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The effects of age and musculoskeletal pain on force variability among manual workers

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ABSTRACT

The present study investigated the influence of age and musculoskeletal pain on force variability during a continuous isometric handgrip force task performed at 30% of maximal voluntary contraction carried out until failure. We recruited 96 male manual workers aged 51–72 years. The participants were stratified according to their age (50–59 and 60 + years) and by pain status (no pain, acute pain and chronic pain). The amplitude and structure of variability expressed as respectively standard deviation (SD) and coefficient of variation (CV), and sample entropy (SaEn) were calculated from the endurance task. The oldest group had an approximately 18% longer endurance time than the youngest group. No between-group differences were found in SD or CV, whereas a significant interaction between age and pain stage was found for SaEn. The youngest group showed lower SaEn than the oldest for both those with chronic pain and those without pain, indicating less force complexity, whereas a tendency for the opposite was found in the acute pain group. Within the pain stage groups, workers with acute pain had higher SaEn compared with both the no pain and chronic pain groups. These findings suggest that age and musculoskeletal pain differentially affects the structure of force variability in manual workers.

1. Introduction

Workers with physically demanding jobs have a high prevalence of musculoskeletal complaints and pain (de Zwart, Broersen, Frings-Dresen, & van Dijk, 1997; Tuomi, Huuhtanen, Nykyri, & Ilmarinen, 2001). Work categorized as being highly repetitive and involving constrained postures has been identified as a risk factor for developing such disorders (Parent-Thirion et al., 2017). Due to an increase in average longevity, retirement age is relentlessly being increased[1]. This could potentially become a problem for elderly manual workers suffering from chronic musculoskeletal pain and discomfort considering that the aging processes remains to be triggered by biological age.

Physiological aging is associated with a loss of maximal force capacity (Hughes et al., 2001; Vandervoort, 2002). However, work-related activity rarely requires maximal exertion. The decline in maximal force capacity results in an increased relative load. It is therefore of interest to study how sub-maximal force production changes with age (Enoka et al., 2003). Along that line, variability of

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[1] Lov om ændring af lov om social pension - Forhøjelse af folkepensionsalder, indførelse af seniorførtidspension. Available from: https://www.retsinformation.dk/forms/r0710.aspx?id=139950

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the motor system (including but not limited to force variability) has received growing attention over the last two decades (Srinivasan & Mathiassen, 2012). Indeed, the amplitude of force variability is generally found to increase with advancing age (Marmon, Pascoe, Schwartz, & Enoka, 2011; Vaillancourt & Newell, 2003) although some find no difference between young and elderly (Christou & Carlton, 2001). Age-related changes in variability may not be a problem in and of itself; however, altered variability has been linked to the development of musculoskeletal pain and discomfort (Madeleine, Mathiassen, & Arendt-Nielsen, 2008). Pain alters the sensory information sent to the central nervous system through nociceptive afferent input (Hodges & Tucker, 2011). In the acute stage, it is possible that variability increases as a compensatory mechanism to find the least painful way to execute a given motor task, whereas at the chronic stage variability may be reduced to avoid painful motor solutions (Madeleine, 2010; Madeleine, Mathiassen, & Arendt-Nielsen, 2008). To the authors' knowledge, no studies have investigated the coupled effects of age and pain stages on force variability.

The amplitude of variability can be studied using linear methods such as calculating the standard deviation (SD) or coefficient of variation (CV) of the force output (Christou & Carlton, 2001). Further, investigating the structure of variability may reveal important changes not delineated by linear approaches, such as the proposed loss of complexity with physiological aging (Lipsitz & Goldberger, 1992). Specifically, approximate and sample entropy (SaEn) can be used to quantify time-dependent structure of variability (complexity of variability) (Richman & Moorman, 2000), wherein complexity may be influenced by the number structural components in a system and how these are coupled to each other (Vaillancourt & Newell, 2002). Using such methods, studies have found not only a reduced structure of variability with increasing age (Vaillancourt & Newell, 2003), but also associations between a reduction in the complexity of variability and the development of pain and discomfort (Søndergaard, Olesen, Søndergaard, de Zee, & Madeleine, 2010). These associations indicate that both age and pain alters the structure of the motor control system. Clearly, there is a need for more research examining how age and musculoskeletal pain affects force variability, possibly through interacting effects.

Thus, the aim of the present study was to investigate the influence of age and pain stage on both the amplitude and structure of force variability during a continuous isometric handgrip task. Based on the existing literature, we hypothesized that the amplitude of variability would be larger with increasing age, whereas the structure would be lower. Further, we expected chronic musculoskeletal pain to be associated with both a reduced amplitude and structure of variability.

2. Materials and methods

2.1. Participants

The protocol for the present entire project has been described previously (Norheim, Hjort Bønløkke, Samani, Omland, & Madeleine, 2017). Participants were recruited through a questionnaire answered by a random sample of 2727 Danish manual workers aged 50–70 years as a part of the ALFA-cohort (Aging and Physical Work). Exclusion criteria included musculoskeletal disorders, cardiovascular disease or health conditions that contradicted physical testing. Ninety-seven participants (96 males, 1 female, aged 51–72 years) were tested after being informed about the purpose of the study and gave written informed consent to participate. Because sex-differences in force variability (Svendsen & Madeleine, 2010) was beyond the scope of the present study, we excluded the one female participant from further analysis. The remaining 96 males were all presently working (68%) in, or had held (32%), a manual profession. The study was approved by the local ethics committee (N-20160023) and carried out in accordance with the Declaration of Helsinki.

2.2. Age and musculoskeletal pain stratification

Deleterious physiological changes occur beyond the fifth decade of life in humans. These include a reduction in the number of motor units (Campbell, McComas, & Petito, 1973), coupled with a noticeable decrease in skeletal muscle strength (Hughes et al., 2001). In fact, starting from the sixth decade muscle strength is lost at a rate of approximately 10–15% per decade (Vandervoort, 2002). We therefore chose to age-stratify the participants into two groups (50–59 years and 60 + years). Regarding musculoskeletal complaints, i.e., pain and discomfort, participants were stratified into different pain stages based on answers to a modified Danish version of the Standardized Nordic Questionnaire (Kuorinka et al., 1987). It included two questions about the *duration* and the *intensity* of pain and discomfort. Specifically, *duration* was determined by the number of days with pain and discomfort within the last 12 months, graded on a 6-point scale (1 = 0 days, 2 = 1–7 days, 3 = 8–30 days, 4 = 31–90 days, 5 = > 90 days, 6 = every day), whereas *intensity* was reported from the last seven days graded on an 11-numeric scale (0 to 10). Both duration and intensity were assessed for the neck/shoulder, arms (elbow, wrist and hand), lower back, hips, and knees. In the present study we stratified participants into three groups based on the rating of pain and discomfort in the neck/shoulder and arm regions (upper extremities): chronic pain (duration: > 3 months, and intensity: > 3), acute pain (duration: < 3 months, and intensity: > 3), and no pain (everyone else). An intensity threshold of > 3 was chosen to differentiate between discomfort and pain (Petrini, Matthiesen, & Arendt-Nielsen, 2015). To test the robustness of the pain stage stratification, we performed sensitivity analyses with one higher and one lower value for the intensity of pain and discomfort (i.e. > 2 and > 4).

2.3. Force variability

The participants performed isometric handgrip tests using a digital hand dynamometer (Model G100, Biometrics Ltd, Gwent, UK). During the tests, participants were seated in chair holding the dynamometer with their palms facing medially. Their upper arms were in a neutral position and their lower arms resting on an armchair with the elbow flexed at 90°. This position was maintained

throughout the test sequence. First, the participants completed three maximal voluntary isometric contraction (MVC) trials lasting 3 s, separated by 2 min. Second, a single fatiguing trial was conducted. The target force was set at 30% MVC and task failure was defined as being unable to maintain 30 ± 2% MVC for more than five consecutive seconds. A computer monitor located 50 cm in front of the participants provided continuous visual feedback of both the target force and the output force during the endurance trial. All participants had normal or corrected-to-normal vision. Strong verbal encouragement was given during all trials. All tests were performed using the dominant hand.

2.4. Data processing

The force signals were A/D-converted (14-bit, NI USB-6001, National Instruments, Austin, TX, USA) and recorded with a custom made program (GripForce v. 1.0.1, Aalborg University, Denmark) in Labview 2015 (National Instruments, Austin, TX, USA), through which visual feedback of the force signal was provided. The pixel per Newton ratio was 3.7 ± 0.6 pixel/N and the visual angle was 4.6°. All force signals were sampled at a rate of 100 Hz. The signals were subsequently filtered using a fourth-order Butterworth filter with a low-pass cut-off frequency of 20 Hz in line with previous studies (Mista, Christensen, & Graven-Nielsen, 2015; Vaillancourt & Newell, 2003). The amplitude of variability was assessed by calculating SD and CV, representing respectively absolute and relative variability. The time-dependent structure of variability was assessed by calculating SaEn, which is a single non-negative number and reflects the complexity of a signal. Henceforth, SaEn will be referred to as force complexity, where low values indicate low complexity and high values indicate high complexity. First the signal is mapped into a so-called embedding space with an embedding dimension of m (Richman & Moorman, 2000). SaEn can be calculated as the negative logarithm of the probability of any two points in an embedding space with dimension of $m + 1$ (embedding dimension) have a distance less than a given r (tolerance distance), provided that those points were closer to each other than r in an embedding space with dimension of m (Richman & Moorman, 2000). To calculate SaEn, we used a fixed $m = 2$ and an $r = 0.2 \times$ SD, as suggested by other studies (Svendsen & Madeleine, 2010; Vaillancourt & Newell, 2000). Regarding data lengths, it has been suggested that lengths ranging from 100 to 5000 data points may be appropriate when calculating complexity of physiological time-series (Pincus & Goldberger, 1994). In a recent study using chaotic theoretical data, Yentes et al. found entropy values for SaEn to stabilize around 2000 data points (Yentes et al., 2013). Too long time-series may, however, lead to non-stationarity (Costa, Goldberger, & Peng, 2005). Therefore, we calculated SaEn values for data lengths of 100–2000 in increments of 100 and found that the entropy values stabilized around a data length of 800 points (< 1% change). Thus, to capture temporal changes in variability, we extracted five 8-s epochs (i.e. 800 data points each) from the force signal and calculated SD, CV and SaEn over these. The five non-overlapping epochs were normalized between subjects by extracting the epochs in steps of 25% of the total endurance time after removal of the first and last five seconds of each trial (Fig. 1). Analyses were carried out using MATLAB R2018a (The MathWorks Inc., Natick, MA, USA).

2.5. Statistics

Between-group differences in the age-stratified groups were tested using independent sample t-tests (age, BMI, handgrip endurance, MVC) and Mann-Whitney U tests (pain level). Similarly, for the pain stage stratified groups, one-way ANOVAs and Kruskal-Wallis test were applied. Normality of the data was tested using the Shapiro-Wilks test and checked for outliers by visual inspection of box plots. SD and CV were not normally distributed and therefore log transformed. Using SD, CV and SaEn as dependent variables, three full factorial repeated measures analysis of variance (ANOVA) models were tested with time as a within-subjects factor, and pain stage and age (Model 1), pain stage (Model 2), and age (Model 3) as between-subject factors. Greenhouse-Geisser corrections were used when the assumption of sphericity of variance was not met. Pairwise comparisons were conducted using Bonferroni *post hoc* tests. All statistical analyses were carried out using SPSS 25.0 (SPSS Inc., Chicago, Illinois, USA). Statistical significance was set *a priori* to $p < 0.05$.

3. Results

3.1. Participants

Compared with the other questionnaire respondents (i.e. the ALFA-cohort), the included participants were similar in terms of age

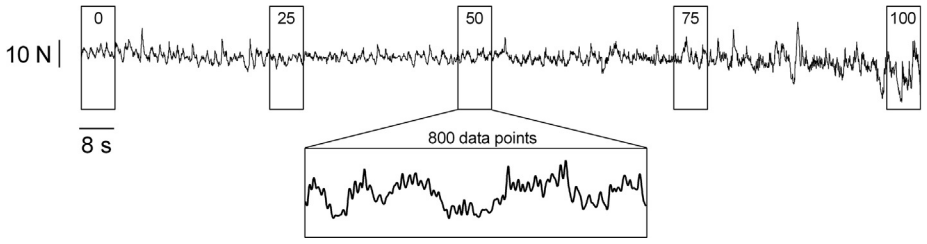

Fig. 1. Illustration of epochs used to calculate force variability during the handgrip endurance trial targeting 30% MVC. After discarding the first and last five seconds of each trial, five 8-s non-overlapping epochs were extracted in steps of 25% for further analysis. N = Newton.

Table 1
Characteristics of participants within group stratifications.

	Pain stage			Age	
	No pain	Acute pain	Chronic pain	50–59 years	60 + years
N (%)	57 (59)	16 (17)	23 (24)	44 (46)	52 (54)
Age (y), mean (SD)	60.2 (5.9)	60.3 (5.7)	59.8 (5.7)	55.1 (2.4)	65.0 (3.4)*
BMI (kg/m^2), mean (SD)	27.7 (3.2)	28.2 (4.5)	28.6 (2.7)	28.2 (2.9)	27.8 (3.6)
Handgrip endurance (s), mean (SD)	262 (96)	253 (1 0 9)	233 (70)	231 (86)	273 (96)*
MVC (N), mean (SD)	511 (74)	473 (94)	497 (1 0 6)	515 (79)	489 (91)
Currently working (yes), n (%)	37 (65)	11 (69)	17 (74)	40 (91)	25 (48)*
Pain[a], median (IQR)					
Neck/shoulder	0 (2)	5 (1)**	5 (3)**	2 (4)	3 (5)
Arms	0 (1)	3 (6)**	4 (6)**	2 (5)	0 (2)*
Lower back	1 (3)	4 (4)**	3 (4)**	3 (4)	1 (3)*
Hips	0 (1)	2 (5)**	1 (4)**	0 (3)	0 (2)
Knees	0 (2)	5 (7)**	5 (5)**	2 (7)	1 (4)*

Note: SD = standard deviation; BMI = body mass index; N = Newton; MVC = maximal voluntary contraction; IQR = interquartile range.
[a] Within the last 7 days on a scale from 0 to 10.
* Significantly different from 50 to 59 years ($p < 0.05$).
** Significantly different from No pain ($p < 0.05$).

(mean ± SD, 59.6 ± 5.6 vs. 59.5 ± 5.7 years), height (1.79 ± 0.07 vs. 1.78 ± 0.07 m) and body mass (87.2 ± 14.4 vs. 85.8 ± 12.6 kg) at the time of the questionnaire (approximately one year prior to the current experiment). Characteristics of the included participants are presented in table 1. Within the age stratification, the 60 + years group had a significantly longer endurance time compared with the 50–59 years group with a mean difference of −41.3 s (95% CI, −78.4 to −4.2 s), $t(94) = -2.212$, $p = 0.029$. Regarding handgrip MVC strength, a non-significant mean difference of 25.5 N (95% CI, −9.3 to 60.3 N), $t(94) = 1.453$, $p = 0.149$ was found. The 50–59 years group had significantly higher ratings of pain within the last seven days in the arms ($U = 854$, $p = 0.021$), lower back ($U = 804$, $p = 0.010$) and knees ($U = 880$, $p = 0.044$) compared with the 60 + group.

3.2. Force variability

Model 1 found a significant main effect of time for SD: $F(3.3,297.2) = 25.959$, $p < 0.001$, CV: $F(3.3,299.1) = 26.040$, $p < 0.001$, and SaEn: $F(4,360) = 7.170$, $p < 0.001$. No significant time × age, time × pain stage, or time × age × pain stage interactions were found (all $p > 0.05$). Between-subjects effects for the three full factorial repeated measures ANOVA models are summarized in Table 2. Sensitivity analyses of the pain stage stratification using a higher and lower cut-off score for the intensity of pain (i.e. > 2 and > 4) provided similar results as those presented here (see Supplementary Material). Model 1 revealed no significant between-subjects effects for SD and CV. Regarding SaEn, Model 1 found an interaction between age and pain stage, $F(2,90) = 4.628$, $p = 0.012$, and a tendency for a between-subjects effect for pain stage, $F(2,90) = 3.032$, $p = 0.053$. Pairwise comparisons showed that within the chronic pain and no pain groups, SaEn was significantly lower for the youngest group with a mean difference of −0.060 (95% CI, −0.119 to −0.001), $F(1,90) = 4.130$, $p = 0.045$, and −0.043 (95% CI, −0.081 to −0.006), $F(1,90) = 5.254$, $p = 0.024$, respectively. Within the acute pain group, however, SaEn tended to be higher in the youngest group with a mean difference of 0.069 (95% CI, −0.002 to 0.140), $F(1,90) = 3.764$, $p = 0.056$. Between-group differences for pain stages was found within the 50–59 y group, $F(2,90) = 6.794$, $p = 0.002$, indicating that the acute pain group had higher SaEn than both the chronic pain group ($p = 0.004$) and the no pain group ($p = 0.003$). No between-group difference for pain stages within the 60 + years

Table 2
Models analyzed with full factorial repeated measures ANOVA.

			Between-subjects effects (p-value)		
	Between-subjects factors	Dependent factors	Pain stage	Age	Pain stage × age
Model 1	Pain stage, Age	SD	0.834	0.934	0.423
		CV	0.725	0.566	0.485
		SaEn	0.053	0.497	**0.012**
Model 2	Pain stage	SD	0.844		
		CV	0.682		
		SaEn	0.120		
Model 3	Age	SD		0.648	
		CV		0.868	
		SaEn		0.057	

Note. Significance is indicated by bold font when $p < 0.05$. ANOVA = analysis of variance; SD = standard deviation; CV = coefficient of variation; SaEn = sample entropy.

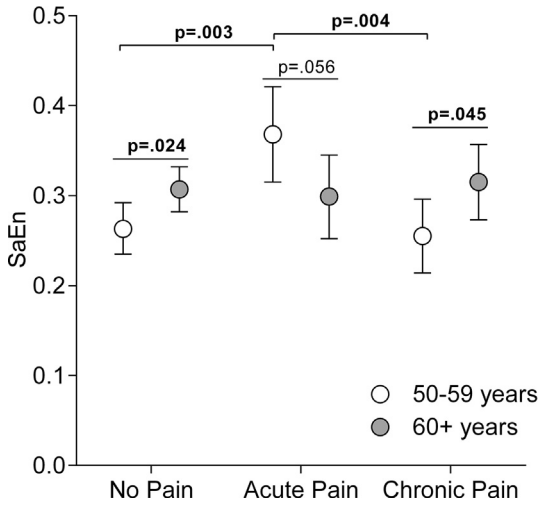

Fig. 2. Comparison of the mean SaEn across all epochs between age and pain stages. Circles are means with error bars representing 95% confidence intervals. *Note*. Significant pairwise comparisons with Bonferroni post hoc adjustment are indicated with bold font when $p < 0.05$. SaEn = sample entropy.

group was found, $F(2,90) = 0.224$, $p = 0.800$ (Fig. 2).

Model 2 found a significant main effect of time for SD: $F(3.3,303.1) = 27.009$, $p < 0.001$, CV: $F(3.278,304.9) = 27.071$, $p < 0.001$, and SaEn: $F(4,372) = 7.706$, $p < 0.001$, but no significant between-subjects effect of pain stage on SD: $F(2,93) = 0.170$, $p = 0.844$, CV: $F(2,93) = 0.385$, $p = 0.682$, nor SaEn: $F(2,93) = 0.120$, $p = 0.120$ (Fig. 3a-c).

Model 3 found a significant main effect of time for SD: $F(3.273,307.7) = 39.659$, $p < 0.001$, CV: $F(2.291,309.3) = 39.846$, and SaEn: $F(4,357.7) = 10.279$, $p < 0.001$. Similarly, model 3 found no significant between-subjects effect of age on SD: $F(1,94) = 0.210$, $p = 0.648$, or CV: $F(1,94) = 0.028$, $p = 0.868$, whereas a trend was found for SaEn: $F(1,94) = 3.711$, $p = 0.057$ (Fig. 3 d-f). See Figs. 2 and 3 for results of pairwise comparisons.

4. Discussion

In the present study, we investigated the influence of age and pain stage on both the amplitude and structure of force variability during a continuous isometric handgrip force task at 30% of MVC carried out until task failure. Contrary to our hypothesis, the youngest group showed lower force complexity than the oldest, for both those with chronic pain and those without pain, whereas a tendency for the opposite was found in the acute pain group. Within the pain stage groups, workers with acute pain had higher force complexity compared with both the no pain and chronic pain groups.

Consistent with previous studies (Hunter, Critchlow, & Enoka, 2004), we found longer endurance times for the oldest group. Longer endurance time has been related to greater spatial muscle activity during static contractions (Farina, Leclerc, Arendt-Nielsen, Buttelli, & Madeleine, 2008) and our findings therefore suggest a larger shift in muscle activity in the oldest group. Further, the oldest group only tended to be weaker compared with the youngest group, which is probably due to the narrow spread of ages. This difference equated a 5% decrease in handgrip strength per decade, which is lower compared with previous findings e.g. (Hughes et al., 2001; Vandervoort, 2002). In absolute terms, however, the maximal handgrip strength of the workers in the present study closely resembled those of a similar Danish cohort of males with a history of physical labour (Møller et al., 2013).

4.1. Age-related differences in force variability

Contrary to our hypothesis, we found no age-related differences in the relative amplitude of force variability. A substantial amount of evidence suggests that the relative amplitude of force variability increases with age. This has been found during index finger abduction (Laidlaw, Bilodeau, & Enoka, 2000; Marmon et al., 2011), knee extension (Tracy & Enoka, 2002), and plantar flexion (Kouzaki & Shinohara, 2010); however, there is a lack of studies measuring force variability during a handgrip task. Handgrip force is relevant, not only because it is used to manipulate objects during both daily living and working life, but also because handgrip force is a known marker of sarcopenia and a predictor of disability (Rantanen, Guralnik, Foley, Masaki, Leveille, Curb, & White, 1999). In a recent study measuring handgrip variability while squeezing a Nintendo Wii Balance Board, it was shown that relative variability was higher in old (mean ± SD age 67 ± 8 y) compared with young (age 24 ± 3 y) individuals (Blomkvist, Eika, de Bruin, Andersen, & Jorgensen, 2018). However, as with many other studies finding such a difference, both the young and older groups contained an uneven distribution of males and females. Given a sex-related difference in force variability (Svendsen & Madeleine, 2010), these findings cannot be readily compared with those of the present study. Furthermore, age-related differences are usually only seen when relative variability is calculated (i.e. CV) (Laidlaw et al., 2000; Tracy & Enoka, 2002), which can be attributed to declines in strength

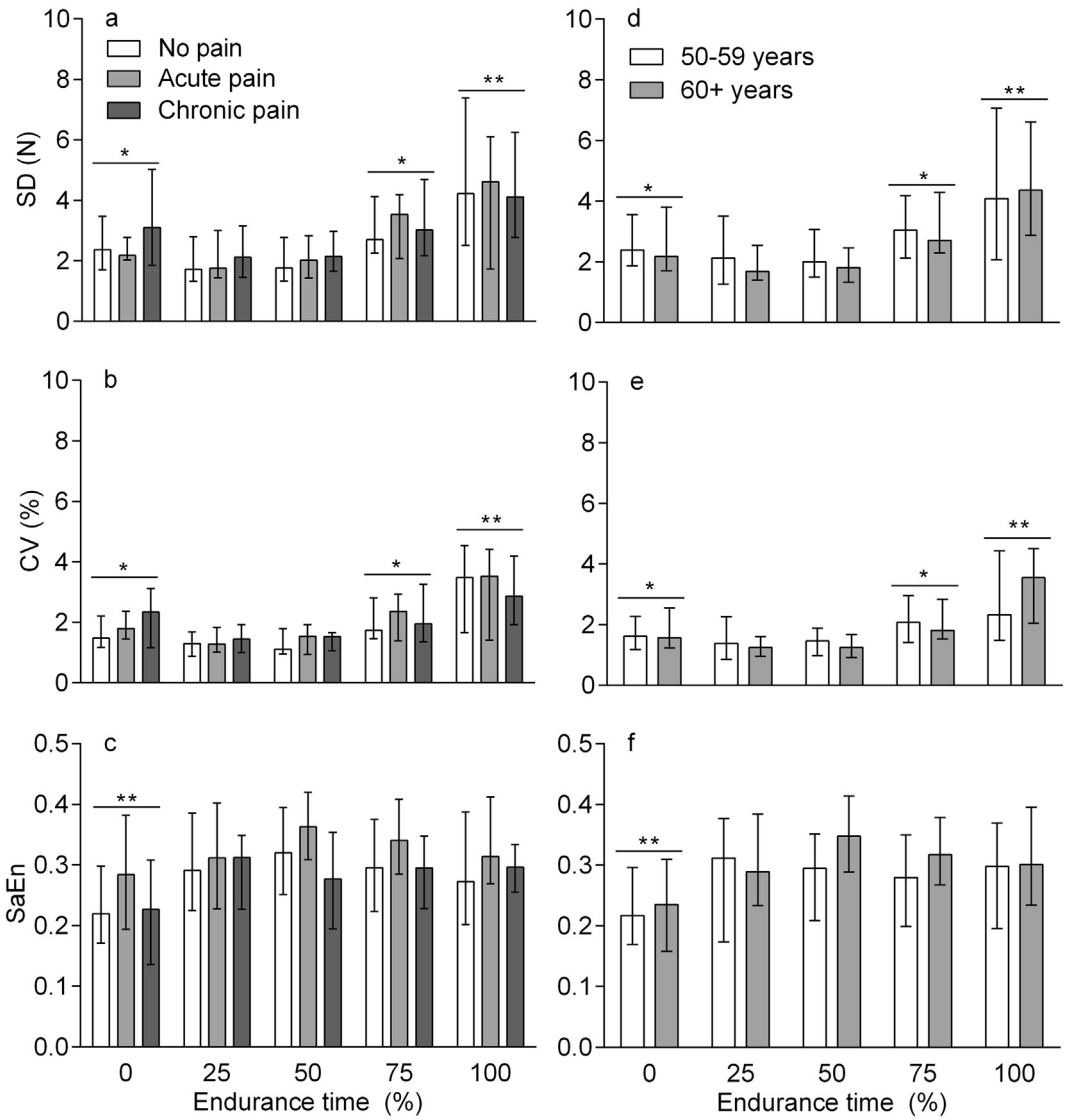

Fig. 3. Temporal changes in standard deviation (SD, N), coefficient of variation (CV, %) and sample entropy (SaEn) during the endurance trial. Bars are medians with error bars representing interquartile ranges (25th and 75th percentile). Subplots a-c are for the pain stage stratification and subplots d-f are for the age stratification. *Note*. *Significantly different from epoch 2 and 3 ($p < 0.05$); **Significantly different from all other epochs ($p < 0.05$). SD = standard deviation; N = Newton; CV = coefficient of variation; SaEn = sample entropy.

as a function of age. Such differences, moreover, may only be seen at force levels < 10% MVC (Kouzaki & Shinohara, 2010; Semmler, Steege, Kornatz, & Enoka, 2000; Tracy, Dinenno, Jorgensen, & Welsh, 2007; Tracy & Enoka, 2002; Tracy, Mehoudar, & Ortega, 2007). In fact, when subjects divided into five decades (from 30 to 79 years) performed isometric pinching at 5% MVC, the relative amplitude of force variability was higher in elderly subjects. However, this age-related difference was only seen for the last decade (70–79 years) (Herring-Marler, Spirduso, Eakin, & Abraham, 2014). In the present study, the relative force level was 30% and both age group showed similar absolute MVC strength. Moreover, the workers were aged 51–72 years and the age-dichotomy only involved two decades. It is therefore possible that age-related differences, if any, were missed due to the narrow spread of ages, force level or the lack of a difference in absolute strength. It is also important to note that age-related differences in force variability are exacerbated by higher visual feedback (Baweja, Kwon, & Christou, 2012; Kennedy & Christou, 2011). Indeed, at visual angles of 0.1°, 1° and 4°, positional variability has been shown to increase in older adults but remain unchanged in young adults (Baweja et al., 2012). The reason why a visual angle of 4.6° in the present study did not yield greater differences in variability with age could again be due to the narrow spread of ages.

Contrary to the suggested age-related loss of complexity (Lipsitz & Goldberger, 1992), the present study found no such difference in the force complexity. In fact, the oldest group actually tended to show higher force complexity compared with the youngest group, which suggests a greater number of and/or couplings between the structural components of the motor control system (Vaillancourt &

Newell, 2002). Vaillancourt and Newell (2003) investigated the amplitude and structure of variability in three different age groups (20–24, 64–69 and 75–90 years) at different levels of force output (5, 10, 20 and 40% MVC) both using a constant force and while following a 1-Hz sinusoidal target (Vaillancourt & Newell, 2003). Surprisingly, an age-related decrease in the structure of variability was found for the constant force task, whereas an increase was found for the sine wave task. The authors argued that the direction of change in complexity with age is dependent on external task demands. The findings of the present study suggest that for force control there does not seem to be a monotonic decrease in complexity with aging. This could possibly explain our findings of a tendency for an increase in force complexity with age.

4.2. Pain stage-related differences in force variability

We expected acute musculoskeletal pain to result in an increased amplitude of variability in line with previous experimental pain studies (Mista et al., 2015). Moreover, chronic musculoskeletal pain was expected to reduce the amplitude of variability, likely by modulation in motor unit discharge rate and alterations in Ia afferent input (Falla, Lindstrøm, Rechter, & Farina, 2010; Muceli, Farina, Kirkesola, Katch, & Falla, 2011). However, pain stage had no effect on the amplitude of force variability in the present study. In a recent study, no between-group effects were found on the amplitude of absolute force variability when chronic elbow pain patients and healthy controls performed isometric wrist extensions at 5, 30, 50, and 70% MVC (Mista, Monterde, Inglés, Salvat, & Graven-Nielsen, 2018). Contrary, Abboud et al. (2014) investigated the variability of muscle activity in patients with chronic low back pain during isometric trunk extension at 30% MVC until task failure and found lower amplitude of variability in the chronic pain patients when compared with healthy controls (Abboud et al., 2014). Further, a greater increase in variability was found in the control subjects throughout the fatiguing task. The differences in the way motor output was examined could possibly explain these differing results as the former study calculated variability from the force output, whereas the latter used electromyography and calculated variability as the spatial variation of muscular activity over the targeted muscle. Regarding the structure of variability, a previous study found evidence of a negative association between discomfort and centre of pressure complexity during 90 min of sitting (Søndergaard et al., 2010). Moreover, force complexity is increased during isometric elbow flexion with acute experimental pain (Mista et al., 2015), whereas no difference was found in chronic jaw pain patients compared with controls during a biting task (Wang et al., 2018). From this it seems that similar to the amplitude of variability, pain stages differentially affect force complexity. The reason for not finding any univariate between-group differences in the amplitude and structure of force variability could possibly be explained by the interacting effects of age.

4.3. Interacting effects of pain and age on force variability

In this study, we investigated for the first time the interacting effects of age and musculoskeletal pain on the amplitude and structure of force variability. When compared with the no pain group, the amplitude of force variability was hypothesized to be higher and lower for the acute pain and chronic pain groups, respectively, with both age groups following a similar pattern, but with the oldest group showing higher relative variability across all pain stages. Contrary to our hypothesis, the amplitude of variability was not affected by age or pain stage, nor were there any interaction between the two. Maximal strength was similar between the two age groups in the present study and differences in strength may explain previous reports of the amplitude of force variability changing with age (Sosnoff & Newell, 2006). As with the amplitude of force variability, force complexity was expected to be higher and lower for the acute pain and chronic pain groups, respectively. This pattern was found for the youngest group, whereas the oldest group showed no effects of pain stage on force complexity (Fig. 2). The reason for the lack of an effect of pain stage within the oldest group could possibly be due to the experience of pain being dependent on age (Petrini et al., 2015). Moreover, underreporting of pain and discomfort may have led to a bias of the pain stage stratification. In fact, the oldest group reported significantly lower levels of pain in the arms, lower back and knees compared with the youngest group. This could be because only about 50% of the participants in the oldest group were still working. Alternatively, attitudes such as stoicism may have caused some of the oldest workers with acute or chronic pain to report lower levels of musculoskeletal complains (Yong, 2006).

In agreement with the loss of complexity hypothesis (Lipsitz & Goldberger, 1992), we expected that the oldest group would show lower force complexity across all pain stages. Interestingly, for workers with chronic pain and for those without pain, force complexity was actually higher in the oldest group. However, for workers with acute pain, force complexity tended to be lower in the oldest group. These somewhat inconsistent findings are not readily intuitive. Looking at the results differently, force complexity in the oldest group more resembled that of the youngest acute pain group. An increase in complexity may therefore signal impairment of motor control (Vaillancourt & Newell, 2002). Clearly, there is a need for further studies examining the interacting effects of pain and age, not only to delineate their importance for motor control, but also to support the growing population of elderly workers suffering from musculoskeletal complaints.

Lastly, in agreement with previous studies (Abboud et al., 2014; Srinivasan & Mathiassen, 2012; Svendsen & Madeleine, 2010) we found an increase in the amplitude of variability as muscle fatigue developed. This has been suggested to stem from an adaptation of the motor control strategy, where muscle recruitment patterns change to sustain performance (Abboud et al., 2014). However, such motor behaviour may not be beneficial for workers who daily are exposed constrained postures, especially when adequate rest is not provided. Although physical activity is related to positive neuromuscular adaptations, the effects of long-term exposure to physical exertion through manual work are still uncertain. In the present study, the workers reporting acute and chronic pain comprised about 41% of the study sample. This suggests a maladaptive response to heavy physical work, which in turn could lead to work absenteeism and early pension retirement. If so, increasing the retirement age may not necessarily keep more workers in the labour market for a

longer time.

Some methodological considerations need to be made. The ages of the workers in the present study only spanned two decades, which may have interred age-related differences in force variability, despite the fact that a substantial number of physiological changes may be seen following the fifth decade of life in the general population (Campbell et al., 1973; Hughes et al., 2001; Vandervoort, 2002). Nevertheless, we believe our findings to be representative of elderly manual workers in their last two decades of working life (Cote et al., 2014; Møller et al., 2013). This was also supported by the participants being of similar age, height and body mass compared with the random sample of manual workers from which they were recruited. Yet, only male manual workers were included and our findings can therefore not be generalized to all individuals aged 50–70 years. Another limitation is the possibility of healthy worker selection. Although a slightly larger proportion of the participants in the chronic pain group were currently working (74%) compared with those without pain (65%), this difference was not significant and we therefore think that this finding does not skew the data substantially. However, there may already be a healthy worker effect in reaching 50 years of age as a manual worker.

In conclusion, the present study demonstrates that age and musculoskeletal pain differentially affects the structure of force variability in manual workers. Further longitudinal studies are needed to validate this interaction and to establish necessary interventions to counteract the large prevalence of pain and discomfort in elderly manual workers.

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Competing Interests

The researchers declare no conflicts of interest.

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Appendix A. Supplementary data

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