Journal of Science and Medicine in Sport 23 (2020) 999–1004

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

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

Original research

Impact of low-volume concurrent strength training distribution on muscular adaptation

Anders Kilen[a,b], Jonathan Bay[a], Jacob Bejder[a], Andreas Breenfeldt Andersen[a], Thomas Christian Bonne[a], Pernille Dyeremose Larsen[a], Andreas Carlsen[a], Jon Egelund[a], Lars Nybo[a], Abigail Louise Mackey[c,d], Niels Vidiendal Olsen[e], Niels Jacob Aachmann-Andersen[f], Jesper Løvind Andersen[c], Nikolai Baastrup Nordsborg[a,*]

[a] *Department of Nutrition, Exercise and Sports, University of Copenhagen, Denmark*
[b] *Center for Military Physical Training, Danish Armed Forces Health Services, Denmark*
[c] *Institute of Sports Medicine Copenhagen, Department of Orthopedic Surgery M, Bispebjerg Hospital and Center for Healthy Aging, Faculty of Health and Medical Sciences, University of Copenhagen, Denmark*
[d] *Department of Biomedical Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Denmark*
[e] *Department of Biomedicine, The Health Faculty, University of Copenhagen, Denmark*
[f] *Department of Neuroanaesthesiology, The Neuroscience Centre, Rigshospitalet, Denmark*

ARTICLE INFO

Article history:
Received 23 December 2019
Received in revised form 25 March 2020
Accepted 27 March 2020
Available online 4 April 2020

Keywords:
Muscle biopsies
Military
Muscle fiber composition and size
Satellite cells

ABSTRACT

Objectives: Military-, rescue- and law-enforcement personnel require a high physical capacity including muscular strength. The present study hypothesized that 9 weeks of volume matched concurrent short frequent training sessions increases strength more efficiently than less frequent longer training sessions.
Design: A randomized training intervention study with functional and physiological tests before and after the intervention.
Methods: Military conscripts ($n = 290$) were assigned to micro-training (four 15-min strength and four 15-min endurance bouts weekly); classical-training (one 60-min strength and one 60-min endurance training session weekly) or a control-group (two 60-min standard military physical training sessions weekly).
Results: There were no group difference between micro-training and classical-training in measures of strength. Standing long jump remained similar while shotput performance was reduced ($P \leq 0.001$) in all three groups. Pull-up performance increased ($P \leq 0.001$) in micro-training (7.4 ± 4.6 vs. 8.5 ± 4.0 repetitions, $n = 59$) and classical-training (5.7 ± 4.1 vs. 7.1 ± 4.2 repetitions, $n = 50$). Knee extensor MVC increased ($P \leq 0.01$) in all groups (micro-training, $n = 30$, $11.5 \pm 8.9\%$; classical-training, $n = 24$, $8.3 \pm 11.5\%$ and control, $n = 19$, $7.5 \pm 11.8\%$) while elbow flexor and hand grip MVC remained similar. Micro-training increased ($P \leq 0.05$) type IIa percentage from $32.5 \pm 11.0\%$ to $37.6 \pm 12.3\%$ ($n = 20$) and control-group increased ($P \leq 0.01$) type IIax from $4.4 \pm 3.0\%$ to $11.6 \pm 7.9\%$ ($n = 8$). In control-group type I, fiber size increased ($P \leq 0.05$) from 5121 ± 959 μm to 6481 ± 2084 μm ($n = 5$). Satellite cell content remained similar in all groups.
Conclusions: Weekly distribution of low-volume concurrent training completed as either eight 15-min bouts or two 60-min sessions of which 50% was strength training did not impact strength gains in a real-world setting.

* Corresponding author.
E-mail address: nbn@nexs.ku.dk (N.B. Nordsborg).

https://doi.org/10.1016/j.jsams.2020.03.013

Practical implications

- Similar effects are obtained from one hour strength training per week organized in one long or eight short sessions during Basic Military Training.
- The current results demonstrate that training duration – frequency combination can be defined in accordance with other priorities, without compromising the expected training outcome.
- Robust strength training effects requires a higher training volume than one hour weekly for nine weeks.
- Pull-up performance can increase with as little as 15 min of specific training per week.
- Standing long jump and shotput performance does not improve when the tasks are not included in the training program.

1. Introduction

Military, rescue and law-enforcement personnel need to balance time allocated to physical training against daily tasks. In a military setting, muscular strength is required for heavy lifting, rapid movement or passing obstacles while carrying loads. However, the majority of daily physical tasks are of low-intensity which is unlikely to increase maximal muscle strength.[1] Therefore, it is of importance to investigate whether strength can be increased in military personnel by adding a low volume of strength training concurrently with other types of exercise and daily activities in a 'real-world' setting. Basic military training includes technical, tactical and physical training. Generally, 6–12 weeks of basic military training can increase maximal oxygen consumption and maximal muscle strength which results in improved endurance performance and functional strength capacity, evaluated as for example push-ups.[2,3]

However, the high volume of low-intensity aerobic activity during military service may attenuate strength training adaptations[4] in accordance with 'concurrent training' interactions.[5] Indeed, basic military training can both cause unaltered and decreased jump performance.[3,6] However, high-intensity strength training during basic military training does have the potential to increase muscle strength.[3,7]

Strength training induced increases of muscular force generating capacity is dependent on training frequency, volume, intensity and design including exercise:rest ratio, type of exercise, exercise order and repetition velocity.[8] Generally, 2–3 training sessions per week with 4 sets per muscle group efficiently increases strength for untrained and moderate trained individuals[9,10] whereas adaptation for trained athletes may require a higher training volume.[11] Importantly, as little as one weekly strength training session can increase muscle strength for both untrained[12] and trained[13] individuals. Additionally, when the content of one strength training bout is distributed across two or three shorter training sessions per week in a strictly controlled study-design, similar[14] or more pronounced strength gains can occur in untrained[12] and trained[15] individuals. However, the efficiency of frequent low-volume bouts in increasing strength has not been established in a 'real-world' setting although it is of high relevance. A possible mechanistic explanation for a more efficient training outcome with increased frequency and constant volume is frequent inhibition of protein degradation and more robust induction of protein synthesis signaling events.[16]

The initial strength gain with targeted training is primarily caused by neurological adaptation whereas changes in muscle morphology, including fiber type distribution shifts, increases in muscle fiber size[17] and augmented satellite cell number[18] only becomes evident after several weeks of training. Thus, evaluation of both the functional and muscular adaptation to different training strategies is important to identify whether potential differences in initial strength gain can be related to muscle morphological adaptation.

Knowledge of optimized training distribution is of substantial importance for practical advice. For example, it may be more efficient to complete several brief strength training sessions as opposed to fewer longer sessions in environments where time for physical training is limited. If so, the results are also of importance for general health interventions when aiming to counteract sarcopenia, for example. In the present study, strength training distribution was manipulated for 290 army recruits. The hypothesis was that 2 h concurrent training completed as 8×15 min bouts more efficiently increases measures of strength than 2×60 min sessions per week.

2. Methods

A 9-week randomized parallel-group intervention was completed in healthy conscripts ($n = 290$, 286 males and 4 females, Table 1). Written informed consent of voluntary participation was obtained after an explanation of risks and benefits. A subgroup (SG) of 87 males consented to a more thorough physiological investigation. The study adheres to the Code of Ethics of the World Medical Association (Declaration of Helsinki) according to the revision valid at the time of data acquisition and was approved by the Danish National Committee for Health Research Ethics (H-3-2013-140).

Participants were randomly allocated to 'micro-training' (MIC, $n = 95$); 'classical-training' (CLA, $n = 95$) and 'control' (CON, $n = 100$). Voluntary participation in SG was registered after group allocation and resulted in 32 participants in MIC_{SG}; 32 in CLA_{SG} and 23 in CON_{SG}.

All groups participated in basic military tasks, including theoretical and practical education in weapon handling, signal procedures and equipment, medical first aid and small unit tactics. Furthermore, basic military training includes a high amount of lower extremity low-intensity aerobic activity (e.g. standing or marching with 0–10 kg loads) for up till 20 h weekly. Week 6–9 included 2–3 h of marching with 20–25 kg loads in total every week.

Added physical concurrent training amounted to 2 h per week. MIC completed four 15-min strength sessions and four 15-min endurance sessions (i.e. two 15-min running and two 15-min muscular endurance sessions) separated by at least two hours and ≤3 sessions daily. CLA completed four identical 15-min sessions in succession, with one session allocated to strength and one to endurance training (i.e. 30-min running followed by 30-min muscular endurance). CON performed two 60-min sessions as standard basic military training fitness program with mixed exercises (∼40% strength training, ∼60% running or muscular-endurance training). The weekly strength and endurance training schedule varied during the study in order to fit the military basic training program. The adherence to the MIC and CLA regime was strictly controlled.

A 15-min strength training included 3-min warmup and 3 sets of one multi-joint exercise with 5 repetitions. Exercises included lower extremity (twice weekly), a push (once weekly) and a pull (once weekly). For logistical reasons, the participants were divided into four equal-sized groups that started with one of the three exercises and then rotated in the same order for the two remaining exercises in every strength training session. Training load was continuously adjusted by the participants in 2.5–5.0 kg steps to obtain their individual 5 repetitions maximum for every training set.

Running included continuous moderate pace running (week 1–3), 60–120 s intervals with equal work:rest ratio (week 4–6) and 30 s high intensity intervals with 3-min rest between (week 7–9) with intensity prescribed by the Borg scale.[19] Before each session, the participants were instructed in which specific levels on the Borg scale they were required to obtain during the different parts of the

Table 1
Participant characteristics (All; all participants, SG; subgroup participants) before a 9 week training intervention amongst 290 conscripts.

		MIC	*n*	CLA	*n*	CON	*n*
Age (years)	All	20.9 ± 1.4	95	20.8 ± 1.2	95	20.8 ± 1.3	100
	SG	20.9 ± 1.2	32	21.3 ± 1.6	32	21.0 ± 1.3	23
Height (m)	All	1.84 ± 0.07*,[a]	92	1.81 ± 0.04***	90	1.86 ± 0.06	98
	SG	1.85 ± 0.08[b]	32	1.80 ± 0.04*	30	1.86 ± 0.05	23
Body weight (kg)	All	79.9 ± 8.7**	72	76.7 ± 9.4***	88	84.6 ± 11.6	83
	SG	80.1 ± 9.4#	30	78.9 ± 8.8***	31	86.4 ± 11.7	21

Micro-training (MIC) completed eight 15 min training sessions per week comprising either strength or endurance training, classical-training (CLA) performed identical strength and endurance training organized as two 60 min sessions per week and control (CON) performed two 60 min sessions as standard military physical training program. Results are presented as mean ± SD. Differences from CON is indicated by #, *, **, *** for $P \leq 0.1$, $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

[a] Different from CLA ($P < 0.01$).

[b] Different from CLA ($P < 0.05$).

program: Warm up ranged from 11 to 13, continuous running from 14 to 17 and interval running from 18 to 20. Muscular endurance training was defined as repeated intermittent, short rest, moderate to high-intensity multi joint exercises, with high cardiovascular and muscular metabolic load. All training sessions were supervised by a military physical trainer who assisted the participants to comply with the given intensities. A detailed description of the training programs are available in supplementary material.

Strength adaptations were evaluated on three consecutive days immediately before and after the intervention. Food and water intake ad libitum was allowed during the test days.

At day 1, weight and body composition was determined on a four-point bio impedance scale (Tanita, BC-418, Tokyo, Japan) at the same time of day before and after the intervention.

At day 2, functional strength was evaluated in standing long jump, pull-ups or inverted rows and a 4 kg medicine ball shotput. Standing long jump was completed with parallel feet and hands fixed at the hip behind a line before jumping as far as possible while keeping the hands fixed at the hip. For the jump to be approved, participants had to land in a full stop with parallel feet at the landing point and hands at the hip. The result was registered as the longest of three attempts and distance was measured between the start line and the shoe front at the landing point. Pull-ups were completed from a fully extended and unsupported position with overhand grip for as many repetitions as possible in one attempt. One repetition was defined as pulling up until the chin was above the handlebar without kipping and returning to a fully extended position. Participants unable to complete one pull-up (MIC, $n = 6$; CLA, $n = 5$; CON, $n = 7$) were excluded from analysis of this exercise. Shotput was performed with the participant sitting on the floor with straight legs and back and head supported by a wall. Holding the 4 kg medicine ball with elbows in shoulder height, fingers on both hands pointing toward each other and thumbs pointing downwards the participants had to push the ball as far as possible forward. The longest of three attempts was recorded (distance between the wall and the landing point). In general, if the best results was recorded in the third attempt for either standing long jump or shot put a fourth attempt was completed in order to minimize learning effects.

At day 3, SG participants were biopsied from m. vastus lateralis at the muscle belly using the percutaneous needle biopsy technique.[20] Tissue suited for histology were embedded in O.C.T. compound (Tissue-Tek, Sakura Finetek Europe, AJ Alphen aan den Rijn, The Netherlands) and frozen by immersion in liquid nitrogen-cooled isopentane. The remaining tissue was immediately frozen in liquid nitrogen. Both samples were stored at −80 °C until subsequent analysis.

Maximal voluntary contraction (MVC) force was determined for knee extensors, elbow flexors and finger flexors after warmup consisting of 3 × 10 squats, 3 × 10 elbow flexions with 5 kg resistance and 3 × 10 submaximal finger flexions, respectively.

Knee extension MVC was evaluated on the right non-biopsied leg, seated with arms crossed over the chest, hip fixed and right knee flexed 90°. Force was recorded at 1 kHz from a horizontally mounted strain gauge (Tedea Huntleigh 615, Herzliya Pituach, Israel) attached in the proximal proximity of the malleolus via a strap.

Elbow flexion MVC was determined from a kneeling position on one leg with the dominant arm resting extended to 90° and an elbow flexion of 90° and fixed at the wrist in a custom dynamometer (Tedea Huntleigh 615, Herzliya Pituach, Israel). The contralateral arm rested on the back.

Dominant *hand grip MVC* was evaluated using a hand grip dynamometer (Hydraulic hand dynamometer, SH5001, Saehan Corporation, Masan, Korea) and a position with 90° shoulder inward rotation, 90° elbow flexion, neutral hand rotation with pollicis pointing up. MVC was defined as the highest 1 s force average obtained during three 5 s MVCs separated by 60 s. If the third attempt was the highest, the participants were given a fourth attempt.

Transverse sections (10 μm) of the Tissue-Tek imbedded muscle biopsies were cut at −20°, placed on one glass slide for each individual and stored at −80° until analysis. Muscle biopsies were analyzed by blinded personnel.

To determine number of satellite cells, sections were stained for Pax7, laminin and type I myosin and analyzed, as previously described.[21] Satellite cells associated with type I or II fibers were counted and expressed relative to the total number of type I or II fibers included in the assessment.[21]

Fiber types were analyzed by incubation for myofibrillar ATPase reactions at pH 9.4 after preincubation at pH 4.3, 4.6, and 10.3.[22] This was followed by rinse in 1% $CaCl_2$ for 1, 2 and 3 min and incubation in a 2% $CoCl_2$ solution for 3 min. The slides were washed 25 times in H_2O and incubated with 1% ammoniumsulfide for 1 min, then washed again 25 times in H_2O and mounted with polyvinylpyrrolidon.[23] Furthermore, a double staining method combining ulex europaeus lectin 1 (UEA-1) and collagen type IV staining was used for immunohistochemistry staining of muscle fiber membranes as described in details elsewhere.[24]

A Olympus BX40 microscope (Olympus Optical Co., Tokyo, Japan), connected to a Sanyo Hi-resolution Color CCD camera (Sanyo Electronic Co., Osaka, Japan), an eight-bit Matrox Meteor Framegrabber (Matrox Electronic Systems, Quebec, Canada), and image-analysis software (Tema, Scanbeam, Hadsund, Denmark) allowed identification of fiber types, size and membrane. Only fibers cut truly perpendicular, as assessed visually, were used to determine fiber size. The relative proportion of five different fiber types (types I, I/IIa, IIa, IIax, and IIx) were determined including their size.[23] Calculations of fiber size were performed only for fiber types I and II. On average, 116 ± 40 ($n = 24$) fibers were used for determining fiber size and 134 ± 25 ($n = 35$) for fiber type in each biopsy.

Table 2
Functional strength evaluated by standing long jump, shot put and pull-up performance amongst 290 conscripts and maximal voluntary isometric (MVC) force production in knee extensors, elbow flexors and hand grip in subgroups (SG) of the 290 conscripts before (Pre) and after (Post) a 9 week training intervention.

	MIC			CLA			CON		
	Pre	Post	n	Pre	Post	n	Pre	Post	n
Standing long jump (m)	2.03 ± 0.22	2.01 ± 0.23	72	1.98 ± 0.22	1.97 ± 0.20	65	2.03 ± 0.21	2.03 ± 0.18	66
Shotput (m)	3.91 ± 0.48	3.66 ± 0.41***	79	3.82 ± 0.53[b]	3.56 ± 0.42***,[a]	69	4.04 ± 0.47	3.72 ± 0.41***	70
Pull-ups (n)	7.4 ± 4.6[a]	8.5 ± 4.0***,[c]	59	5.7 ± 4.1	7.1 ± 4.2***,[a]	50	5.4 ± 4.0	5.4 ± 3.5	51
	MIC_{SG}			CLA_{SG}			CON_{SG}		
Knee extensor MVC (N)	652 ± 110 [d]	726 ± 134***	30	661 ± 111[e]	755 ± 119***	24	760 ± 137	812 ± 165*	19
Elbow flexor MVC (N)	439 ± 89	454 ± 77 #	29	419 ± 61	416 ± 64	25	455 ± 79	449 ± 67	17
Hand grip MVC (N)	480 ± 106	484 ± 118	23	462 ± 66	448 ± 103	23	525 ± 104	505 ± 73	17

Micro-training (MIC) completed eight 15 min training sessions per week comprising either strength or endurance training, Classical-training (CLA) performed identical strength and endurance training organized as two 60 min sessions per week and Control (CON) performed two 60 min sessions as standard military physical training program. Results are presented as mean ± SD. Differences from Pre is indicated by #, *, *** for $P \leq 0.1$, $P \leq 0.05$ and $P < 0.001$.

[a] Different from CON_{POST} $P \leq 0.1$.
[b] Different from CON_{PRE} $P \leq 0.05$.
[c] Different from CON_{POST} $P \leq 0.001$.

Only individuals completing >85% of the physical training sessions and pre and post testing are included in the analysis (MIC: n = 79, CLA: n = 69 and CON: n = 70). Due to the low number of females, they were included with the males in the analysis.

Statistical analyses were performed using SPSS (IBM SPSS Statistics v24.0). A linear mixed-model approach[25] was used to investigate differences within and between groups. Fixed factors were "group" (MIC, CLA, CON) and "trial" (PRE, POST). Participant was specified as a repeated factor and identifier of random variation. Significant main effects followed by a Sidak-adjusted pairwise comparison. Difference between groups was only calculated if $n \geq 10$ in each group for the given variable. Residual and Q–Q plots confirmed covariance homogeneity. Additionally, muscle fiber composition and satellite cell content changes where analyzed by a paired students t-test while disregarding group allocation due to small groups providing low statistical power. Results were considered significant for $P \leq 0.05$. Results are reported as means ± SD.

3. Results

Functional strength measurements are presented in Table 2. No group × trial interaction existed for standing long jump or shotput and no main effect for trial or group was apparent for standing long jump. In contrast, a shotput main effect existed for group ($P \leq 0.05$) and trial ($P \leq 0.001$) with all groups decreasing ($P < 0.001$) performance (MIC, 6.0 ± 7.5%: CLA, 6.2 ± 8.7% and CON, 7.5 ± 9.3%, $P \leq 0.001$).

A group × trial interaction and a main effect for group and trial ($P \leq 0.01$) existed for pull-ups. Post hoc paired analyses demonstrated improved ($P < 0.05$) pull-up performance in MIC (51.3 ± 97.6%) and CLA (60.7 ± 95.1%) while CON remained similar. A group × trial interaction ($P \leq 0.05$) and group main effect ($P \leq 0.001$) existed for body mass. Body mass remained similar within MIC (79.5 ± 10.0 kg vs. 79.9 ± 8.7 kg; n = 67) and CLA (76.7 ± 9.4 kg vs. 77.2 ± 8.6 kg; n = 74) but decreased ($P \leq 0.01$) in CON (84.6 ± 11.0 kg vs. 82.3 ± 10.8 kg; n = 77). A main effect for trial ($P \leq 0.001$) was apparent for body fat percentage, which decreased in MIC (11.2 ± 6.2% vs. 9.8 ± 4.8%, $P \leq 0.01$, n = 52), CLA (12.6 ± 6.5% vs. Post 11.5 ± 5.5%, $P \leq 0.01$, n = 75) and CON (11.6 ± 5.2% vs. 10.7 ± 6.2%, $P \leq 0.05$, n = 75) from pre to post, respectively.

For knee-extensor MVC (Table 2), no group × trial interaction was apparent but main effects existed for trial ($P \leq 0.001$) and group ($P \leq 0.05$). Specifically, knee extensor MVC increased ($P \leq 0.05$) similarly in all three groups (MIC: 11.9 ± 12.7%; CLA: 14.7 ± 12.9%; CON: 7.2 ± 12.4%). No interaction or main effects were apparent for elbow flexor or handgrip MVC.

A group × trial interaction ($P \leq 0.01$) existed for fiber type IIa distribution (Table 3), whereas there was no main effect for group or trial. Specifically, IIa fiber type distribution increased ($P \leq 0.05$) ~5% points in MIC whereas CLA or CON fiber type distribution remained similar. No group × trial main effect existed for fiber type area. However, a tendency for a trial main effect (P = 0.06) existed for type I fiber area. In support, the pairwise analyses revealed CON type I area increased 17.6 ± 17.1% ($P \leq 0.05$) whereas MIC and CLA fiber type area remained similar. To increase statistical power, a paired t-test on combined data from MIC, CLA and CON was performed, demonstrating that the percentage of type I fibers decreased ~4% points ($P \leq 0.05$) and type II fiber size increased ~13% ($P \leq 0.05$).

There was no group × trial interaction for SC per type I or II fibers (Table 3). A main effect of group ($P \leq 0.05$) for SC per type I fiber and a main effect for trial ($P \leq 0.05$) for SC per type II fiber existed. However, no change in SC number per fiber type was detectable within or between groups (Table 3). When analyzing SC number irrespective of training groups an increase was apparent for SC per type II fiber ($P \leq 0.01$) as well as SC per all fibers combined ($P \leq 0.05$).

4. Discussion

In contrast to our hypothesis, weekly distribution of one hour targeted strength training in a setting of basic military training did not influence functional strength, maximal muscle strength or muscle overall morphological variables. However, when disregarding group allocation, reduced body fat percentage, increased pull-up performance, decreased shot put performance, increased knee extensor MVC force and elevated satellite cell expression was apparent after basic military training whereas total body mass, standing long jump performance as well as muscle fiber type distribution and fiber size remained unaffected.

The most direct measure of muscular strength in the present study was MVC of the knee extensors, elbow flexors and finger flexors. Importantly, a post hoc power analysis revealed a detection limit of ~7% between groups in knee extensor MVC. Thus, any undetected between group differences in knee extensor MVC would be of limited practical importance. Likewise, undetected physiological relevant changes in arm- and finger flexor maximal strength are unlikely. Furthermore, functional evaluations of strength also remained similar between groups, despite the large group sizes of ~50–70 persons yielding a detection limit of <5% for standing long jump, shotput and pull-ups. Correspondingly, no indications of between group differences existed in the muscle morphological results albeit they must be interpreted with care due to a relatively low n and substantial variance.

Table 3
Fiber type distribution, fiber type size and satellite cells (SC) per type 1 fiber, type 2 fiber and satellite cells per both fiber types combined before (Pre) and after (Post) a nine week training intervention in subgroups (SG) of 290 conscripts.

	MIC_{SG} ($n = 20$)		CLA_{SG} ($n = 7$)		CON_{SG} ($n = 8$)		ALL_{SG} ($n = 35$)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Type I (%)	51.5 ± 14.9	47.6 ± 15.2	52.6 ± 12.7	49.6 ± 15.1	52.0 ± 16.2	48.1 ± 10.3	51.8 ± 14.4	48.1 ± 13.4*
Type I/IIa (%)	1.1 ± 1.6	1.2 ± 1.7	1.1 ± 1.7	2.5 ± 2.6	1.6 ± 2.5	2.8 ± 3.3	1.2 ± 1.8	1.8 ± 2.4
Type IIa (%)	32.5 ± 11.0	37.6 ± 12.3*	36.3 ± 11.7	35.9 ± 8.1	32.8 ± 9.8	27.5 ± 10.9	33.3 ± 10.7	35.0 ± 11.7
Type IIax (%)	6.8 ± 5.1	7.0 ± 7.4	5.2 ± 4.2	5.7 ± 8.8	4.4 ± 3.0	11.6 ± 7.9**	5.9 ± 4.5	7.8 ± 7.9
Type IIx (%)	8.2 ± 9.6	6.5 ± 7.9	4.8 ± 5.3	6.2 ± 6.3	9.1 ± 9.5	10.0 ± 9.0	7.7 ± 7.3	8.8 ± 7.8
	MIC_{SG} ($n = 12$)		CLA_{SG} ($n = 7$)		CON_{SG} ($n = 5$)		ALL_{SG} ($n = 24$)	
Type I (μm^2)	4748 ± 1573	5118 ± 1600	5135 ± 1625	5347 ± 786	5121 ± 959	6481 ± 2084*	4938 ± 1439	5469 ± 1559
Type II (μm^2)	5150 ± 1520	5687 ± 1572	6273 ± 2009	6941 ± 1814	5496 ± 871	6679 ± 1694	5549 ± 1591	6260 ± 1700*
	MIC_{SG} ($n = 18$)		CLA_{SG} ($n = 5$)		CON_{SG} ($n = 5$)		ALL_{SG} ($n = 28$)	
SC/type I	0.09 ± 0.04	0.10 ± 0.05	0.10 ± 0.06	0.07 ± 0.01	0.08 ± 0.03	0.06 ± 0.03	0.09 ± 0.04	0.09 ± 0.04
SC/type II	0.09 ± 0.04	0.11 ± 0.08	0.12 ± 0.06	0.14 ± 0.08	0.06 ± 0.03	0.08 ± 0.01	0.09 ± 0.05	0.12 ± 0.08**
SC/all fibers Combined	0.09 ± 0.04	0.12 ± 005	0.10 ± 0.04	0.12 ± 0.06	0.08 ± 0.03	0.07 ± 0.02	0.09 ± 0.04	0.11 ± 0.04*

Micro-training (MIC) completed eight 15 min training sessions per week comprising either strength or endurance training, Classical-training (CLA) performed identical strength and endurance training organized as two 60 min sessions per week and Control (CON) performed two 60 min sessions as standard military physical training program. ALL: all three groups combined. Results are presented as mean ± SD. Differences from Pre is indicated by, *, ** for $P \leq 0.05$ and $P \leq 0.01$, respectively.

The current results conflicts with our pilot study where knee-extensor MVC increased ~6% after strength training completed as 3 × 15 min per week and remained constant after 1 × 45 min per week.[14] The reason is unclear but may be related to the less daily physical activity in the pilot study, allowing a more focused effort and higher intensity during the targeted training.

Due to a similar response between groups, the following section considers the general effect of basic military training combined with one hour weekly strength training.

The increase in knee-extensor MVC corresponds to earlier observations in military populations.[2] It appears possible that the current observation of increased MVC in all groups is a result of the basic military training more than the targeted strength training. In support of this interpretation, elbow flexor as well as finger flexor MVC remained unaltered despite our high statistical power.

Neural adaptations appear a likely primary cause for the increased knee-extensor strength with possible mechanisms including increased neural drive from higher motor centers, increased motor neuron excitability and down regulated inhibitory signalling.[26] Minor changes in muscle fiber type distribution and increases in fiber size and satellite cell number, which became apparent when combining training groups, demonstrate initial muscle morphological adaptation and myogenic cell proliferation. In accordance with previous findings,[17,18] fiber type 1 distribution decreased while fiber type II area and SC per type II fibers and all fibers combined increased. The magnitude of morphological adaptations was possibly blunted by an inferior stimuli, i.e. too low training volume of added strength training or a too short training intervention for adaptations to manifest and/or overruled by high volume low intensity activities, i.e. an interference effect. Because, interference effects are more likely in well-trained individuals[5] the current observations probably reflect the low volume of strength training and/or short duration of the intervention.

Moreover, handgrip MVC remained unchanged even though the muscle group is expected to be engaged in deadlift where maximal hand grip strength can be a limiting factor[27] and in pull-ups. In our pilot study, where deadlift and pull-ups also were included, an ~8% increase in handgrip strength existed.[14] This is a relevant finding in terms of real-world applicability since handgrip strength is of importance in many military task including various load-carrying tasks[28] and could affect marksmanship performance.[29]

The increased knee-extensor MVC did not translate into improved standing long jump despite a detection limit of ~5%. Standing long jump is primarily dependent on rate of force development and maximal strength relative to body weight.[30] Vertical jump performance decreases as a result of military basic training,[6] strenuous military training[31] and active deployed duty[32] which may support why standing long jump was unaffected while MVC increased. Importantly, the lack of improvement of standing long jump raises the questions whether standard functional capacity measures are sufficiently sensitive to detect small and initial adaptations related to specific training regimes. Furthermore, shotput performance, which is also dependent on rate of force development, decreased ~6% in all groups, corresponding to a ~5% decrease observed after deployed duty.[32] The reduction of shotput performance is intriguing. We observed body mass to remain stable while fat percentage was reduced. Thus, it appears that muscle mass was gained. Since muscle mass correlates to shotput performance[33] an increased shotput performance could be expected in the present study. In contrast, the compromised performance indicate that neuro-muscular performance can have been compromised. Possibly, the relatively high volume of low intensity activity may have counteracted adaptations in power generating capacity.[3] The results from our MVC measures and functional evaluations suggest that more precise evaluations of maximal force should be applied in combination with targeted training.

Improved pull-up performance in MIC and CLA was not associated with an increase in elbow flexor MVC, suggesting that the increase reflects a learning effect and/or isometric elbow flexions may not fully represent the adaptations expected after pull-up training. Moreover, CON did not regularly perform pull-ups in the added specific strength training and the unchanged performance confirms that military basic training per se cannot be expected to improve upper-body strength, in line with a previous study in Norwegian conscripts.[34] Finally, the increased pull-up performance in MIC and CLA demonstrate that even a low volume of specific training (15 min weekly) can improve functional upper body performance.

In a practical context, the present findings demonstrate that low-amounts of strength training during basic military training must be considered an education of soldiers in physical training. Thus, this initial strength training program should be followed up by a more extensive program, where more robust gains in strength and functional capacity can be expected.

It is a limitation of the current study that no non-training group could be included. This was obviously not possible, due to the requirements of the Basic Military Training program. Therefore, it cannot be excluded that some of the observed changes could be the result of the general activity more than the added physical training.

In conclusion, completion of 8×15 min or 2×60 min weekly concurrent training with ~50% of sessions consisting of strength training, resulted in a similar increase in knee extensor MVC while functional measures of leg strength remained constant.

Conflict of interest

The authors declare no conflict of interest.

Geografical location of study (all testing and training)

The Danish Royal Life Guards Barracks, Hoeveltevej 111-117, 3460 Birkeroed, Denmark.

Acknowledgements

The Present study was conducted with the support of the Danish Armed Forces and Center for Military Physical Training as executive unit. We are thankful for the enthusiasm from 'The Danish Royal Life Guards" in Hoevelte, as well as for the support from the Medic platoon of the Logistic Army Regiment, Aalborg. The skilled technical assistance of Dr. Jens Jung Nielsen, Line Birch Overby, Niels Dall, Maria Juul, Rasmus Meldgaard, Steffan Aagaard Karlsen and Stine Friman Nielsen was highly appreciated.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2020.03.013.

References

1. Farup J, Kjølhede T, Sørensen H et al. Muscle morphological and strength adaptations to endurance vs. resistance training. *J Strength Cond Res* 2012; 26(2):398–407.
2. Santtila M, Häkkinen K, Karavirta L et al. Changes in cardiovascular performance during an 8-week military basic training period combined with added endurance or strength training. *Mil Med* 2008; 173(12):1173–1179.
3. Santtila M, Kyröläinen H, Häkkinen K. Changes in maximal and explosive strength, electromyography, and muscle thickness of lower and upper extremities induced by combined strength and endurance training in soldiers. *J Strength Cond Res* 2009; 23(4):1300–1308.
4. Kraemer WJ, Vescovi JD, Volek JS et al. Effects of concurrent resistance and aerobic training on load-bearing performance and the Army physical fitness test. *Mil Med* 2004; 169(12):994–999.
5. Bishop DJ, Bartlett J, Fyfe J et al. Methodological considerations for concurrent training, in *Concurrent Aerobic and Strength Training [Internet]*, Schumann M, Rønnestad BR, editors, Cham, Springer International Publishing, 2019, p. 183–196. Available at: http://link.springer.com/10.1007/978-3-319-75547-2_13. Cited 24 January 2019.
6. Rosendal L, Langberg H, Skov-Jensen A et al. Incidence of injury and physical performance adaptations during military training. *Clin J Sport Med Off J Can Acad Sport Med* 2003; 13(3):157–163.
7. Groeller H, Burley S, Orchard P et al. How effective is initial military-specific training in the development of physical performance of soldiers? *J Strength Cond Res* 2015; 29(suppl 11):S158–S162.
8. Grgic J, Schoenfeld BJ, Davies TB et al. Effect of resistance training frequency on gains in muscular strength: a systematic review and meta-analysis. *Sports Med Auckl N Z* 2018; 48(5):1207–1220.
9. Ralston GW, Kilgore L, Wyatt FB et al. The effect of weekly set volume on strength gain: a meta-analysis. *Sports Med Auckl N Z* 2017; 47(12):2585–2601.
10. Peterson MD, Rhea MR, Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res* 2005; 19(4):950–958.
11. Rhea MR, Alvar BA, Burkett LN et al. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc* 2003; 35(3):456–464.
12. Ochi E, Maruo M, Tsuchiya Y et al. Higher training frequency is important for gaining muscular strength under volume-matched training. *Front Physiol [Internet]* 2018. Available at: https://www.frontiersin.org/article/10.3389/fphys.2018.00744/full. Cited 24 January 2019.
13. Schoenfeld BJ, Peterson MD, Ogborn D et al. Effects of low- vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. *J Strength Cond Res* 2015; 29(10):2954–2963.
14. Kilen A, Hjelvang LB, Dall N et al. Adaptations to short, frequent sessions of endurance and strength training are similar to longer, less frequent exercise sessions when the total volume is the same. *J Strength Cond Res* 2015; 29(suppl 11):S46–S51.
15. McLester JRJ, Bishop E, Guilliams ME. Comparison of 1 day and 3 days per week of equal-volume resistance training in experienced subjects. *J Strength Cond Res* 2000; 14(3):273.
16. Mascher H, Tannerstedt J, Brink-Elfegoun T et al. Repeated resistance exercise training induces different changes in mRNA expression of MAFbx and MuRF-1 in human skeletal muscle. *Am J Physiol Endocrinol Metab* 2008; 294(1):E43–E51.
17. Folland JP, Williams AG. The adaptations to strength training: morphological and neurological contributions to increased strength. *Sports Med Auckl N Z* 2007; 37(2):145–168.
18. Zammit PS, Partridge TA, Yablonka-Reuveni Z. The skeletal muscle satellite cell: the stem cell that came in from the cold. *J Histochem Cytochem Off J Histochem Soc* 2006; 54(11):1177–1191.
19. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; 14(5):377–381.
20. Bergström J. Percutaneous needle biopsy of skeletal muscle in physiological and clinical research. *Scand J Clin Lab Invest* 1975; 35(7):609–616.
21. Mackey AL, Andersen LL, Frandsen U et al. Distribution of myogenic progenitor cells and myonuclei is altered in women with vs. those without chronically painful trapezius muscle. *J Appl Physiol Bethesda Md 1985* 2010; 109(6):1920–1929.
22. Brooke MH, Kaiser KK. Three 'myosin adenosine triphosphatase' systems: the nature of their pH lability and sulfhydryl dependence. *J Histochem Cytochem Off J Histochem Soc* 1970; 18(9):670–672.
23. Andersen JL, Aagaard P. Myosin heavy chain IIX overshoot in human skeletal muscle. *Muscle Nerve* 2000; 23(7):1095–1104.
24. Qu G, Yan H, Strauch AR. Actin isoform utilization during differentiation and remodeling of BC3H1 myogenic cells. *J Cell Biochem* 1997; 67(4):514–527.
25. Cnaan A, Laird NM, Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med* 1997; 16(20):2349–2380.
26. Aagaard P, Simonsen EB, Andersen JL et al. Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol Bethesda Md 1985* 2002; 93(4):1318–1326.
27. Ratamess NA, Faigenbaum AD, Mangine GT et al. Acute muscular strength assessment using free weight bars of different thickness. *J Strength Cond Res* 2007; 21(1):240–244.
28. Knapik JJ, Harper W, Crowell HP. Physiological factors in stretcher carriage performance. *Eur J Appl Physiol* 1999; 79(5):409–413.
29. Copay AG, Charles MT. The influence of grip strength on handgun marksmanship in basic law enforcement training. *Polic Int J Police Strateg Manag* 2001; 24(1):32–39.
30. Samson MM, Meeuwsen IB, Crowe A et al. Relationships between physical performance measures, age, height and body weight in healthy adults. *Age Ageing* 2000; 29(3):235–242.
31. Nindl BC, Barnes BR, Alemany JA et al. Physiological consequences of U.S. Army Ranger training. *Med Sci Sports Exerc* 2007; 39(8):1380–1387.
32. Sharp MA, Knapik JJ, Walker LA et al. Physical fitness and body composition after a 9-month deployment to Afghanistan. *Med Sci Sports Exerc* 2008; 40(9):1687–1692.
33. Aandstad A. Association between performance in muscle fitness field tests and skeletal muscle mass in soldiers. *Mil Med* 2019.
34. Dyrstad SM, Soltvedt R, Hallén J. Physical fitness and physical training during Norwegian military service. *Mil Med* 2006; 171(8):736–741.