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The elixir of muscle activity and kinesiology in a health perspective: Evidence of worksite tailored exercise training alleviating muscle disorders

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A R T I C L E I N F O

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A B S T R A C T

Physical activity is known to benefit health while muscle activation and movements performed during occupational work in contrast may result in work-related musculoskeletal disorders. Therefore, we posed the research question: which mode of muscle activation may result in a reversal of work-related disorders? To address this, we performed electromyographic (EMG) and kinematic assessments of workers with diverse exposure categories: sedentary monotonous work, prolonged walking/standing, and physically heavy work. The various job-specific exposure variables could be categorized in terms of duration, intensity, repetition, static component, peak force etc. that were subsequently identified as risk factors. Based on sports science principles we developed tailored exercise programs to counteract job exposure. EMG activity during exercise training was monitored to identify principal differences between exercise training and job patterns. Evidence from more than 20 RCT studies including >4000 workers showed positive effects such as decreased muscle pain and increased workability. Finally, we identified plausible underlying mechanisms in muscle tissue – human and animal - that confirmed metabolic, morphological, and hormonal changes with e.g. repetitive work that were reversal to adaptations reported with exercise training. Progress has been made in developing intelligent physical exercise training, IPET, as the best complementary activity to job exposure and includes muscle activations and movements that limit work-related inactivity atrophy as well as overload injury.

1. Introduction

The first Basmajian Lecture was given – now 25 years ago - in 1996: “Reflections on John V. Basmajian: Anatomist, Electromyographer, Scientist” and summarizes his immense contribution for about half a century (Wolf, 1997). Basmajian was a true interdisciplinary scientist, spanning from basic to clinically applied research, and who in one of his last papers entitled: “The elixir of laughter in rehabilitation” stated that “everyone advocates cheerfulness on the part of the healing professions despite lacking evidence” (Basmajian, 1998). The research presented at the 2020 Basmajian lecture in many ways resampled that of Basmajian’s research and particularly so in terms of “lacking evidence”, which here regards “exercise training at the worksite to alleviate musculoskeletal pain”. Importantly, WHO and US physical activity guidelines advocate physical activity (PA) for health, specifically for the working-age population and in general to be promoted at the worksite (Bull et al., 2020; Piercy et al., 2018). However, actions are still limited due to lack of dissemination of interdisciplinary research knowledge in this area. The present review will summarize lines of evidence published during the last two decades that collectively support actions to be taken at worksites to offer individually tailored physical exercise training in a health perspective and specifically for improving musculoskeletal health.

This area of research in a broader perspective is not novel - but there are a lot of controversies that will be addressed because they are important for our choices regarding healthy longevity. Already Hippocrates advised us more than 2000 years ago that exercise – though not too much of it – was good for health (Paffenbarger et al., 2001). In contrast 300 years ago a Danish physician-in-ordinary to the king in his medical thesis emphasized detrimental health effects of inappropriate PA and specified two types of PA: 1) If the purpose of the activity is to promote health (PA at leisure) and 2) If the activity is for other purposes such as occupational tasks (work), and that may cause musculoskeletal

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disorders (Struensee, 1757.). We have epidemiological data supporting this dichotomy of the effects of PA among the working population showing the risk of long-term sickness absence to decrease with increased leisure time PA but to increase with increased levels of occupational PA, musculoskeletal disorders being a major cause (Holtermann et al., 2012). Therefore, we posed the research question: which mode of muscle activation may prevent and/or rehabilitate work-related musculoskeletal disorders? To address this question the present paper focuses on the topics: 1) contrasting patterns of muscle activity at work and leisure, 2) activity dependent responses of muscle growth versus deterioration, 3) tailoring physical exercise training to prevent and conquer work-related musculoskeletal disorders, and 4) evidence based on RCT's of physical exercise training for health and worksite benefits.

2. Contrasting patterns of muscle activity at work and leisure

All active human movement is induced by muscle activation and therefore analysis of EMG may enlighten us about patterns of health-enhancing and detrimental effects of PA. EMG allows to directly measure the muscle activity patterns and can subsequently be analyzed in the domains of duration, frequency, and intensity. Fig. 1 depicts examples from the upper trapezius muscle during different work tasks and the training exercise: lateral raise. The raw EMG images intuitively show that activity patterns vary depending on type of activity (work task vs. exercise) and between work tasks from different occupations (violinist and surgeon vs. firefighter). Such differences can be quantified by e.g. a Cumulative Distribution Function or Amplitude Probability Distribution Function (APDF) showing very different shapes during these activities and correspondingly revealing highly different values for the three EMG levels of static (P = 0.1), mean (p = 0.5), and peak (p = 0.9). For the violinist and the surgeon significant static loadings were seen that were close to the same level as the mean values of around 10% MVE (maximal voluntary exertion) and with peak values up to 20% MVE. In contrast, the firefighter experienced an increase from a static level of around 10% MVE to a peak level of 70% MVE. This pattern to some extent resembles the activity level during a training exercise, although the exercise demonstrates an even wider range of muscle activity, from around 1% static level to 80% peak level. Importantly, the EMG during the training exercise showed distinct resting periods between contractions where the muscle can recover. The contraction/relaxation ratio during muscle activity - illustrated when performing the lateral raise exercise - involves a mix of low and high intensities. Such intermittent medium to high activation of short epochs not being sustained for long duration may be essential for the effect on viability versus degradation of muscle and which is carefully observed to be optimized in sports exercise training plans for each session as well as for training periods for month or years (Garber et al., 2011). Some job categories may carry the potential to maintain musculoskeletal health – like the exercise training – by optimal scheduling of the productive work (Holtermann et al., 2019), while other job demands per see may not allow for much variation and intensity in muscle activity. In such case the option is warranted to increase the resilience of the workers by training to alleviate their physical workload in combination with knowledge of sound ergonomic work principles (Johnston et al., 2014; Sjøgaard et al., 2014). The violinist, surgeon, and firefighter represent workers within diverse job categories within the three major job profiles, where high prevalence of musculoskeletal disorders is reported: sedentary monotonous work (e.g. office/computer workers, sewing-machine workers, and musicians), prolonged standing/walking (e.g. surgeons, cleaning personnel, and industrial workers), and physically heavy work (e.g. manual handling, military helicopter crew, and firefighters). The static, mean, and peak EMG levels are summarised in Table 1 for such job categories and show a large range within each of the job profiles. The table shows data for the upper trapezius muscle for all jobs and for one of the other muscles having some of the highest mean level recorded for that job. The mean values are ranging from around 4 to 30% MVE in all job profiles, but of note is the rather high static load of muscle in the job profile of sedentary monotonous work that is typically maintained throughout the workday and the very high peak loads in the standing/walking and particularly the physically heavy work that is often recorded during specific job tasks of shorter duration. This implies that different mechanisms of muscle pain development may play a role for different job profiles and warrants the need for different exercise training to counterbalance occupational exposure.

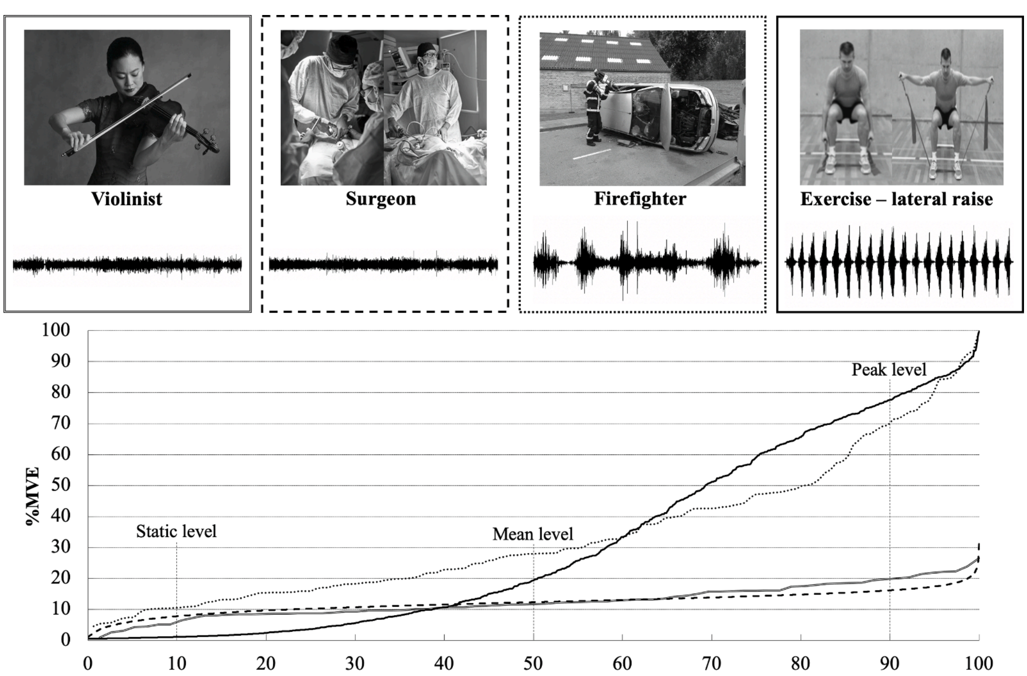

Fig. 1. Raw EMG images and the Cumulative Distribution Function of three work tasks and the exercise: lateral raise. Duration recorded for work tasks: violinist 1.3 min, surgeon 133 min, and firefighter 2.5 min.

Table 1
Muscle activity during different occupational job profiles: sedentary monotonous, standing/walking, and physically heavy work. Muscle activity for neck/shoulder muscles is presented as static, mean, and peak level analyzed by an Amplitude Probability Distribution Function (APDF). The muscles are, UT: upper trapezius, UNE: upper neck extensor, ISP: infraspinatus, AD: anterior deltoid, MD: middle deltoid, ECU: extensor carpi ulnaris, and ECR: extensor carpi radialis.

Job profile/task	Muscles	APDF			References
		Static (P = 0.01)	Mean (P = 0.05)	Peak (P = 0.09)	
Sedentary monotonous					
Office workers (with computerwork)	UT	1–2	4–5	8–9	(Jensen et al., 1998; Jensen et al., 1999)
	ECU	2	8	13	
Sewing machine operators	UT	4	7	25	(Zhang et al., 2011)
	UNE	3	7	11	
Sewing machine operators	UT	9	16	25	(Jensen et al., 1993)
	ISP	4	9	20	
Musicians (violinists)	UT	6	10	16	(Mann et al., 2021)
	ECU	13	23	34	
Standing/walking					
Surgeons (conventional surgery)	UT	3	9	12	(Dalager et al., 2020)
	ECU	3	14	30	
Cleaning (mopping)	UT	2	6	11	(Wallius et al., 2016)
	AD	2	5	9	
Cleaning (scrupping)	UT	7	14	21	(Søgaard et al., 2001)
	MD	12	30	48	
Physically heavy					
Bagage handlers (in an airplane)	UT	2	7	24	(Koblauch, 2016)
	AD	1	5	23	
Helicopter pilots (military flights)	UT	2	4	8	(Murray et al., 2016)
	UNE	7	10	19	
Firefighters (cutting car open)	UT	3	28	69	Drongstrup Jensen Unpubl data
	ECR	3	16	74	

Large differences even exist regarding the occupational exposure within each job category, that may depend on both job demands and individual factors, and therefore may request more subtle EMG analyses. One such example is presented for playing the violin. Compared to the easy task of playing an "A major scale", the music piece showed a statistically significant higher muscle activity in some of the left forearm muscles and women had significantly higher activity in ECR and EDC than men (Mann et al., 2021). The higher activity may be due to the additional technical demands that are often intrinsic parts of a music piece such as high speed, vibrato, or thirds. Such demands may be more challenging for women than for men. Therefore, possible aggravating effect of these technical demands were studied during the standardized task of playing a simple "A major scale" with and without these demands. As can be seen in Fig. 2 the overall activation pattern across the muscles is similar for the music piece and the technically demanding tasks and with the same significantly higher activation in women compared to men for the three forearm muscles. For the rest of the muscles the activity level was similar for men and women. The larger relative load evoked by the technical demands for women may be due to smaller anthropometry and thereby be the underlying cause of the higher frequency of muscular pain among the female musicians. In general female report significant more work-related muscle pain than men and the same mechanisms are likely to apply for most job categories (Côté, 2012). Also, there is a side dominance with generally higher EMG levels on the left compared to right for violinists. For the upper trapezius the bilateral pattern, however, is more uniform for both muscle activity and muscle pain reports. In this respect Fig. 3 for instance shows for 10 computer workers that clicking with the computer mouse with right vs the left hand did not systematically for all subjects show the EMG amplitude in the trapezius muscle to be highest in the side performing the mouse click (Søgaard et al., 2014). The level of upper trapezius muscle activity being side independent of hand/arm tasks indicates the role of this muscle to be responsible for other purposes such as stabilizing the head in relation to visual demands during e.g. hand eye coordination. Such dual task demands may underlie the particularly frequent occurrence of work-related trapezius myalgia.

EMG depicts the activity pattern of muscle but not the contraction mode of activity i.e. static vs. dynamic, and more comprehensive job exposure assessments include besides EMG also kinematic analysis. These can be performed by sophisticated 3D opto-electric analysis, accelerometry, or observational methods (Takala et al., 2010).

Recently, accelerometry has gained attention in large scale epidemiological studies because dynamic activity can be explicated in a cost-effective manner. Such analyses seem particularly relevant for job categories of standing/walking and physically heavy work where EMG measures alone will lack important exposure variables. Accelerometry can assess activity types and work intensity at larger scale and during real life settings, since accelerometers are generally small, inexpensive and do not interfere with most activities. By adding heart rate monitoring to the objective movement exposure measurements with accelerometry, an even more accurate estimate of the whole-body work intensity can be obtained in field settings (Jorgensen et al., 2013). Fig. 4 shows the average distribution of activity types from two different kinds of working shifts (12-hour and 24-hour shifts) measured with accelerometry. In this visualization, both occupational groups are considered "physically heavy", and it is surprising to note how much of their work time they spent sedentary or doing very low intensity PA. For example, 89% and 80% of the work time was spent lying, sitting, and standing among firefighters and wind technicians, respectively (Fig. 4). In absolute time estimates, these observations suggest that firefighters and wind technicians spent on average 158 min and 144 min on working tasks that involve dynamic physical activities (walk + move + other) pr. work shift, respectively. Surprisingly, for the firefighters no vigorous intensities were measures and for the wind technicians only 2% of the work time was moderate to vigorous physical activities, i.e. more strenuous than walking (MET intensities > 3). These data suggest that the typical PA patterns of these occupational groups may not have sufficient intensities for promoting or maintaining the physical capacity of the workers or for sustaining satisfactory musculoskeletal health. The lack of sufficient duration of dynamic moderate to vigorous intensity PA in combination with prolonged low level sustained static muscle contractions with inadequate recovery characterizes the majority of occupational PA – contrasting recommendations for training profiles in a health perspective. These contrasting activity modes during occupational and leisure time PA may underly the PA health paradox that is being debated mainly for cardiovascular disorders but is equally

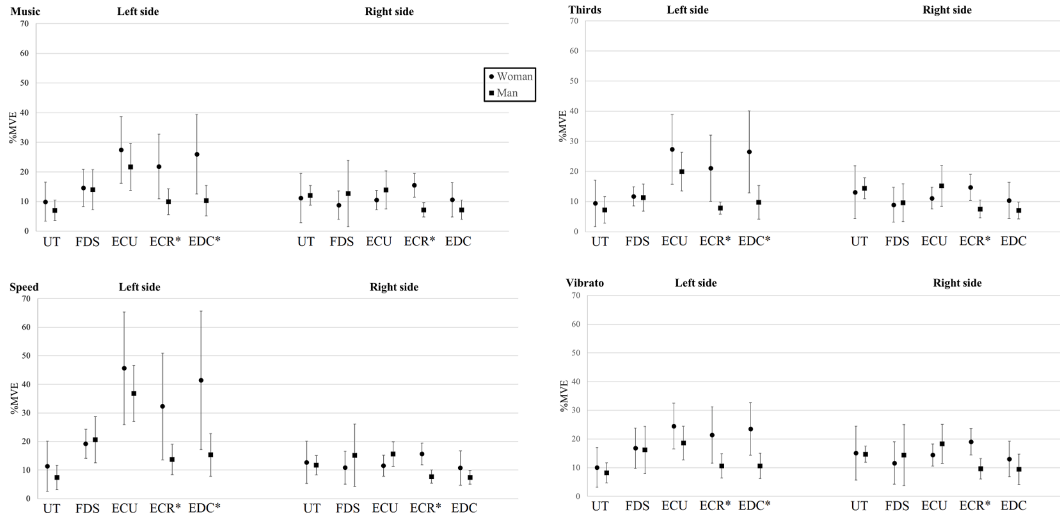

Fig. 2. EMG recordings during violin playing presented as mean RMS level (%MVE ± SD) measured for each muscle for both left and right side during a music piece (except of Mozartś Violin Concert no.5) and A major scale played in fast playing speed (32nd notes), with vibrato (pulsating changes of pitch), and thirds (double fingering). *Denotes a statistically significant ($p \leq 0.05$) difference in muscle activity between men and women. UT: upper trapezius, FDS: flexor digitorum superficialis; ECU: extensor carpi ulnaris; ECR: extensor carpi radialis, EDC: extensor digitorum communis.

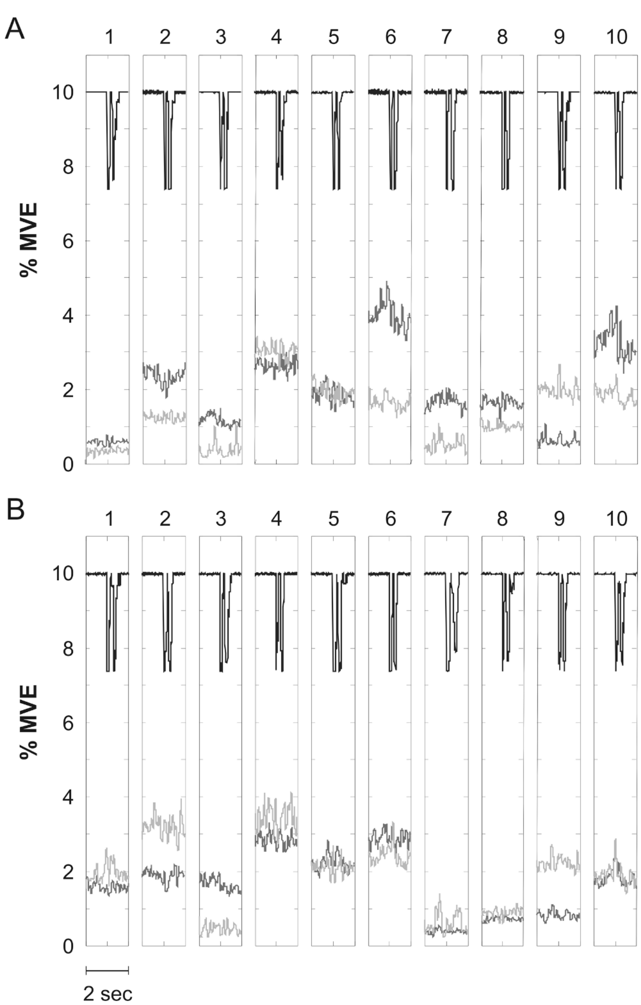

Fig. 3. Raw surface EMG recordings from the upper trapezius muscle (black trace is right side and grey trace is left side) for 2 sec during double clicking synchronized with signals from the mouse clicks. A: clicking with right hand, B: clicking with left hand.

relevant regarding musculoskeletal disorders (Coenen et al., 2020). More focus on methods to incorporate assessment of muscle activity mode in a health perspective is therefore warranted in a forthcoming research agenda regarding the PA. In this context it is important to emphasize that PA is not necessarily health enhancing just because it is performed at leisure. Excess training and overuse during leisure time sports can result in deleterious effects and produce significant injuries e. g. among competitive/elite sports like tennis, golf, and cycling the typical related disorders being tennis elbow, golfers' elbow, or knee-related pain.

Exposure analysis of various job categories revealing specific types of activity and muscle contractions in terms of duration, intensity, static or dynamic components, peak force, repetition etc. combined with reports on musculoskeletal disorders allows to identify potential risk factors. These include sustained static load, awkward postures, and peak loadings – in particular unexpected sudden loadings. Likewise, also activities that are requested to promote muscle growth and avoid muscular atrophy due to inactivity must be specified. A combination of job exposure assessment and sports science evidence of specific training exercises improving muscle function, morphology, metabolism, and biomarkers for pain and growth is requested.

3. Activity dependent responses of muscle growth versus deterioration

Muscle plasticity in relation to activity patterns has been studied for more than five decades and shown the ability to adjust molecular, metabolic, and mechanical properties of muscle in response to altered functional demands, such as changes in neuromuscular activity and/or mechanical loading. Understanding the adaptive potential of muscle is important in the treatment for repairing muscle damage in various muscle diseases and in the prevention of muscle degeneration during inactivity and overloading (Pette and Vrbova, 2017). To extend such basic understanding of underlying mechanisms we have experimentally studied *in vitro* muscle models, *in vivo* animal models, human laboratory experiments, and real-life human activities at work and exercise training. The mode of activity, the intensity and duration of activity, as well as the activity/rest cycle or recovery periods are decisive for the effect on muscle viability or atrophy. Fatigue development is considered a first step in a vicious circle of muscle degradation, disorder, and pain. In general, fatigue develops faster during high compared to low intensity contractions, but also when changing the mode of activity from static to

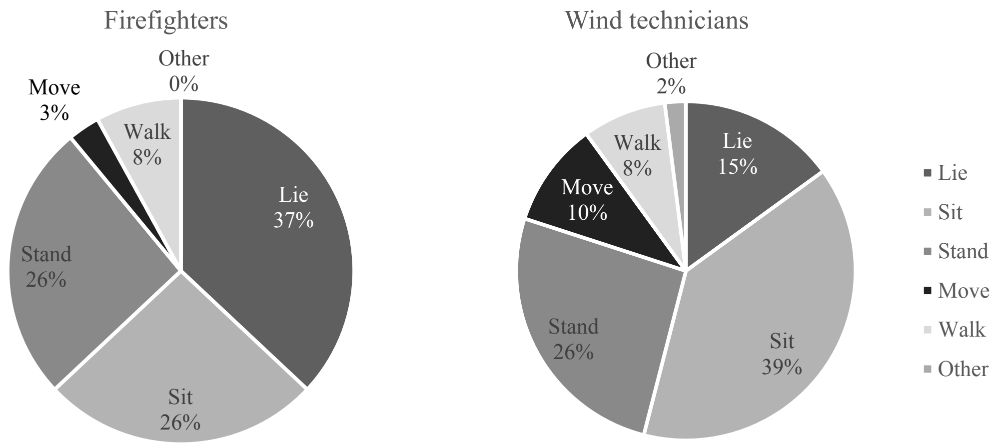

Fig. 4. Distribution of activity types measured with accelerometry for wind technicians and fire fighters during working hours presented as arithmetic means. A working shift for a wind technician corresponds to 12 h whereas it is twice as long for the included fire fighters (24-hour shifts) due to the different nature of occupational shift patterns. Distributions are therefore reflected relative and not as absolute hours/minutes. The category "other" includes running, stair climbing, climbing/biking and rowing activities. N = 25 wind technicians (52 offshore working shifts) and 13 fire fighters (13 working shifts).

dynamic contractions - as demonstrated in a muscle model where fatigue developed faster when the same electrical stimulation patterns induced repeated dynamic shortening contractions compared to static contractions (Vedsted et al., 2003). The transition from fatigue to disorder may relate to the fatigue state (Cairns et al., 2005). Thus, if fatigue is due to inactivation at the muscle membrane, e.g. due to changed potassium transients, deleterious effects on intracellular structures are protected (Sejersted and Sjøgaard, 2000). However, if intracellular calcium (Ca^{2+}) transients are disturbed intracellular structures of the sarcoplasmic reticulum and the contractile filaments may degrade (Ørtenblad et al., 2000) and recovery be prolonged due to structural tissue changes probably related to protein turnover rates necessary for regeneration and repair of damaged proteins in the muscle. Time for adequate recovery relative to the fatiguing muscle contractions may be essential for maintaining a healthy muscle and avoiding overtraining or overloading.

3.1. Mechanisms of occupational exposures causing muscle disorders

A well-established animal model allowed us to study repeated voluntary activity in combination with subcellular Ca^{2+} changes together with metabolic and inflammatory responses (Hadrevi et al., 2019). The Ca^{2+} regulatory excitation–contraction coupling properties are key topics of interest in the development of work-related muscle myalgia and may constitute an underlying cause of muscle pain and loss of force generating capacity. Rats performing six weeks of high force high repetition tasks for several hours/week – simulating occupational work – compared with controls showed changed myocellular Ca^{2+} transients, Ca^{2+} handling proteins, and indication of increased cytosolic [Ca^{2+}] together with indicators of muscle fatigue and pain behavior. Further, increased muscle inflammatory cytokines and heat shock proteins were seen. The latter have been hypothesized to play a key role in work-related muscle disorders (Punnett and Wegman, 2004); and e.g. the stress inducible HSP72 was shown to increase -in a similar pattern as in the rat model- in humans following a seven hours repetitive manual work task (Sjøgaard et al., 2013). Likewise, in a muscle degenerative perspective it is of note that following the repetitive work myostatin (a growth regulating protein) and the insulin-like-growth factor (IGF-1Eα) were decreased. Further, in humans with work-related myalgic compared with healthy muscle the satellite cell pool – i.e. the stem cells of the muscle – demonstrated a pattern similar to an aged muscle (>70 years) with higher number around type 1 fibres and fewer around type 2 fibres (56). Additionally, the neuronal nitric oxide synthase (nNOS) that is important in modulating cellular function, showed a dislocation to the sarcoplasm that may lead to dysfunctional regulation of NO causing poor oxygenation (Jensen et al., 2015) and the key metabolic protein, PDH-E1α, playing an important role for the mitochondrial choice of substrate was lower in myalgic compared to healthy muscle (Sjøgaard et al., 2013). In concert, oxidative metabolism in the myalgic trapezius muscle was impaired in terms of lower oxyhaemoglobin during a repetitive manual task (Sjøgaard et al., 2010). Finally, interstitial serotonin – an algesic substance - was increased in workers with myalgia before as well as after an eight hour working day compared with healthy controls (Larsson et al., 2008). An overview of these findings is presented in Table 2 together with deficiencies seen in muscle mechanical performance and pain perception. Such data document the role of the peripheral muscle fatigue due to specific patterns of muscle contraction as stages towards work-related muscle disorders and pain, disregarding a solely psychological response in the central nervous system to stressful or boring occupational tasks.

3.2. Modes of exercise training and their effects on muscular viability

In contrast to the possible deterioration induced by PA during e.g. occupational tasks, sports science has evidenced specific training modes that improve muscular mechanical performance in terms of strength, speed, and endurance. Such studies have documented major adaptations - depending on the training mode - in morphology with increases in muscle fiber cross-sections and/or number of capillaries, in substrate and enzyme concentrations for oxidative and/or glycolytic metabolism, as well as in hormonal changes such as increased growth hormone - on protein, gene or mRNA levels (Booth, 2015; Neufer et al., 2015). The major body of such studies include healthy athletes or untrained adults, and the pertinent question arises if workers' myalgic muscle has a similar training potential.

We studied workers with trapezius myalgia before and after 10 weeks of training that was performed for one hour per week either as specific strength training for the trapezius muscle or as aerobic training by leg-cycling with relaxed shoulder muscles. After the training period a decrease in the HSP 72 was significant for both strength and aerobic training and an increase in the PDH-E1α after strength training – in contrast to the changes following the repetitive task mentioned above (Sjøgaard et al., 2013). See Table 2 for an overview of the contrasting findings. Thus, satellite cells increased for both fibre types 1 and 2 (Mackey et al., 2011), which was significant for strength training of the painful shoulder muscles and a tendency was seen for the aerobic leg training. A similar pattern was seen for decrease in nNOS translocation to sarcoplasm (Jensen et al., 2015) while an increase in capillary density was seen only after strength training of the myalgic muscle (Andersen et al., 2014). Interestingly, the oxyhaemoglobin in the trapezius muscle during a repetitive manual task was increased only following the aerobic leg training (Søgaard et al., 2012). In summary, the myalgic muscle is trainable in terms of morphologic and metabolic potential but also in terms of mechanical performance and most of all resulting in a pain reduction (Table 2). Differences in occupational PA and physical

Table 2
Contrasting responses to repetitive monotonous work, aerobic training, strength training. Repetitive work was either studied as acute changes after 7 hrs work or as differences between workers with work-related myalgia (MYA) performing repetitive occupational work compared with healthy controls (CON). Aerobic training was studied after 12 weeks dynamic leg training on the myalgic trapezius muscle. Strength training was studied after 12 weeks neck/shoulder resistance training on myalgic trapezius muscle. ↑ denotes higher in MYA vs CON or increase with muscle activity or training, (↑) indicates a tendency. ↓ denotes lower in MYA vs CON or decrease with muscle activity or training, (↓) indicates a tendency. – no difference between MYA vs CON or unchanged with muscle activity or training. VAS is a visual-analog-scale pain scale and PPT is the pressure pain threshold.

Category	Response variable	Repetitive work	Aerobic training	Strength training
Mechanical	*strength*	↓ (Andersen et al., 2008)	– (Andersen et al., 2008)	↑ (Andersen et al., 2008)
	speed	↓ (Andersen et al., 2008)	– (Andersen et al., 2008)	↑ (Andersen et al., 2008)
	endurance	↓ (Andersen et al., 2014)		
	EMGmax	↓ (Andersen et al., 2008; Andersen et al., 2008)	– (Andersen et al., 2008)	↑ (Andersen et al., 2008)
Morpholgy	*cross section*	– (Andersen et al., 2008)		↑ (Nielsen et al., 2010; Andersen et al., 2009)
	satellite cells	↓ (Mackey et al., 2010)	(↑) (Mackey et al., 2011)	↑ (Mackey et al., 2011)
	capillary density	– (Andersen et al., 2014; Andersen et al., 2008)	– (Andersen et al., 2014)	↑ (Andersen et al., 2014)
	nNOS sarcoplasm	↑ (Jensen et al., 2015)	(↓) (Jensen et al., 2015)	↓ (Jensen et al., 2015)
Metabolism	*oxyhaemoglobin*	↓ (Sjøgaard et al., 2010)	↑ (Søgaard et al., 2012)	– (Søgaard et al., 2012)
	Pyruvate-dehydrogenase PDH-E1α	↓ (Sjøgaard et al., 2013)	– (Sjøgaard et al., 2013)	↑ (Sjøgaard et al., 2013)
	Heat Shock protein mRNA HSP72	↑ (Sjøgaard et al., 2013)	↓ (Sjøgaard et al., 2013)	↓ (Sjøgaard et al., 2013)
Markers for pain	*algesic substances*	↑ (Larsson et al., 2008)		
	VAS	↑ (Sjøgaard et al., 2010; Søgaard et al., 2012; Andersen et al., 2008)	(↓) (Søgaard et al., 2012; Andersen et al., 2008)	↓ (Søgaard et al., 2012; Andersen et al., 2008)
	PPT	↑ (Nielsen et al., 2010)	(↓) (Nielsen et al., 2010)	↓ (Nielsen et al., 2010)

exercise training are characterized by the modes of muscle activation but also the duration and repetition of activities and subsequent resting/recovery periods are decisive in a health perspective. Typically, physical exercise training is performed a few hours a week while occupational PA generally is performed repeatedly for more than 30 h a week. This distinction is important because many occupational exposures may not imply a risk for developing muscle disorders if they were only performed a few hours a week. Actually, some occupational exposure may be beneficial, preventing inactivity and design of healthy physical work task profiles may become a future option in developing healthy jobs (Holtermann et al., 2019) and may be combined with individually tailored physical exercise training at the work site (Sjøgaard et al., 2014). The subtle balance of optimal levels of exercise and leisure or occupational PA that are endemic to, essential for, and intrinsic to health and wellbeing has been reviewed regarding multiple biological systems and point to future perspectives of exercise itself probably resulting in epigenetic alterations with transgenerational influences (Hart and Zernicke, 2020).

4. Tailoring physical exercise training to prevent and conquer work-related musculoskeletal disorders

Based on sports science principles we developed programs for individual physical exercise training, IPET, to counteract job exposure overloading during heavy occupational tasks or physical inactivity during e.g. sedentary work. To account for PA at the job is important, because in a health perspective it is the individual's total daily PA pattern that matters, i.e. the accumulated PA and inactivity pattern at work and leisure (Rollo et al., 2020; Søgaard and Sjøgaard, 2017). Further, exercise as medicine is shown to be effective in preventing and rehabilitating a long number of diseases, in particular lifestyle diseases (Pedersen and Saltin, 2015). Finally, exercise training can improve workers physical capacity to match job demands. Therefore, the individually tailored training aims at combating musculoskeletal disorders and/or health risk indicators, improving shortcomings in physical capacity, and counterbalancing job exposure. This implies individual assessments in three categories: health profile, physical profile, and job profile. These profiles may be assessed in detail with numerous validated measures and evidenced cut-points as we have reported for some studies (Andersen et al., 2008; Andersen et al., 2008; Blangsted et al., 2008). Examples are 1) body fat percent, waist/hip ratio, blood pressure, blood lipid and glucose levels, and musculoskeletal disorder assessment by a chiropractor for the health profile, 2) maximal oxygen uptake, maximal muscle strength in multiple body regions, and a balance test for the physical capacity profile, and 3) biomechanical work exposure as described above including EMG measures for the job profile.

In praxis extensive testing may not always be feasible and less delicate assessments may still be of value. In its simplest practical form, we developed questionnaires and a simple test as shown in Table 3 with collapsing all body regions into 4 main areas. Another practical issue is to attain adherence to the training. Timewise workers find it difficult to fit in a training schedule in their daily life. Therefore, a possible way to promote the training is to allow for this activity during working hours and negotiations have shown that one hour a week is acceptable in many workplaces – especially if the planning is flexible, which we have shown possible in many respects (Dalager et al., 2015). Interestingly, a more recent study showed training at the worksite to be more effective than homebased training (Jakobsen et al., 2018). A critical issue is the total training duration of only 1 hr/week which may be borderline to attain a training effect. Therefore, it is particularly essential to deliver optimal training programs regarding choice of exercises and their duration and intensity. In order to prioritize time allotted to the various individual exercises recommended - based on the assessment of health, physical capacity, and job profiles - we developed an algorithm how to timewise optimize different categories of exercises, see Table 4. As a basis 5 min are always the shortest duration for an exercise. Further, 30 min should

Table 3
Overview of tests, questionnaires, and cut-points used to prescribe individual modes of exercise training in the IPET algorithm. Musculoskeletal disorders are evaluated from the question: *"How intense was your pain on average in [name of body part] during the past three month?"* categorized on a 0–10 NRS (numerical rating scale) where responses ≥ 1 lead to prescription of body region specific strength training. If pain or discomfort is perceived in more than two body regions, the prescription of specific strength training is prioritized for the two most affected body parts. The physical capacity profile cut-points "low" are defined from self-reported questions: *"How would you describe your physical strength/aerobic capacity"* answered on a 0–10 NRS where "low" includes 0–4 response categories. The balance test is a self-test assessing the ability to stand on one (non-dominant) leg. The cut-point for passing the test is standing for ≥ 30 s.

		Test/questionnaire /self-report	Aerobic training AT	Strength training (S1 + S2 + SA)					Functional Training FT
			Moderate/high intensity	Elbow/ hand	Shoulder/ neck area	Lower back	Hip/ knee/ ankle	All-round (SA)	Balance/ functional (FT)
Health Profile	Musculoskeletal disorders (NRS-intensities ≥ 1 on a 0–9 scale)	Elbow/hand		X					
		Shoulder/neck			X				
		Lower back				X			
		Hip/knee/ankle					X		
	Body composition	BMI (>25)	X						
Physical Profile	Aerobic	Capacity (low)	X						
	Strength	Capacity (low)						X	
	Balance	Test (<30 sec)							X
JobProfile	Occupational exposure category	Sedentary monotonous	X						
		Standing/walking	X					X	
		Physically heavy						X	

Table 4
Algorithm for recommending IPET training program for 1 hr/week depending on individual profile and job profile showing all possible combinations of the up to five training categories specified in table 3. *AT = Aerobic training. S1 = First priority specific strength training. S2 = Second priority specific strength training. SA = All-round strength training. FT = Functional balance training. Minimum duration for each training category is 5* min *and the displayed numbers represent the total duration in minutes allocated.* The 106 combinations can each be combined with three different job profiles: sedentary/monotonous (20 min aerobic training), walking/standing (15 min aerobic training and 5 min all-round strength training), or heavy physical job (20 min all-round strength training), respectively, resulting in a total of 318 programs for individual physical exercise training, IPET.

Individual profile							
Number of cut-points exceed	Combinations	Aerobic training	Strength training			Functional training	Possible Combinations
		Moderate/High Intensity	*Specific 1*	*Specific 2*	*All-round*	*Balance*	
		AT	S1	S2	SA	FT	
0		15			15		1
1	AT	20			10		1
	S1		20		10		4
	SA	10			20		1
	FT	‘			20	10	1
2	AT + S1	15	15				4
	AT + SA	15			15		1
	AT + FT	15			5	10	1
	S1 + S2		15	15			6
	S1 + SA		15		15		4
	S1 + FT		15		5	10	4
	SA + FT				20	10	1
3	AT + S1 + S2	10	10	10			6
	AT + S1 + SA	10	10		10		4
	AT + S1 + FT	10	10			10	4
	AT + SA + FT	10			10	10	1
	S1 + S2 + SA		10	10	10		6
	S1 + S2 + FT		10	10		10	6
	S1 + SA + FT		10		10	10	4
4	AT + S1 + S2 + SA	10	10	5	5		12
	AT + S1 + S2 + FT	10	10	5		5	12
	AT + S1 + SA + FT	10	10		5	5	4
	S1 + S2 + SA + FT		10	5	10	5	12
5	AT + S1 + S2 + SA + FT	10	5	5	5	5	6
Total possible combinations of training categories based on individual profile recommendations per job profile							106

address the individual profile (health and physical capacity profiles combined) and 20 min the job profile, which leaves 10 min for practical issues e.g. to go to the place for exercise, organize training equipment, or change clothes if needed. The exercises are categorized into aerobic, strength, and functional training. The strength training can maximally be allocated to 2 body specific regions (those with highest pain rating out of 4 main areas) and/or all-round strength training. In total a maximum of 5 training categories can thus be recommended and which results in a maximum of 24 combinations. If a worker regarding the individual profile is recommended all 5 categories 10 min are recommended for aerobic training and 5 min for each of the three types of strength training and 5 min for the functional training which typically is balance training, i.e. in total 30 min. If a worker is fully fit and healthy, i.e. no specific recommendation identified according to table 3, then 15 min are allocated to aerobic and 15 min to all-round strength training. All other combinations are identified in Table 4. In total this corresponds to 106 combination of programs for the individual profile because the specific strength training can be chosen for up to 2 body areas (those with highest pain) among the total of 4 body areas. Each of these training programs can then be combined with one of the three specific programs recommended for workers engaged in the job profiles: sedentary/monotonous (20 min aerobic training), walking/standing (15 min aerobic training and 5 min all-round strength training), or heavy physical job (20 min all-round strength training), respectively. This results in a total of 318 different programs for one-hour training sessions to be offered to the working population but may of course be increased manifold if further individualized.

A number of strength training programs were developed (Andersen et al., 2012; Andersen et al., 2008; Andersen et al., 2010; Johnston et al., 2014; Lange et al., 2013; Murray et al., 2015; Ying et al., 2020; Zebis et al., 2011)\ while other interventions programs also included aerobic and functional training (Andersen et al., 2008; Blangsted et al., 2008; Burich et al., 2015; Christensen et al., 2016; Gram et al., 2012; Holtermann et al., 2010; Jay et al., 2014; Sjøgaard et al., 2014). Strength training was in most studies designed to counteract neck/shoulder pain related to low-level static contraction performed during monotonous repetitive work or to train muscle strength due to low force capacity or for improving capacity to meet challenging high- performance job tasks. Specific EMG studies were performed to identify the optimal exercises for training, e.g. evidencing exercises that activate the target muscles > 60% MVC corresponding to 10RM (Andersen et al., 2012; Andersen et al., 2008; Ying et al., 2020). However, also more general all-round exercises were included as well as dynamic training with large muscle groups with high intensities, e.g. HIIT programs for improving cardiovascular fitness. The physiological and epidemiological evidence for allocating specific exercises including their intensities has been detailed previously in many studies e.g. (Chen et al., 2018; McArdle et al., 2010; Pedersen and Saltin, 2015; Sjøgaard et al., 2014).

5. Evidence based on RCT's of physical exercise training for health and worksite benefits

More than 20 RCT studies including > 4000 workers have been conducted the last two decades with data from 17 Danish studies summarized previously (Søgaard and Sjøgaard, 2017) and other studies published more recently or being in the process of publishing data e.g. (Aegerter et al., 2020; Christensen et al., 2016; Escriche-Escuder et al., 2020; Johnston et al., 2014). These physical exercise intervention studies have followed the model of IPET scheduled above to various degrees. However, the most essential criteria have been followed: training at or near the worksite for around one hour per week, for about ten weeks or more. The composition of exercises have in several studies had an emphasis on strength training and which may be one of the reasons for this type of training having been evidenced superior to other modes for sedentary monotonous work (Chen et al., 2018) as well as physically heavy work (Sundstrup et al., 2020). However, both aerobic and functional training have documented effects for the specific job categories studied. So far less focus has been on modulation of recommended exercises in relation to the individual profile. When introducing IPET at the general level to all workers in a company and not only to specific groups like e.g. those with musculoskeletal disorders, the individual profile training recommendations may become particularly important. Forthcoming interventions may shed more light on this concept. Importantly, no major deleterious effects were reported for any of the training interventions, only minor sprains or strains that recovered within short time. This ensures that the training programs were feasible in this respect. In contrast, many positive effects were seen and the main findings were: 1) reductions in musculoskeletal disorders, 2) reduced health risk indicators and improved physical capacities, and 3) increased productivity and monetary outcome on the company level.

5.1. Musculoskeletal health

In many of the RCT studies primary outcome was the occurence of musculoskeletal disorders and the aim to reduce these disorders in terms of pain intensity, duration and prevalence. Neck pain was reduced among office/computer workers (Andersen et al., 2014; Andersen et al., 2008; Blangsted et al., 2008; Dalager et al., 2015; Dalager et al., 2017; Johnston et al., 2021), industrial laboratory technicians (Jay et al., 2015; Zebis et al., 2011), cleaners (Jorgensen et al., 2011) as well as fighter and helicopter pilots (Lange et al., 2013; Murray et al., 2017), forearm pain was reduced among laboratory technicians (Zebis et al., 2011), and low back pain was reduced among office and health care workers (Andersen et al., 2010; Rasmussen et al., 2015). In the mixed populations including pain and no-pain cases the magnitude of changes in pain intensity were from overall mean values of little below 3 (on a 0–9 point numeric rating scale) to a little above 2. However, analyzing the effects among workers with pain levels ≥ 3 (pain cases) the effects were much more pronounced and clinically relevant with decreases in the overall mean pain values to almost half, i.e. from around 5 to below 3. This reduction was particularly large among those with high adherence, as pain reduction related to training volume in a dose–response relationship with the highest pain reduction being up to 80% over a 12 week period (Andersen et al., 2008).

5.2. Health and physical capacity

In a health perspective not only musculoskeletal health improved but also health risk indicators for cardio-metabolic disorders such as BMI, body fat%, and blood cholesterol. This was seen in several job groups: Office/computer workers (Pedersen et al., 2009), health care workers (Christensen et al., 2015), and construction workers (Gram et al., 2012). Further, as a health risk indicator for cardio-vascular diseases, blood pressure decreased for office workers (Dalager et al., 2016; Pedersen et al., 2009) and health care workers (Christensen et al., 2015), although in one study of cleaners it increased (Korshøj et al., 2015) but mostly remained unchanged. Further, training improved physical capacities in terms of muscular function as well as cardio-respiratory function, CRF. Strength training of the painful muscles recovered maximal muscle activation assessed by EMG and strength by 8–40% (Andersen et al., 2014; Dalager et al., 2015; Murray et al., 2020; Pedersen et al., 2009). Importantly, with strength training the improved functional capacity allowed for decreased relative muscle load during occupational repetitive work tasks (Søgaard et al., 2012). Interestingly, not only muscle strength increased but also strength-endurance (Andersen et al., 2014; Dalager et al., 2015), which may have particular importance for performing the occupational repetitive work tasks. Of note is that the increase in core/abdominal strength among cleaners may underlie the increased balance control reported in this job group (Jorgensen et al., 2011). Increases were also seen in CRF – in absolute and/or relative terms – among office/computer workers (Dalager et al., 2016; Pedersen et al., 2009), health care workers (Christensen et al., 2015), cleaners (Korshøj et al., 2015), and construction workers (Gram et al., 2012) in the order of 5–15%. This allowed for a relative lower workload in particular for the latter three occupations with physically heavy work.

5.3. Company benefits

Employers in general were positive to promote PA at the worksite for workers health promotion, but when negotiating worktime for employee physical exercise training it was always emphasized that this was acceptable only if production was maintained. Poor health among employees implies substantial costs for the companies. The costs relate to increased sickness presenteeism (decreased on-the-job performance while being at the workplace) as well as absenteeism (habitual absence from work) leading to loss of work productivity. Sickness presenteeism was assessed as self-reported on-the-job performance, using questions in regard to productivity, work ability, and quantity and quality of work performance. Importantly, in none of our studies we found a decrease in the variables underlying on-the-job performance, in spite of spending one hour a week performing physical exercise training during work time. On the contrary, one study among health care workers showed a significant 8% increase in productivity with the intervention after three months, although not after one year of intervention (Christensen et al., 2013) and another study among dentists showed improved self-reported quality of work (Fredslund and Sjøgaard, 2014). Among office and computer workers the training group compared with the control group showed a significant a 6% increase in productivity and a 29% reduction in absenteeism after one year among those who adhered to the training for 70% or more (Justesen et al., 2017). This emphasized the importance of attending the training since those with less than 70% adherence did not show such effect. A more recent study among office workers was designed with productivity as the primary outcome and neck pain as secondary outcome. This study showed after 1 year the monetized productivity loss and presenteeism was lower in the exercise group compared to the comparator group (Pereira et al., 2019). Further, those with neck pain in the exercise group had lower sickness absenteeism after 1 year than those in the comparator group. In conclusion, using an employer's perspective several RCT studies have shown that physical exercise training during worktime out wights the one hour time spend training and that it is a superior investment compared to implementation of other employee benefits like general health promotion information.

6. Concluding remarks

The RCT interventions reported above have used the IPET concept in a rather standardized protocol for exercise prescription since the employee groups have been relatively homogeneous in nature and the surroundings and/or available equipment have not varied significant between participants. This may be one of the explanations for only moderate levels of adherence and compliance reported in these studies, which in turn may have resulted in lower effect sizes than could possibly be attained. It is well known when implementing physical exercise at the worksite that it is important to use an individualized approach with exercise tailored detailed to the needs and preferences of each employee and preferably allowing for relevant employee influence on the exercise programming (Marshall, 2004). The perspectives of IPET are to enlarge the scope and allow for even more individualization and employee preference, e.g. related to prescription of differentiated exercises and/or using different equipment for a larger within-group variety of movement skill and exercise history. As the IPET concept gets incorporated further into app-solutions and potentially wider scale exercise rehabilitation programs, a more pragmatic approach, including more opportunities for differentiation and progression models, should therefore be tested and implemented. Still, there is a need to further systematize target categories of physical exercises and training protocols and to disseminate user-friendly, self-administrable concepts of exercise training protocols. To balance the daily PA profile of the working population it is also pertinent to better and more detailed clarify the diversity of PA in multidimensional terms and to categorize quality and quantity of job exposure profiles beyond the sedentary monotonous, standing/walking and physically heavy job profiles using e.g. smart technologies. The ultimate perspectives of such research is to play a major role in conquering life style diseases.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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