 114$) were assigned randomly to one of five exercise training programs, or a control group. Participants represented a range of ages, from 20 to 65 years of age, who were not previously diagnosed with diabetes or cardiovascular disease. All participants were cleared using the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) (Warburton et al. 2011). Participants in this training program include only individuals who responded 'No' to each of the PAR-Q+ questions. Ethical approval was obtained through the Clinical Research Ethics Board at the University of British Columbia and written informed consent was obtained from each participant prior to data collection. Participants were recruited through notices posted in community centers and public locations around the community.

Individual characteristics collected included age, sex, self-reported smoking status, and medical personal and/or family history of diabetes, cardiovascular disease and hypertension. Anthropometric measures of height, body mass and waist circumference (and BMI calculated) were collected according to standardized protocols established by the Gledhill and Jamnik (2003). Measurements of height were determined using a Seca 214 portable height rod stadiometer (Seca Corp., CA, USA). Body mass was recorded using a Health o meter Professional model 142KLS scale (Sunbeam Products Inc, Ontario).

Resting blood pressure was evaluated following 3 min of seated rest (BP-TRU, VSM Medical, Vancouver, BC). Arterial compliance was evaluated using three supine resting measures of applanation tonometry (HDI/Pulsewave CR-2000 Cardiovascular Profiling System, Egan, Minnesota) on the right wrist with an appropriate-sized blood pressure cuff and a rigid plastic wrist stabilizer, after 5 min of supine rest. A fasting blood sample was used to measure blood glucose and lipid profile using the point of care Cholestech LDX system (Cholestech, Inverness Medical, Hayward, CA). Blood measures of glycosylated hemoglobin were evaluated by measuring A1C (A1C Now+, Bayer, Sunnyvale, CA). An oral glucose tolerance test was performed where participants consumed a 100-mg glucose tolerance beverage (Trutol, Thermo Scientific, Mississauga, Ont.) following the initial lipid and blood glucose evaluation. Two hours following the glucose tolerance drink, another measure of blood glucose was performed using the Cholestech LDX system. Metabolic syndrome risk was assessed using the International Diabetes Federation definition, with Canadian waist circumference thresholds of $\geq$102 cm among men and $\geq$88 cm among women (Alberti et al. 2009). Maximal aerobic power (VO_2max) was evaluated directly using a calibrated mass spectrometer (Amis 2000, Innovision, Odense, Denmark) with breath-by-breath analysis during a Bruce Treadmill VO_2max protocol (Bruce et al. 1973).

Prior to and following the training program, 1 week of physical activity was measured using self-report via the Godin–Shephard Leisure-Time Exercise Questionnaire (Godin and Shephard 1985). Each measure was repeated both prior to and following 13 weeks of physical activity training. Five community-based physical activity programs, as well as a control group, were assessed in this intervention. Each exercise program ran 13 weeks in duration, from May to August. Participants were assigned randomly to one of the following exercise programs: 10 min of brisk walking once per week, 10 min of brisk walking three times per week, 30 min of brisk walking three times per week, 60 min of brisk walking three times per week or 30 min of running three times per week, or a control group prescribed no additional exercise training. Throughout the 13 weeks, participants attended the same physical activity program, led by a qualified exercise professional (Certified Exercise Physiologist and/or Certified Personal Trainer). Participants were asked to keep a log of all physical activity, including the training sessions to track program compliance. Participants were instructed to complete the assigned training program in addition to their regular physical activity.

Statistical analysis

Statistical analyses were performed using Statistica 9.0 (Stats Soft, Tulsa, OK). Changes in health measures within groups were evaluated using repeated measures ANOVA analysis, while baseline differences between groups were evaluated using ANCOVA analysis adjusted for age and gender. Any differences between groups in the changes in health measures with training were evaluated using ANCOVA analysis of post-training measure adjusted for age, gender, and pre-training measure. Tukey's HSD post hoc analysis was employed to determine where any differences in the health improvements existed. All statistical assessments were considered significant at $p < 0.05$.

Results

Of the recruited 114 participants initially assessed, 6.1 % ($n = 7$) withdrew from the investigation prior to completing the initial assessment and 30.7 % (n = 35) were lost due to follow-up. Overall, a total of 72 participants were assessed post-training. Participants in each physical activity program were similar in age, spanning 20–65 years (Table 1). Attrition rates (18–47 %) and program compliance rates (86.1–99.2 %) were similar across all groups. In addition, no difference in age or sex was identified between groups. Participants were generally active prior to the investigation, with no difference in pre-training activity levels between groups. There were no exercise-related adverse events. Metabolic syndrome was identified among seven of the 72 (9.7 %) participants, demonstrating a range of elevated risk factors. Significant increases in self-reported physical activity levels with training were observed among those participating in the greater duration and intensity programs.

Maximal aerobic power was found to significantly improve with training, among the 30-min brisk walking 3×/week and 30-min running 3×/week groups (Fig. 1). Relative to the changes experienced by the control group, the 30- and 60-min brisk walking 3×/week groups experienced significantly greater increases in VO_2max. The 10-min brisk walking programs did not experience significant changes in aerobic capacity.

As outlined on Fig. 2, changes in blood pressure measures (Fig. 2a, b) were not observed with training in this normotensive cohort. With training, improvements in body mass status (Fig. 2c) were observed among the 30-min brisk walking 3×/week group. Further, the changes in weight among the 30-min brisk walking and running 3×/week groups were found to be significantly different from the changes among the control group. Changes in waist circumference were found among both the 10- and 30-min brisk walking 3×/week groups (Fig. 2d), where the 30-min group decreased in waist circumference and the 10-min group increased in waist circumference. Changes in waist circumference observed among the 10- and 60-min brisk walking 3×/week group were found to be significantly different than that of the control group, where the 60-min group experienced a decrease in waist circumference, while the 10-min group experienced an increase.

Prior to the intervention, all groups were found to have similar hemodynamic measures, including total cholesterol, HDL cholesterol, triglycerides, low-density lipoprotein (LDL) cholesterol, fasting plasma glucose, glucose tolerance and A1C (Table 2). The control group did not demonstrate changes in hemodynamic measures. The 30-min brisk walking and running 3×/week groups improved their total cholesterol levels ($p = 0.05$). Over the 13 weeks, HDL levels significantly decreased among the 10-min brisk walking group 3×/week and the 60-min brisk walking group 3×/week. Triglyceride levels significantly improved among the running group participants with training, while LDL cholesterol levels were not found to change among any group with training. Fasting plasma glucose levels were observed to significantly improve among the 10-min brisk walking 1×/week group, while there was a trend for glucose tolerance to improve among the 60-min brisk walking group ($p = 0.06$). Blood A1C measures were not observed to change with training. Overall, arterial compliance measures were found to be similar across all groups prior to the intervention. With training, neither small nor large arterial compliance was found to improve among any groups.

Discussion

This investigation evaluates the health benefits of increasing physical activity among a generally healthy and

Table 1 Characteristics of participants by training program

	Control group	10-min brisk walking 1×/wk	10-min brisk walking 3×/wk	30-min brisk walking 3×/wk	60-min brisk walking 3×/wk	30-min running 3×/wk	*p* value
Final *n*	10	10	10	18	10	14	
Attrition rate *n*, (%)	5 (33.3)	5 (33.0)	9 (47.0)	6 (25.0)	7 (41.0)	3 (18.0)	0.36
Program compliance mean ± SD (%)		89.8 ± 23.3	99.2 ± 2.4	86.1 ± 16.4	87.5 ± 11.7	87.1 ± 14.5	0.59
Female *n*, (%)	6 (60.0)	4 (40.0)	6 (60.0)	13 (72.2)	8 (80.0)	8 (57.1)	0.51
Age mean ± SD (year)	36.7 ± 15.4	45.6 ± 10.8	39.3 ± 14.8	46.4 ± 10.4	42.4 ± 13.2	42.3 ± 13.3	0.47
Godin physical activity level							
Pre-training	33.4 ± 19.8	29.9 ± 14.7	34.1 ± 22.8	30.4 ± 17.8	30.7 ± 22.8	32.3 ± 21.0	1.00
Post-training	40.8 ± 22.4	61.7 ± 40.5	33.0 ± 19.6	36.3 ± 20.5	41.7 ± 20.4	46.0 ± 19.2	
p value	0.16	0.14	0.77	0.06	<0.001	0.04	0.29†
Metabolic syndrome risk factors							
Waist circumference ≥102 cm or ≥88 cm *n*, (%)	2 (20.0)	2 (20.0)	2 (20.0)	3 (16.7)	6 (60.0)	3 (21.4)	0.18
Triglycerides ≥1.7 mmol L^{-1} *n*, (%)	1 (10.0)	2 (20.0)	1 (10.0)	4 (22.2)	2 (20.0)	1 (7.1)	0.84
HDL <1.0 mmol L^{-1} or <1.3 mmol L^{-1} *n*, (%)	2 (20.0)	2 (20.0)	2 (20.0)	5 (27.8)	2 (20.0)	4 (28.6)	0.99
SBP ≥130 mmHg or DBP ≥85 mmHg *n*, (%)	3 (30.0)	3 (30.0)	0 (0.0)	0 (0.0)	3 (30.0)	3 (21.4)	0.08
Fasting blood glucose ≥5.6 mmol L^{-1}	2 (20.0)	2 (20.0)	1 (10.0)	1 (5.6)	1 (10.0)	0 (0.0)	0.53
Metabolic syndrome *n*, (%)	1 (10.0)	1 (10.0)	0 (0.0)	3 (16.7)	2 (20.0)	0 (0.0)	0.46

DBP diastolic blood pressure, *SBP* systolic blood pressure, *SD* standard deviation, *wk* week

† Difference in physical activity change between groups

relatively active (Godin 2011) population by a spectrum of physical activity programs including lower volume 10 min once weekly exercise training. Generally, improvements in health measures were observed among physical activity training programs of greater duration and/or intensity, with limited improvements with smaller increases in regular physical activity. However, low-volume exercise training (10-min brisk walking 3×/week) demonstrated improvements among fasting plasma glucose. Larger volume exercise training programs demonstrated more consistent improvements including body composition, aerobic capacity, musculoskeletal and hemodynamic improvements. These findings are consistent with systematic reviews of the literature conducted by our laboratory that greater volumes of activity/exercise lead to greater health benefits (Warburton et al. 2010). However, they also support the systematic reviews evidence that volumes of exercise far below international recommendations may have health benefits. As little as 1 h of walking per week has been shown to reduce cardiovascular-related death (Oguma and Shinoda-Tagawa 2004).

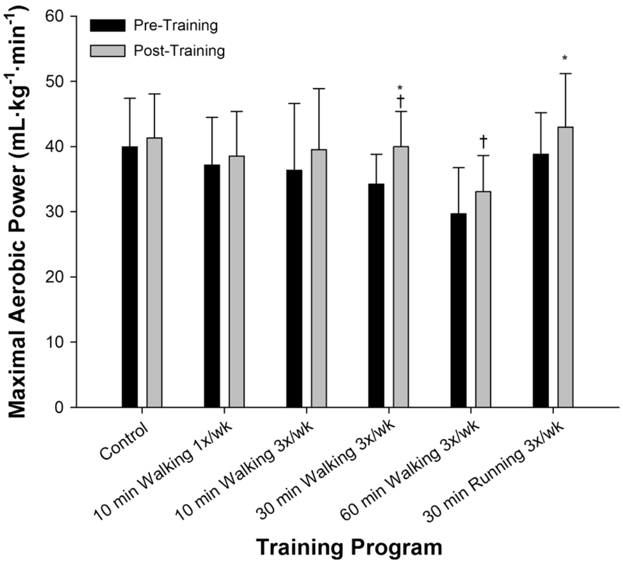

Fig. 1 Increases in maximal aerobic power with training among five 13-week training programs and a control group. *Asterisk* indicates significant difference from pre-training to post-training, $p < 0.05$. *Dagger* indicates significantly different change from change among control group, $p < 0.05$. *Black* pre-training, *Gray* post-training

Health improvements among walking or running programs 30 min in duration have frequently been identified in past (Dunn et al. 1999; King et al. 1995; Rippe et al. 1988). These findings are consistent with traditional physical activity recommendations of 30 min of exercise on most days of the week (Haskell et al. 2007a). Benefits of physical activity as identified in this intervention are consistent with previous evidence finding improvements in body

Fig. 2 Changes in systolic (**a**) and diastolic (**b**) blood pressures, weight (**c**) and waist circumference (**d**) with training among five 13-week training programs and a control group. *Asterisk* indicates significant difference from pre-training to post-training, $p < 0.05$. *Dagger* indicates significantly different change from change among control group, $p < 0.05$. *Black* pre-training, *Gray* post-training

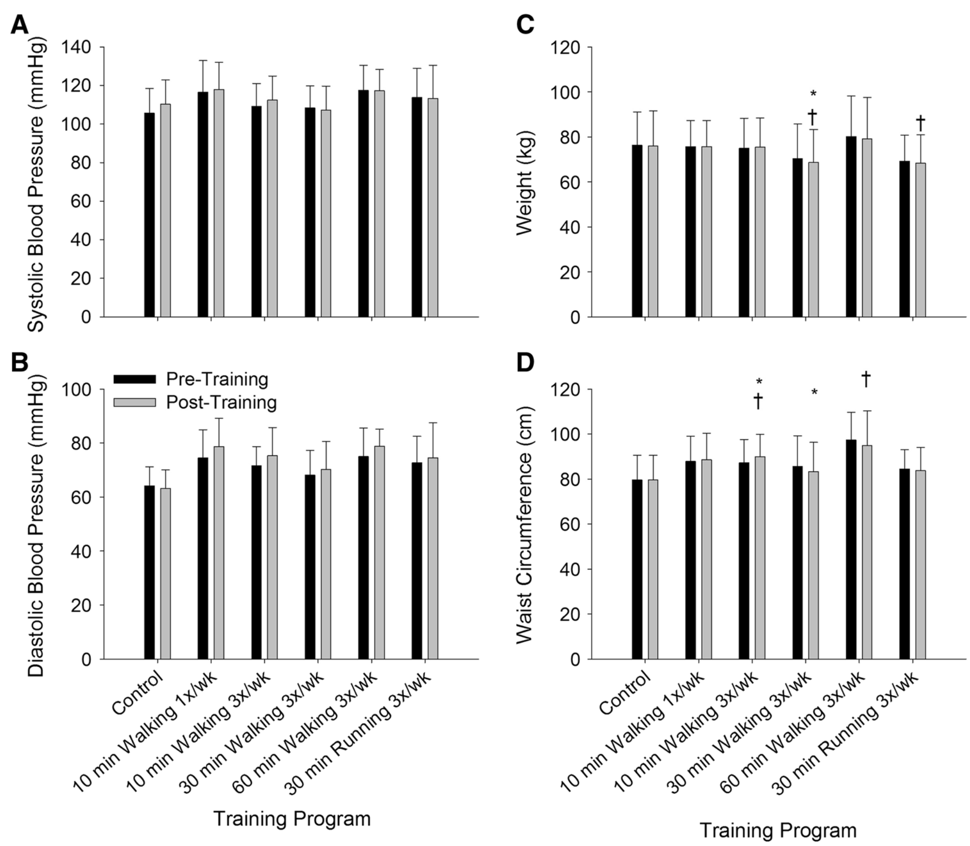

Table 2 Hemodynamic and vascular characteristics of participants by training program and training status, change ± SD

		Control group	10-min brisk walking 1×/wk	10-min brisk walking 3×/wk	30-min brisk walking 3×/wk	60-min brisk walking 3×/wk	30-min running 3×/wk	*p* value
Total cholesterol (mmol/L)	Pre-training	4.78 ± 1.04	4.87 ± 0.52	5.25 ± 1.56	4.97 ± 1.13	5.16 ± 1.19	5.28 ± 1.34	0.93
	Post-training	4.71 ± 0.84	4.73 ± 1.10	4.96 ± 1.39	4.69 ± 1.01	5.18 ± 1.20	5.06 ± 1.13	
	p value	0.72	0.59	0.18	0.08	0.94	0.05	
HDL cholesterol (mmol/L)	Pre-training	1.49 ± 0.50	1.46 ± 0.40	1.52 ± 0.39	1.55 ± 0.42	1.55 ± 0.48	1.31 ± 0.38	0.68
	Post-training	1.41 ± 0.57	1.31 ± 0.44	1.39 ± 0.35	1.40 ± 0.30	1.32 ± 0.40	1.23 ± 0.41	
	p value	0.54	0.12	0.03	0.09	0.004	0.26	
Triglycerides (mmol/L)	Pre-training	1.26 ± 0.80	1.34 ± 0.67	1.59 ± 0.90	1.19 ± 0.45	1.35 ± 0.44	1.69 ± 1.53	0.97
	Post-training	1.29 ± 0.55	1.22 ± 0.71	1.09 ± 0.40	0.99 ± 0.42	1.58 ± 0.64	1.32 ± 1.23	
	p value	0.68	0.40	0.12	0.18	0.13	0.04	
LDL Cholesterol (mmol/L)	Pre-training	2.70 ± 1.02	2.92 ± 0.44	3.30 ± 2.00	2.95 ± 0.94	2.99 ± 0.90	3.34 ± 1.11	0.90
	Post-training	2.92 ± 0.72	2.85 ± 0.85	3.37 ± 1.46	2.80 ± 0.86	3.14 ± 1.09	3.53 ± 1.39	
	p value	0.37	0.81	0.77	0.20	0.65	0.19	
Fasting glucose (mmol/L)	Pre-training	5.05 ± 0.80	5.14 ± 0.73	5.04 ± 0.48	4.97 ± 0.42	5.01 ± 0.43	4.92 ± 0.48	0.90
	Post-training	4.64 ± 0.35	4.73 ± 0.61	4.97 ± 0.41	4.88 ± 0.56	4.88 ± 0.49	4.89 ± 0.43	
	p value	0.18	0.01	0.50	0.37	0.16	0.82	
2 h post glucose tolerance (mmol/L)	Pre-training	6.40 ± 1.27	5.90 ± 2.10	6.04 ± 1.13	6.15 ± 1.19	6.49 ± 0.92	6.47 ± 1.70	0.87
	Post-training	5.91 ± 1.26	5.92 ± 2.04	5.81 ± 0.55	6.06 ± 1.42	5.77 ± 0.95	5.95 ± 1.42	
	p value	0.39	0.94	0.54	0.85	0.06	0.11	
A1C (%)	Pre-training	5.5 ± 0.2	5.4 ± 0.6	5.4 ± 0.4	5.5 ± 0.3	6.1 ± 1.6	5.4 ± 0.3	0.18
	Post-training	5.5 ± 0.3	5.6 ± 0.6	5.3 ± 0.3	5.4 ± 0.3	5.5 ± 0.5	5.3 ± 0.3	
	p value	1.00	0.27	0.69	0.47	0.26	0.53	
Small artery compliance (mL/mmHg × 100)	Pre-training	7.45 ± 3.24	6.69 ± 3.14	7.04 ± 1.57	7.46 ± 3.21	5.86 ± 2.27	7.35 ± 3.32	0.14
	Post-training	8.08 ± 3.36	6.51 ± 3.02	7.57 ± 2.25	7.53 ± 3.09	6.63 ± 4.12	7.30 ± 3.35	
	p value	0.89	0.76	0.40	0.93	0.38	0.94	
Large artery compliance (mL/mmHg × 10)	Pre-training	19.20 ± 10.12	15.13 ± 2.64	13.53 ± 2.74	14.38 ± 3.63	15.60 ± 3.90	13.62 ± 2.89	0.63
	Post-training	17.51 ± 6.45	14.40 ± 4.66	14.76 ± 3.84	15.39 ± 5.14	15.16 ± 3.77	13.97 ± 3.13	
	p value	0.39	0.43	0.28	0.26	0.71	0.73	

HDL high-density lipoprotein, *LDL* low-density lipoprotein, *SD* standard deviation composition, blood pressure, lipid profiles, glucose homeostasis, and other measures of physical fitness with exercise training (Shephard and Balady 1999; Warburton et al. 2010, 2007, 2006b). The (Oguma and Shinoda-Tagawa 2004) 30-min training programs investigated in this intervention represent ~500–1,200 kcal/week of additional exercise (Warburton et al. 2006a). Improvements in mortality from ischemic heart disease have previously been identified with exercise increases from 500 to 3,500 kcal/week (Paffenbarger et al. 1993). The identification of weight loss only among larger programs supports the larger physical activity volume required for weight maintenance and weight loss (Haskell et al. 2007a). In addition, improvements in aerobic fitness have generally been identified among training programs conducted 3×/week or 35 min/session (Duncan et al. 2005; Wenger and Bell 1986), matching our finding of significant improvements among programs with 30 min/session for 3×/week (i.e., 90 min/week of moderate intensity exercise) or more.

Wisloff and associates previously reported a decrease in the relative risk of death from cardiovascular disease (CVD), ischemic heart disease or stroke with physical activity frequency as low as once weekly (Wisloff et al. 2006). Further, it was previously identified that increases in the frequency of physical activity were not found to be associated with reduced risk of death from CVD, ischemic heart disease or stroke (Wisloff et al. 2006). In addition, improvements in aerobic fitness and body composition have been identified among previously inactive postmenopausal women with low-volume exercise training programs (Asikainen et al. 2002a, b, 2003). Conversely, improvements in aerobic fitness were identified among the greater intensity or frequency programs, with sessions at least 30 min in duration among previously sedentary adults (Duncan et al. 2005). Our investigation identified improvements among the larger volume training programs, supporting the dose–response benefits of greater amounts of physical activity. The lack of improvements in body composition and aerobic fitness among the lower volume training programs in this investigation may result from the younger, healthy, active participants utilized in this investigation, rather than the inactive, postmenopausal status of other investigations (Asikainen et al. 2002a, b, 2003). These results suggest greater volumes and intensity programs are required to improve the health of adults who are healthy and generally active. While multiple bouts of 10-min exercise per day have also previously been found to provide similar benefits to one continuous 30-min bout (Murphy et al. 2002), these findings support recent physical activity recommendations where increases in physical activity are recommended in bouts of 10 min or more as 10-min duration can be associated with improvements, while greater volumes are more beneficial (Haskell et al. 2007b; World Health Organization 2010). Further, these results demonstrate consistent improvements in health measures can be achieved with 90 min of exercise per week, well below the 150 min currently recommended. These findings have important implications for the development of effective exercise interventions, particularly for those with low functional capacities.

The lowest attrition rates were observed among the 30-min programs. In addition, the highest program compliance of attending and completing the training program was observed among the 60 min of exercise 3×/week program. These results further support the use of greater program duration and/or intensity to improve the health of relatively healthy, active adults, through increased physical activity.

Study limitations and strengths

The use of relatively healthy, active individuals, in this training investigation may limit the generalizability of these results to individuals who are sedentary or less healthy. While individuals who are active may require greater intensity and/or duration training programs to improve their health, less active individuals may achieve greater benefits from lower volume training programs. Small sample size following program attrition likely reduced the significant improvements identified across all training programs. Reductions in the absolute measure of most health measures may suggest improvements; however, statistical significance could not be identified in many instances. Further, this small sample size also likely reduced the ability to determine significant differences in improvements relative to the control group. Future investigations should evaluate similar training programs with larger numbers of participants to further identify the health benefits associated with low-volume exercise training. The decrease in HDL cholesterol observed across all intervention and control groups likely results from seasonal variation in physical activity resulting from activities of daily living, where the completion of exercise training was evaluated in the fall months, following peak leisure activity spring and summer months (Matthews et al. 2001; Uitenbroek 1993).

This investigation included training programs three times weekly, reflecting the frequency of many general population training programs. Further the combination of instructor led sessions with at home sessions may reflect general public experience of exercise where individuals train without supervision.

Conclusion

Health benefits were consistently observed in exercise programs involving 90 min of moderate intensity exercise per week. The largest health improvements were observed among training programs of greater duration and/or intensity supporting the dose–response relationship demonstrated consistently in epidemiological research. Individuals who are generally healthy and active require greater volume training programs to elicit health improvements.

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Conflict of interest We have no conflict of interest to declare.

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