Training of aerobic fitness (VO_{2max}) and muscle strength – a cost/benefit analysis

Haakon Breien Benestad[1], Kristin Larsen Sand[1] and Jo Christiansen Bruusgaard[2]

[1]Institute of Basic Medical Sciences, Section of Physiology, University of Oslo, Norway
[2]Department of Health Sciences, Kristiania University College, PB 1155 Sentrum, 0107 Oslo, Norway

Haakon Breien Benestad: h.b.benestad@medisin.uio.no
Kristin Larsen Sand: k.l.sand@medisin.uio.no
Jo C. Bruusgaard: jo.bruusgaard@kristiania.no

Abstract

Background. The review summarizes dose-response studies of exercise.

Method. A systematic literature search in the Ovid Medline, Web of Science and SportDiscus databases was performed, limited to randomized studies of aerobic fitness and strength training, respectively. Studies with at least three "doses" of frequency, duration or intensity of training were examined in order to find out what effect could be expected from the next highest “dose”.

Results. 16 studies of aerobic fitness and 27 strength studies matched our inclusion criteria and are surveyed and presented in tables. We found that as little as 20-minute exercise twice a week may be sufficient to develop and maintain satisfactory aerobic fitness, provided that the exercises are performed in intervals varying between 65% and 90% of HR_{max} intensity. For strength gain and maintenance, resistance training at 60-70% of 1RM, once a week, with one set of 8 repetitions per muscle group, appears to give satisfactory strength.

Conclusion. We suggest that most people can exercise less than recommended and still maintain a useful performance level.

Methods

Literature search

Three databases were searched:

1. Ovid Medline: (exp exercise/ph OR exp sports/ OR physical activit*.tw.) AND (dose-response.tw OR maximum heart rate*.tw OR maximum oxygen uptake.tw). Limit to randomized controlled trial. (June 21, 2017; 399 hits)
2. Web of Science: ((exercise OR physical activit* OR sports) AND ("dose-response" OR "maximum heart rate" OR "maximum oxygen uptake") AND random*), restricted to the categories (SPORT SCIENCES OR PHYSIOLOGY) (June 21, 2017; 346 hits)
3. SportDiscus: (Exp exercise OR "physical activit*".tw. OR exp sports OR "resistance training") AND ("Dose-respons".tw. OR "heart rate" OR "oxygen uptake" OR "oxygen consumption" OR "metabolic equivalent") (July 5, 2017; 766 hits)

The searches were limited to randomized studies of aerobic fitness and strength training, respectively, where at least three "doses" were examined, one of which could be a control/basal level. Although the searches were unrestricted in time, the first findings were in Medline from 1979, from the Web of Science 1991 and from SportDiscus 1983. Only studies with healthy people were chosen, but subjects could be overweight and there were no age limits. Journal articles were limited to the English and Scandinavian languages. Titles and abstracts were read to find studies that satisfied the inclusion criteria. Relevant articles identified by the general PubMed search were reviewed, along with additional materials found in the reference lists of articles from the search, as well as relevant works from our private literature archives.

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Table 1. *Example of recommended aerobic fitness training, to develop and maintain the function*

Frequency	Intensity (% HR_{max})	Type of activity	Low-intensity intervals between spurts	Duration	Mode of training
3-5 d/wk	65–90 #	4-min intervals	4 min	20–60 min*	Running, cross-country skiing, swimming, bicycling (all trains many and large muscle groups)

Lower intensity for sedentary individuals, therefore with longer duration.

* Less than 20 min/d may also be beneficial, especially for sedentary persons, possibly as multiple series of ≥ 10 min (Garber et al., 2011). The recommendations include stretching and warm-up exercises, as well as relaxation exercises, which may be important especially for the elderly (Pollock et al., 1998).

Table 2. *Example of recommended muscle strength training, to develop and maintain the function*

Frequency	Intensity	Repetitions per muscle group	Number and rest between sets	Type of muscle contraction
2-3 d/wk *	60–70% of 1 RM # ¤	8–12 §; >8–10 exercises, for the greatest muscle groups ¤	2–4 sets for most adults; 1 set for elderly persons and newcomers. 2–3 min rest between the sets	CON (e.g. 180–240$^{0}\cdot s^{-1}$); may choose or include ISOM or ECC

*In addition, warm-up exercises. Variable, composite programs that one switches between, and circle training, may be advantageous. Older people may use more and easier repetitions than younger ones.

80–100% for the well-trained, who usually use weights, fewer repetitions and up to 6 sessions per week. 40–50% initially for older and sedentary beginners. To improve muscle strength: Increase the load 2–10% when a participant can perform 1–2 repetitions more than the prescribed ones, possibly also increase the frequency of training.

¤ Endurance is best exercised with lighter resistance, more repetitions and shorter rest periods than strength training. Muscle power is increased with lower load and greater velocity (Ratamess et al., 2009).

§ 10–15 repetitions, with less strain, for older and weaker persons; 6–8 for greater effect on strength, and correspondingly greater load.

Table 3. *Some exercise variables*

Acronym	**Explanation**
HR_{max}	Maximum heart rate/peak heart rate
HRR	Maximum heart rate reserve
VO_{2max}	Maximum oxygen uptake
VO_2R	Maximum oxygen uptake reserve
d/wk	Frequency of training
ECC	Eccentric contractions
CON	Concentric contractions
ISOM	Isometric contractions
1 RM	Maximum force, 1 repetition
9 RM	Maximum force, with 9 repetitions.
Set	No. of repetitions of an exercise
Strength · velocity	Muscle power

Table 4. *Survey randomized dose-response studies of fitness training*

Shorthand group designation and result (% improved VO_{2max})				Session characteristics, etc.	Sessions/ wk	Test period (wk)	Participants: number, gender, (mean) age (yr), and body mass index (BMI), training state, type of exercise	Reference
1 d/wk **2.3**%	2 d/wk **8.0**%	3 d/wk **4.2**%	-	Continuous exercise, increasing in 40 min to 80% HR_{max} 1 *vs*. 2 *vs*. 3 d/wk	1; 2; 3	16	72 ♀, 60–74 yr, BMI < 28, sedentary, cycle ergometer and treadmill	(Hunter et al., 2013)
Control: **0.0**%	60%, 3 d: **12.1**%	60%, 5 d: **13.9**%	-	60% VO_{2max}: 60 min → > 150 min/wk, 3 sessions/wk *vs*. 60 min → > 240 min/wk, 5 sessions/wk	3 *vs*. 5	24	56 ♀, 61 yr, BMI < 34, sedentary, walking	(Ready et al., 1996)
Advice only: 24 wk: **2.0**%; 104 wk: **2.0**%	75%, 4/wk 24 wk: **3.4**% 104 wk: **3.0**%	55%, 7/wk 24wku: **3.9**% 104 wk: **3.5**%	75%, 7/wk 24 wk: **7.2**% 104 wk: **4.9**%	65–75% HRR, 3–4 sessions/wk *vs*. 45–55%, 5–7 sessions /wk *vs*. 65–75%, 5–7 sessions /wk; all 30 min/session.	3–4 *vs*. 5–7	24 and 104	260 ♂/♀ (for 24-wk data; 399 for 104-wk data), 30–69 yr, BMI 19–45, sedentary, walking	(Duncan et al., 2005)§
Control: **− 0.6**%	4kcal: **4.2**%	8kcal: **6.0**%	12 kcal: **8.2**%	All 50% VO_{2max}; 72 min/wk, 4 kcal/kg×wk *vs*. 136 min, 8 kcal/kg×wk *vs*. 192 min, 12 kcal/kg×wk	2.6–3.1	≈ 26	464 ♀, 45–75 yr, BMI 25–43, sedentary, bicycling/ treadmill	(Church et al., 2007)
Contin. low-intensity: **3.4**%	4 x 16: **6.5**%	4 x 8: **10.4**%	4 x 4: **5.6**%	Low-intensity, continuous, 4–6 sessions/wk *vs*. Low-intensity, continuous 2–3 sessions/wk + 2 sessions/wk interval sessions: 4 × 16 min intervals (88% HR_{max}) *vs*. 4 × 8 min (90% HR_{max}) *vs*. 4 × 4 min (94% HR_{max})	4–6 *vs*. 2–3 low-intens. + 2 high intens.	7	35 ♀/♂, 25–49 yr , trained amateur cyclists	(Seiler et al., 2013)
Control: **0**%	20-min: **8.8**%#	40-min: **9.1**%#	-	20 min, 134 kcal/session *vs*. 40 min, 269 kcal/session	5	10–15	222 ♂/♀, 7–11 yr, BMI 26, sedentary, aerobics	(Davis et al., 2012)

High intensity interval training: 1x/session **5.0**%	2x/sess. **7.0**%	4x/sess. **8.6**%	5 x/sess. **7.1**%	90–100 % HR_{max} in 20 s, 10 s rest between each spurt; 1 *vs.* 2 *vs.*4 *vs*. 5 spurts/session [group 3 with 3 x/session: result not given]	2	8	26 ♂, 12–18 yr, BMI 23, sedentary, optional bicycling, running, rowing, etc., (all groups also one strength training session/wk)	(Logan et al., 2016)
45% – 1000: **1.0%**	55% – 1000: **1.7**%	45% – 1500: **1.9**%	55% – 1500: **3.3**%	45% VO_{2max}– 1000 kcal/wk; 55% – 1000 kcal/wk; 45% – 1500 kcal/wk; 55% – 1500 kcal/wk	5	24	121 ♀, 48–63 yr, BMI < 32, sedentary, walking	(Asikainen et al., 2002)
Control: − **0.5**%	30 min: **11.0**%	45 min: **26.2**%	-	50% VO_2R, 30 min/session *vs*. 50%, 45 min/session	5	12	26 ♀, 45–75 yr , sedentary, walking	(Dalleck et al., 2009)
Control: − **1.1**%	55%, low volume **6.5**%	80%, low volume **11.2**%	80%, high volume **19.6**%	40–55% VO_{2max}, 179 min/wk, 17.0 km/wk *vs*. 65–80%, 114 min/wk, 17,8 km/wk *vs*. 65–80%, 175 min/wk, 27,7 km/wk	3.0 – 3.7	≈ 26	163 ♀/♂, 40–65 yr, BMI 25–35, sedentary, walking/jogging	(Duscha et al., 2012)
65%, contin.: **10.0**%	90%, 3-min intervals: **22.5**%	120%, 30-s spurts: **16.7**%	-	60–65% VO_{2max}, 45 min, 360 kcal (continuous) *vs*. 85–90%, 18 min, 180 kcal (high-intensity intervals) *vs*. ⩽ 120%, 10 min, 110 kcal (spurts, intervals)	5	8	42 ♂, 26 yr, BMI < 25, sedentary, cycling	(Matsuo et al., 2014)
Control: − **6.5**%	50%: **20.2**%	70%: **22.3**%	-	50 *vs*. 70% VO_{2max}, all: individually adapted duration; volume constant: 14.2 kcal/kg×wk in 4 wk, 18.9 kcal/kg×wk in 5 wk, 23.6 kcal/kg×wk in 5 wk.	3→4→ 5	14	22 ♀, 30–50 yr, BMI > 25, sedentary, treadmill	(Lee et al., 2012)
Control: **1.9**%	50% conti-nuous: **9.6**%	75% conti-nuous: **14.3**%	95% interval: **20.2**%	50% HRR, 60 min, 4 sessions/wk *vs*. 75%, 40 min, 4 sessions/wk *vs*. ≤ 95%, 7 5-min spurt intervals, 3 sessions/wk; volume constant –intensity variable	4 *vs.* 4 *vs.* 3	6	55 ♀/♂, 18–44 yr, sedentary, ergometer bicycling	(Gormley et al., 2008)

Control: − **4.2**%	40–50%: **6.9**%	70–75%: **15.4**%	-	40–50% VO_{2max} *vs*. 70–75%, both groups: constant energy consumption/session (300→400 kcal)	(<3) - 3	12	45 ♀, 45 yr, BMI ≥ 25, sedentary, walking/jogging	(Cho et al., 2011)
Control: − **5.8**%	56%: **4.4**%	67%: **9.3**%	86%: **16.3**%	56% HR_{max}, 4.8 km/t *vs*. 67%, 6.4 km/t *vs*. 86%, 8.0 km/t; all test groups: 4.8 km/session	5	24	59 ♀, 20–40 yr, sedentary, walking	(Duncan et al., 1991)
Control: − **3.4**%	60%: **15.7**%	80%: **23.1**%	-	60% VO_{2max} *vs*. 80% VO_{2max}; both session s increased to 400 kcal/wk last 16 wk	3	24	42 ♂, 30–45 yr, sedentary, cycling	(O'Donovan et al., 2005)

All VO_{2max} results calculated from group means given as mL/kg × min, final values in % of start value, except #-groups' mean final values in % of control baseline.

§: VO_{2max} in L/min. The "moderate intensity-low frequency" group did not perform better than the "physician advice control group". 24-month data are "intent-to-treat" values.

Table 5. *Survey randomized dose-response studies of strength training*

Group designation and result (% increase 1 RM, mean for exercises tested, post/pre values)				Repetitions: No. of contractions (C) and sets (S), etc.	Sess. per wk	Test period, wk	Participants: number, gender, (mean) age (yr), and body mass index (BMI), training state, number of exercises (E), session duration	Reference
1 d/wk: **18**%	2 d/wk: **18**%	3 d/wk: **23**%	-	1 *vs*. 2 *vs*. 3 d/wk; 60 → 80% 1 RM, 10 C; 2 S [+fitness training]	1; 2; 3	16	72 ♀, 60–74 yr, sedentary, 10 E (2 E tested)	(Hunter et al., 2013)
Control **3.9**%	1 d/wk: **37**%	2 d/wk: **42**%	3 d/ wk: **40**%	80% 1 RM, 8 C; 3 S	1 *vs*. 2 *vs*. 3	24	46 ♂/♀, 65–79 yr, sedentary, 8 E	(Taaffe et al., 1999)
Low volume: **5.7**%	Moderate volume: **5.2**%	High volume: **6.7**%	-	12→7→9 C, RM until exhaustion, 3 *vs*. 6 *vs*. 12 S	4	10	27 ♂, 24 ± 5 yr, trained, 24 E (for 3 muscle groups), 6 E /session	(Ostrowski et al., 1997)
Low volume: **4.6**%	Moderate volume: **4.2**%	High volume: 4.**8**%	-	60-80 ↔90-100% 1 RM; means: Low volume: 14 C in 7.4 S (1923 reps./wk) *vs*. Moderate vol.: 18 C in 8.2 S (2481 reps./wk) *vs*. High vol.: 22 C in 9.5 S (3030 reps./wk)	4-5	10	51 ♂, 17 yr, weight lifters, 10+ E (squat exercise results given)	(Gonzalez-Badillo et al., 2005)
3-S-30% [Tested maximal voluntary contract. in Nm] **27**%	1-S-80%: **29**%	3-S-80%: **36**%	-	3-S-30% 1 RM (until "tired") *vs*. 1-S-80% 1 RM (until exhaustion) *vs*. 3-S-80% 1 RM (until "tired"); knee extension	3	10	18 ♂, 21 ± 1 yr, BMI ≅ 23, active, but without weight training, legs trained with 2 of 3 E	(Mitchell et al., 2012)

Control: **2.0**%	1-S: [mean of 5 E] **18**%	3-S: [mean of 5 E] **17**%	5-S: [mean of 5 E] **19**%	Total volume (TV = C x S x kg resistance): 1-S: TV 28 x 10^3 *vs.* 3-S: TV 87 x 10^3 *vs.* 5-S: TV 162 x 10^3; all: 8–12 RM until exhaustion	3	24	48 ♂, 24.4 ± 0.9 yr, BMI ≈ 26, military trained, but not strength trained, 9 E (5 E tested by 5 RM) ≅ 60 min/session	(Radaelli et al., 2015)
Control: − **2.2**%	1 S: **9.5**%	3 S: **15**%	-	8–12 C, until exhaustion; 1 S *vs.* 3 S	3	9 + 9	29 ♂/♀, 26 ± 8 yr , sedentary, 4 E [crossing over with washout]	(Humburg et al., 2007)
Control: ≈ − **4**%	2 E-NRF: **0.6**%	4 E-NRF: **4.6**%	4 E-RF: **2.1**%	(N)RF=(not)repetition failure: NRF: 2 E, 5→2 C, 75→92% 1RM, sum C: 392 *vs.* NRF: 4 E, 5→2 C, 75→92% 1RM, sum C:784 *vs.* RF: 4 E, 10→4 C; 75→92% 1RM, sum C: 1568 3–4 S	2	8	43 ♂, ≈ 26 yr, ≈ 82 kg, endurance and strength trained rowers, 2E-NRF, 30 min/session, 4E-NRF, 45 min/session 4E-RF, 60 min/session; prone bench pull tested	(Izquierdo-Gabarren et al., 2010)
1-S: **11**%	4-S: **14**%	8-S: **20**%	-	Mean C, 6 wk: 1-S, 131 C (barbell back squat repetitions) *vs.* 4-S: 370 C *vs.* 8-S: 670 C; All: 80% 1 RM until exhaustion.	2	6	32 ♂, 27.5 yr, strength trained, several standardized E (1 E, squat strength, tested)	(Robbins et al., 2012)
Control: − **1.7**%	1-S: **5.4**%	3-S: **13.1**%	-	6–9 RM, until exhaustion; 1 *vs.* 3 S	2	6	27 ♀, 20–40 yr , trained, multiple E (2 E tested)	(Schlumberger et al., 2001)
Control: −**3**%	40%: **30**%	80% : **27**%	-	40% 1 RM, 16 C *vs.* 80% 1RM, 8 C; 3 S	3	≈ 26	25 ♀, 41–60 yr, BMI ≅ 26, sedentary, 12 E (all tested) ≅1 hr/session	(Bemben et al., 2000)
Control (not random-ized): **9**%	MI: **29**%	HI: **18**%	-	MI: 13–15 RM (68% 1RM), *vs.* HI: 6 – 8 RM (80% 1RM) ; 1 S	2	8	43 ♀/♂, 5–12 yr, BMI ≈ 20, sedentary, 11 E (arm- and leg strength tested), 10 + 30–40 min/session	(Faigenbaum et al., 1999)
Control: -	15 RM: **48**%	9 RM: **51**%	6 RM: **50**%	6 RM, 4 S *vs.* 9 RM, 3 S *vs.* 15 RM, 2 S;	2	18	76 ♂/♀, 61–85 yr, sedentary, 8 E, ≅1 h/session	(Harris et al., 2004)

Control: **4**%	LI: **33**%	HI: **35**%		High-intensity (HI): 80% 1 RM, 4–6 C, 5 S *vs*. LI: 40% 1 RM, 8–12 C, 5 S. [Intensity adjusted in both groups →same total work in HI og LI)]	3	10	27 ♂/♀, 66–83 yr, BMI < ≈ 28, sedentary, 1 E (leg-press)	(Hortobagyi et al., 2001)
Control : − **1.1**%	50% **17.2**%	80% **17.8**%	-	50% 1 RM, 13 C *vs*. 80% 1 RM, 8 C; 1 S	3	24	62 ♂/♀, 60–83 yr, BMI ≅27, sedentary, 12 E	(Vincent et al., 2002)
Control: **4**%	20%: **13**%	50%: **16**%	80%: **20**%	20% 1 RM, 5 C *vs*. 50% 1RM, 5 C *vs*. 80% 1RM, 5 C 3 S	2	8-12	112 ♀/♂, 69 ± 6 yr, Sedentary, 5 E (rapid CON, slow ECC)	(de Vos et al., 2005)
1 S 30–40 RM: **18.4**%	2 S 15–20 RM: **23.8**%	3 S 6–8 RM : **26.0**%	-	Equal-volume groups: 6–8 RM, 3 S *vs*. 15–20 RM, 2 S *vs*. 30–40 RM, 1 S	3	9	50 ♀, 23 ± 4 yr, trained, 6 E (2 E tested)	(Stone and Coulter, 1994)
Control : − **1.0**%	LI: **40**%	HI: **48**%	-	LI: 55–65% 1 RM, 14–16 C *vs*. HI: 75–85% 1 RM, 8–10 C; 2 S	3	12	41 ♂/♀, 61–86 yr, ≅ 63 kg, sedentary, 12 E (arm strength values given)	(Tsutsumi et al., 1997)
Control : **0.1**%	MI: **36**%	HI: **41**%	-	MI: 55–65% 1 RM, 14–16 C *vs*. HI: 75–85% 1 RM, 8–10 C; 2 S	3	12	36 ♀, 60–86 yr, sedentary, 6 E /session (arm and leg strength tested)	(Tsutsumi et al., 1998)
Control : − **4.0**%	Variable intensity (VI): **19**%	High intensity (HI): **18**%	-	VI: 50,65 or 80% 1 RM *vs*. HI: 80%, ≤ 10 C, both until exhaustion; 2 S	3	25	36 ♂/♀, 61–77 yr, BMI normal, sedentary, 10 E (2 E tested), ≅ 45 min/session	(Hunter et al., 2001)
Control: (60 °/s) ♂: −**1.5**% ♀: −**1.2**%	50%: **3.7**% **3.0**%	70%: **8.2**% **7.1**%	90%: **11**% **15**%	50% 1 RM, 12–14 C *vs*. 70% 1RM, 8–10 C *vs*. 90% 1RM, 4–6 C; 3 S	3	16	64 ♂/♀, ♂ 71 yr, ♀67 yr, BMI ♂: 32, ♀: 29, sedentary, ≅45 min/session	(Beneka et al., 2005)
Control: **0.7**%	40%: **36%**	60%: **51**%	80%: **69**%	40% 1 RM, 15 C *vs*. 60% 1RM, 10 C *vs*. 80% 1RM, 8 C; 3 S	3	24	50 ♂, 65–78 yr, BMI ≅ 30, sedentary, 10 E (2 E tested), ≅60 min/session	(Fatouros et al., 2006)
Control: − **0.6**%	55%: **54**%	82%: **77**%	-	55% 1 RM, 14-16 C *vs*. 82% 1RM, 6-8 C; 2–3 S	3	24	52 ♂, > 65 yr (71 yr), sedentary, 10 E (2 E tested), 50–60 min/session	(Fatouros et al., 2005)

Control: **4.3**%	60% 1 RM: **44**%	80% 1 RM: **78**%	-	60% 1 RM, 15 C *vs*. 80% 1 RM, 8 C; 3 S	3	12	33 ♂/♀, 60–74 yr, BMI ≅ 30, sedentary , 6 (+2) E ≅ 60 min/session: 10 + 45 + 5 min	(Kalapotharakos et al., 2005)
Control: **0**%	40% 1 RM: **37**%	80% 1 RM: **57**%	-	40% 1 RM *vs*. 80% 1 RM; 8 C 3 S	3	10	22 ♂/♀, 73–95 yr, feeble, institutionalized, 1 E	(Seynnes et al., 2004)
Control: **1.3**%	40% 1 RM: **42**%	80% 1 RM: **59**%	-	40% 1 RM, 14 C *vs*. 80% 1 RM, 7 C; 3 S (constant relative volume)	3	52	25 ♀, 65–79 yr, BMI < 30, sedentary, 3 E	(Taaffe et al., 1996)
Control: **–1.6%**	High repet. **19%**	Low repet. **28%**	-	High: ≈ 30–50% 1RM, 20–25 C *vs*. Low: ≈ 75–90% 1RM, 8–12 C; 3 S	4	12	46 ♀, 23 yr, BMI ≅ 26, trained, 5 E (2 tested)	(Au et al., 2017)