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Efficacy of six months neuromuscular exercise on lumbar movement variability – A randomized controlled trial

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Abstract

Introduction

Lumbar movement variability during heavy, repetitive work may be a protective mechanism to diminish the progression of lumbar disorders and maintain neuromuscular functional integrity. The effect of neuromuscular exercise (NME) on the variability of lumbar movement is still to be determined.

Methods

A randomised controlled trial was conducted on a population of nursing personnel with subacute LBP. Following randomization, the NME group participants completed an NME program of six months duration. The participants in the control group only attended the assessment sessions. The outcomes were assessed at: baseline; after six months intervention; 12 months. The primary outcome was lumbar movement variability based on angular displacement and velocity.

Results

A positive treatment effect on lumbar movement variability was seen after six months of NME intervention. Angular displacement improved, and angular velocity remained constant. At the 12-month follow up, however, the effect faded in the NME group. Lumbar movement variability worsened in the control group over all time periods.

Conclusion

NME may improve lumbar movement variability in the short term and may indicate improved neuromuscular functional integrity. The design of an optimal NME program to achieve long-term improvement in lumbar movement variability is a subject worthy of further research.

Trial Registration Number

NCT04165698

Key Words

Low Back Pain, Nonlinear Dynamics, Exercise Movement Techniques, Randomized Controlled Trial, Recurrence Quantification Analysis

1. Introduction

Low back pain (LBP) is a frequent occupational health problem in industrialized countries. International studies have reported a higher prevalence of LBP in nursing personnel than in other occupations, with the annual prevalence ranging from 45% to 77% (Harcombe et al., 2014, Wang et al., 2015, Yassi et al., 2013). Work-related tasks of nurses, such as patient handling, increase the risk of developing persistent LBP (Holtermann et al., 2013). The consequences are significant functional disability and working days lost (Harcombe et al., 2014), long-term absence (Andersen et al., 2012) and dropout from the profession early in the career (Faber et al., 2010). Lumbar movement variability during patient handling may be a protective mechanism to diminish the progression of

lumbar disease (Madeleine et al., 2009, Madeleine et al., 2008). Research evidence on effective interventions is currently inadequate.

Repetitive, heavy lifting is an occupational necessity in nursing and is thought to accelerate lumbar spine diseases, such as cumulative trauma disorders (CTDs) (Solomonow, 2012). Repetitive lifting of patients using poor ergonomics and trunk postures, e.g. with bent stance and a distorted back are characteristic causes of CTD (Holtermann et al., 2013, Roffey et al., 2010, Seidler et al., 2011, Smedley et al., 1995, Yassi et al., 2013). During extreme spinal postures, cumulative load induces height loss of the intervertebral discs (Gooyers et al., 2012). These, coupled with inadequate rest time, are predictors of a clinically important deterioration in low back function (Marras et al., 2014). Non-lifting patient care, the greatest proportion of the working shift, adds to the accumulated load on the lumbar soft tissues, since it is frequently performed in extreme, flexed spinal postures (Hodder et al., 2010, Holmes et al., 2010). According to Marras, 2000, Marras et al., 2014, Solomonow, 2012, risk factors for the development of CTD of the lumbar spine are: long loading durations; high magnitude loads; high movement velocities; large numbers of repetitions; and inadequate rest periods between work sessions. They report that continued longer term exposure could result in chronification of the disorder. A highly repetitive loading frequency at high velocities, as present in the handling of patients, is the most prominent risk factor (Solomonow, 2012). Repetitive tissue stressing of the lumbar spine is associated with greater anterior, posterior and compressive shear loading of the lumbar vertebra endplates, prompting increased cytokines expression levels and neutrophil density (Yang et al., 2011). Lengthy periods of recurrent work induces muscles spasms and transient disc creep with reduced stability in the spine, followed by acute inflammation and hyperexcitability of the muscles, tissue degradation and greater local lumbar stability (Solomonow, 2011, 2012, Solomonow et al., 2012). Pain has been linked to an alteration in the structural variability of lumbar movement, as a consequence of LBP, spinal laxity and lumbar disc creep. This has been observed during repetitive lifting and cyclic flexion-extension at high velocities (Asgari et al., 2015, Bauer et al., 2017, Bauer et al., 2015b, Dideriksen et al., 2014, Gizzi et al., 2018, Howarth et al., 2013).

Sufficient movement variability during repetitive work could provide protection against lumbar disorders. The degree of structure in a movement's variability indicates how a repeated movement evolves over time, and describes the complexity and predictability of that movement. Pain-free workers have shown less structured movement variability than those with pain (Madeleine et al., 2009, Madeleine et al., 2008). When uniform movements are repeated regularly, the associated soft tissues receive an increasing dosage of stress exposure. In cases of less structured movement variability, tissue loads are modified, tissue stress more broadly distributed and the cumulative load

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on particular tissues reduced (Cote, 2012, Madeleine et al., 2008, Mathiassen et al., 2003). Kopp, 1973 theorized that movement variability is an indicator of neuromuscular integrity (or voluntary motor abilities) that reflects coordination and the smooth regulation of movement. Accordingly, the potential to train individuals to perform tasks with less structured variability is an area of current interest both to occupational medicine and LBP research. Findings from studies on the shoulder region suggest that biofeedback training helps to reduce electromyogram amplitude, selectively activate subdivisions and increase motor variability of the trapezius muscle (Holtermann et al., 2013, Palmerud et al., 1995, Samani et al., 2010). Studies to show whether specific training can alter the structure of lumbar movement variability have not as yet been performed. Neuromuscular exercise (NME) is a training targeted at improving lumbar muscle control, flexibility and strength. It has the potential to increase the quantity of lumbar movement patterns available to an individual. This would afford them the opportunity of undertaking repetitive tasks in a variable manner, resulting in a reduction in cumulative stress on specific tissues.

In a research environment, the recognized standard tool for non-invasive analysis of lumbar movement is a 3D high-speed camera system (Cuesta-Vargas et al., 2010, McGinley et al., 2009). Certain constraints, such as lengthy exposure over time, can limit their application in specific settings. A movement analysis system to assess lumbar movement variability has been developed to overcome these limitations (Bauer et al., 2015a, Ernst et al., 2013). It uses wireless inertial measurement units (IMUs), a standardized IMU placement protocol and a reliable measurement protocol. The IMU system is concurrently valid when compared to optoelectronic measurement systems (Bauer et al., 2015a).

The objective of this study was to investigate the impact of NME on the variability of lumbar movement patterns during a work-related repetitive lifting task in female nurses suffering from recurrent LBP. A comparison was made to a control group of nurses with LBP who did not receive an intervention. It is hypothesised that the structure of lumbar movement variability decreases after six months of NME intervention. The longer-term effectiveness of NME was assessed at a 12-month follow up session.

2. Methods

This study is a planned sub-study of NURSE-RCT, NCT4165698 (sub-study 3) (Suni et al., 2018). The effects of NME were assessed prior to intervention at baseline, after six months of intervention and at a 12-month follow-up. The study was conducted according to the Declaration of Helsinki, approved by the local ethics committee and received informed consent from all participants. A flow chart of the study process is presented in Figure 1.

2.1 Participants

Female nursing personnel were recruited from Tampere University Hospital between May and August of 2013. Inclusion and exclusion criteria are listed in Table 1. For more details see the protocol by Suni et al., 2016.

2.2 Randomization and blinding

Participants were randomly assigned to the two study groups using sealed and sequentially numbered envelopes. Each participant received an envelope containing the group allocation at the baseline measurement session and after opening the envelope the participant was offered to join the allocated study group. Then, they were given information regarding their concrete participation. The study personnel responsible for the eligibility assessments and study measurements were blinded to the group allocations. ~~The statistician and the outcome evaluators were also blinded to the assigned groups until the statistical analysis was completion.~~

2.3 Intervention

The NME intervention was performed near the nurses' work places. NME participants were asked to attend training sessions of 60 minutes twice a week for six months. The objectives were to restore pain-related degradations of balance and coordination, and to increase endurance and strength. Over the first seven weeks, the nurses learned how to perform the exercises correctly, how to control their lumbar neutral zone and the associated breathing patterns. In the following weeks, the intervention was more exacting, with increasing demands on the subject's strength, balance, endurance and coordination. Following the initial bi-weekly exercise sessions, instructed by experienced NME-trained personnel, the intervention was replaced by one instructed session per month and weekly home sessions. The nurses were encouraged to continue with the home exercises at the end of the intervention period and were offered two instructed exercise sessions at the start of the remaining follow-up period to promote this. The control group received no intervention and only attended the three measurement and feedback sessions. The key exercises and overall training principles are described in by Suni et al., 2016. The training principles of the study and key exercises were outlined in a special booklet and DVD to support the subjects during their home sessions.

2.4 Equipment

Trunk movements were captured using an IMU system (ValedoMotion, Hocoma AG, Volketswil, Switzerland), through sensors attached at the level of the sacrum (S2) and the first lumbar vertebra (L1), as described in a separate study (Ernst et al., 2013) (Figure 2). The IMU sensors comprised a magnetometer, tri-axial gyroscope and accelerometer. The raw data from the IMUs was sampled at 50Hz (Valedo® Research, Hocoma AG), converted into quaternions (Madgwick et al., 2010) and, finally, into the angular difference between them by applying the tilt/twist formulation (Crawford et

al., 1999). The global coordinate system defined the sagittal and frontal planes. The lumbar spine angle was calculated from the differential signals of the S2 and L1 sensors. The outcome variables were derived from the sagittal plane flexion/extension angle, with flexion being positive and extension negative. The alignment of the two IMUs was represented by an angle of zero degrees. The angular displacement data was filtered with a second-order zero-phase low-pass Butterworth filter (1Hz cut-off frequency). Angular velocity was derived from this filtered data. The data processing steps are explained in detail in a separate study and were shown to provide concurrently valid estimates of lumbar movement and reliable measures of its determinism (Bauer et al., 2015a).

2.5 Experimental Procedures

Participants performed a 'Pick Up a Box' test of five cycles, starting in the upright standing position (Figure 3). During each cycle of 4.8 seconds duration, the participant was required to squat, pick up a box from the ground and then return to the squat position, whilst guided by a metronome set at 50bpm. The participants were allowed a rehearsal of the lifting cadence. The box weight was set at 10% of the participant's body weight. The test was repeated three times (Bauer et al., 2015b).

2.6 Outcomes

The primary outcome was lumbar movement variability, expressed as the determinism of lumbar angular displacement (DET AD) and velocity (DET AV). Determinism indicates the degree of the structure of variability. Lower determinism signifies lower predictability of a time series.

2.6.1 Movement Analysis

The raw data from the IMUs was sampled at 50Hz (Valedo® Research, Hocoma AG), converted into quaternions (Madgwick et al., 2010) and, finally, into the angular difference between them by applying the tilt/twist formulation (Crawford et al., 1999). The global coordinate system defined the sagittal and frontal planes. The lumbar spine angle was calculated from the differential signals of the S2 and L1 sensors. The outcome variables were derived from the sagittal plane flexion/extension angle, with flexion being positive and extension negative. The alignment of the two IMUs was represented by an angle of zero degrees. The angular displacement data was filtered with a second-order zero-phase low-pass Butterworth filter (1Hz cut-off frequency) with a correction factor according to (Winter DA., 2009). Angular velocity was derived from this filtered data. The data processing steps are explained in detail in a separate study and were shown to provide concurrently valid estimates of lumbar movement and reliable measures of its determinism (Bauer et al., 2015a). Recurrence quantification analysis (RQA) was applied to the lumbar angular displacement and velocity data (Figures 4&5) to quantify the structure of lumbar movement variability. This method is described in detail in a reference work (Webber et al., 1994). RQA is a nonlinear data analysis method, used to quantify the number and duration of recurrences of a time series. Thus, it quantifies

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the degree of structure in the variability of a time series. In RQA, time-delayed samples from movement data are projected into a phase space plot and form a phase space trajectory. This phase space reconstruction procedure was conducted individually for the angular displacement and velocity data, using the parameters specified in Table 2. The optimal delay was defined as the first minimum of mutual information, following mutual information analysis. Mutual information quantifies the amount of information obtained about a timeseries through observing the time delayed timeseries. The first minimum of mutal information is the first local minima obtained when computing the mutual information obtained by time delayed timeseries with increasing delays. The embedding dimension was defined through computing the correlation dimension under diverse embedding dimensions. The starting point, where the correlation dimension did not increase significantly despite increasing the embedding dimension, defined the optimal embedding dimension. The standard deviaton of the phase space trajectory was used to compute epsilon, or the tolerance for determining a recurrent point in the phase space. A recurrent point is defined as a point that is close (determined through epsilon) to another point in the phase space. If two or more parts of the phase space trajectory evolve in the same way (indicated by series of recurring points) that indicates recurrent movement patterns. Therefore, recurrent movement patterns are situated in close proximity to each other in the phase space plot, and form the shape of diagonal lines of points in a recurrence plot (RP). All recurrent points were moved into a two dimensional *N*x*N*-sized RP, with N being the number of points in the RP. From this, the determinism (*DET*) was calculated. *DET* is the amount of recurrent movement patterns, or diagonal lines of a predefined minimal acceptable length (lmin), over all points in the RP. The parameter lmin was selected through visual examination of the RP. Thus, the paramter lmin determines how long two parts of the phase space trajectory have to evolve the same way in order to be considered recuring movement patterns. Thus, *DET* is a measure of the predictability of the time series, and formulated as (equation 1):

$$(1) \; DET = \frac{\sum_{l=lmin}^{lmax} l * P(l)}{\sum_{l=1}^{lmax} l * P(l)} * 10^2$$

where *l* is the length of the diagonal lines, *lmin* and *lmax* the minimal acceptable, respectively, maximal possible length of diagonal lines and *P(l)* being the number of diagonal lines of length *l*. The mean values of the primary outcomes from the three test repetitions were calculated for further analysis. For all data processing steps and calculations Matlab 2018b® (MatLab (ver. 9.4.0.813654, R2018b, MathWorks Inc., Natick, MA, USA)), with RQA code from the University of Potsdam, Germany (Marwan et al., 2002), was used.

2.6.2 Clinical outcomes and covariates

All participants rated their mean level of LBP pain intensity over the past four weeks, using a visual analogue scale (VAS) ranging from "no pain" (0mm) to "the worst possible pain imaginable" (100mm). Lumbar movement is affected by LBP intensity, body mass index (BMI) and age and were thus used as covariates in the subsequent analysis of lumbar movement variability (Bauer et al., 2015b).

2.7 Statistical Analysis

A linear mixed model was fitted to the outcome data. The modelled observation Y_{ijk}(k_{th} participant in the i_{th} group at time j) was formulated as (equation 2)

$$(2)\ Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + U_{k(i)} + \beta_{covariates} + \varepsilon_{ijk},$$

With μ as the intercept, α_i as the i_{th} group effect, β_j as the j_{th} time effect, $(\alpha\beta)_{ij}$ as the ij_{th} group-time interaction (or the treatment effect, the quantity of interest), $U_{k(i)}$ as the random intercept of subject k nested in group I, $\beta_{covariates}$ as the effect of LBP intensity, BMI and age at baseline, and ε_{ijk} as the measurement error. We assumed that $U_{ik} \sim N(0, v^2)$ with v^2 as the between-subject variance and $\varepsilon_{ijk}\ N(0, \tau^2)$ with τ^2 as the within-subject variance.

The model parameters were estimated with a Bayesian approach, using uninformative priors on the model's parameters. To sample from the posterior distributions, the Gibbs sampling approach, a Monte-Carlo-Markov-Chain (MCMC) algorithm, was used (Plummer, 2003). The model parameters' means, standard deviations and 95% Highest Posterior Density intervals (95% HPDI) were reported from the posterior distributions. The outcomes were analysed by 'intention to treat'. R (Rx64 3.3.1 R Foundation for statistical computing, Austria) was used for the statistical analysis.

3. Results

Eighty-three female nursing personnel suffering from LBP were recruited for this study. Sixteen nurses withdrew from the study before the end of the six months intervention and five during the follow-up period (Figure 1). The descriptive characteristics of the participants are presented in Table 3. Figure 6 shows the observed means of the two groups through the three time points. Table 4 contains posterior summaries and 95% HPDI of the treatment effects between each of the three time points. Further posterior summaries, derived from the Bayesian estimation, are presented in Appendix 1. The groups presented similarly at baseline (Appendix 1). Lumbar movement variability showed a treatment effect after the six months of NME intervention. In the NME group, DET AD decreased and DET AV remained constant throughout the intervention phase. The 95%HDPI did not cross zero (Table 4). Both DET AD and DET AV increased in the control group between the three

points in time (Table 3). This demonstrates that the NME intervention decreased and preserved the structure of lumbar movement variability, when compared to no active intervention.

4. Discussion

This study has shown that NME may decrease or sustain the structure of lumbar movement variability. The observed treatment effect was substantial because it constituted about half of the standard deviations of the outcomes (see Tables 3 & 4). Consequently, NME can increase or uphold neuromuscular functional integrity, indicating that the neuromuscular system is more capable of generating suitable responses to the stressors and functions of nursing activities. In contrast, lumbar movement variability worsened in the non-intervention control group.

Determinism, as a measure of the structure of lumbar angular displacement and velocity, indicates how predictively a person performs a repetitive movement. Adequate lumbar motor variability allows new movement solutions to be found in response to shocks in the external environment (Riley et al., 2002), such as sudden perturbations (Hodges et al., 2009). It may consequently be of relevance for the maintenance of occupational health and performance (Srinivasan et al., 2012). Reduced variability of trunk and lumbar movement has previously been reported during gait and repetitive lifting in people with chronic LBP (Dideriksen et al., 2014, van den Hoorn et al., 2012). People suffering from chronic pain may revert to stereotypical motor solutions rather than utilizing a variety of alternatives to perform repeat tasks (Cote et al., 2005), despite this causing faster trunk muscle fatigue (van Dieen et al., 2009), decreased task performance (Gates et al., 2008) and lengthy stereotypical loading of the painful area. Lumbar movement could become more deterministic if left untreated, resulting in the neuromuscular system being incapable of restoring its own integrity (Costa et al., 2005, Lomond et al., 2010) and potentially leading to a chronic state of CTD. NME may reverse or lessen this pain-related loss in complexity of the neuromuscular system.

Motor variability increases in the short term after task-specific exercise, for instance after biofeedback training for office workers (Samani et al., 2010), and in the long term due to skills development from the repetition of occupational tasks, such as throwing or lifting (Granata et al., 1999). It is regarded as a protective strategy preventing musculoskeletal disorders, such as CTD, by reducing cumulative stereotypical load (Solomonow, 2012). These studies examined the short-term effects of training and the physiological process of skills acquisition in pain-free participants. Our study focussed on nursing personnel suffering from subacute LBP and the results suggests that six months of NME intervention reduces or preserves the structure of lumbar movement variability. The observed treatment effect diminished between the post-intervention assessment at six months and the follow-up at twelve months. Continuous, rigorous and targeted NME training could be

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indispensable to the maintenance of lumbar movement variability in populations that are at high risk, such as nursing personnel. While the optimal NME program design to attain a sustainable improvement in lumbar movement variability remains unidentified (e.g. factors such as intensity of training, dosage, type of feedback), this study indicates that, over a six month period, NME can improve lumbar movement variability or impede its decline.

4.1 Limitations

The dropouts in both study groups can be partly explained by the nurses' shift work, but these resulted in reduced precision of the treatment effect estimation. The nurses in our study presented with only low levels of LBP at baseline, but it is essential to identify interventions that hinder the development of the disorder and prevent it from becoming a chronic, disabling LBP in the working population. The basic assumption behind the analyses conducted in this study is a linear relationship between treatment and the outcome variables. Possible non-linear relationships were not analysed and could usefully be a subject of exploration for further research. Future studies might consider the Euclidian norm of the 3-D joint angles. These were not analysed due to the IMU systems limited concurrent validity when measuring lateral flexion or rotation movements of small magnitude during large flexion extension movements, which could be related to the IMUs size (Bauer et al., 2015a). While a treatment effect on the structure of lumbar movement variability was found by our data processing, relevant information from higher frequency contents might have been missed. Selecting a filtering technique demands a concession between noise allowed through and loss of information. Future studies should address filter designs that can retain information from higher frequency contents whilst eliminating noise. The lifting load was normalized to body weight because measures of strength were not collected in this study. The sample was restricted to females, the results might therefore not be generalizable to a general nursing population.

Conclusions

NME may reverse or lessen a further decline of lumbar movement variability in the short term. It may improve or maintain neuromuscular functional integrity as a result. The optimal NME design to deliver longer-term improvement (factors such as training intensity, dosage and type of feedback) requires further investigation in future studies.

Acknowledgements

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CONSORT

TRANSPARENT REPORTING of TRIALS

CONSORT 2010 Flow Diagram

Enrollment

Assessed for eligibility (n= 157)

Excluded (n= 74)
- Not meeting inclusion criteria (n= 72)
- Declined to participate (n= 2)
- Other reasons (n= 0)

Randomized (n= 83)

Allocation

Allocated to neuromuscular exercise (n= 42)
- Received allocated intervention (n= 42)
- Did not receive allocated intervention (n=0)

Allocated to control group (n= 41)
- Received allocated intervention (n=41)
- Did not receive allocated intervention (n= 0)

Follow-Up

Discontinued intervention during six months (n= 11)

Lost to follow-up after twelve months (n=0)

Discontinued participation during six months (n= 5)

Lost to follow-up after twelve months (n=5)

Analysis

Analysed (n= 42)
- Excluded from analysis (n= 0)

Analysed (n=41)
- Excluded from analysis (n= 0)

16

17

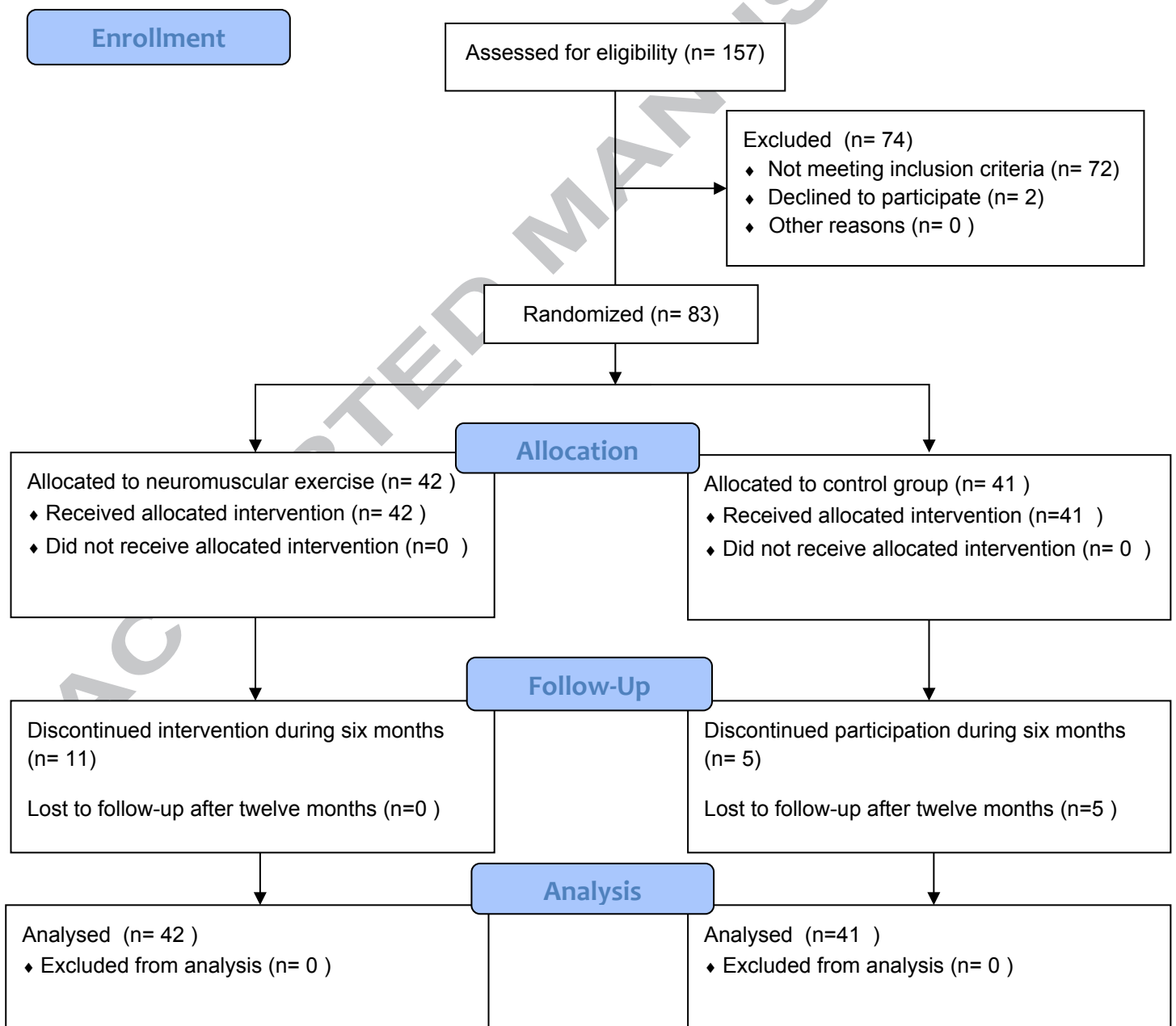**Figure 1. CONSORT 2010 Flow Diagram**

Fig 1.

Experimental setup: IMUs were placed on the level of sacrum (S2) and L1 (L1).
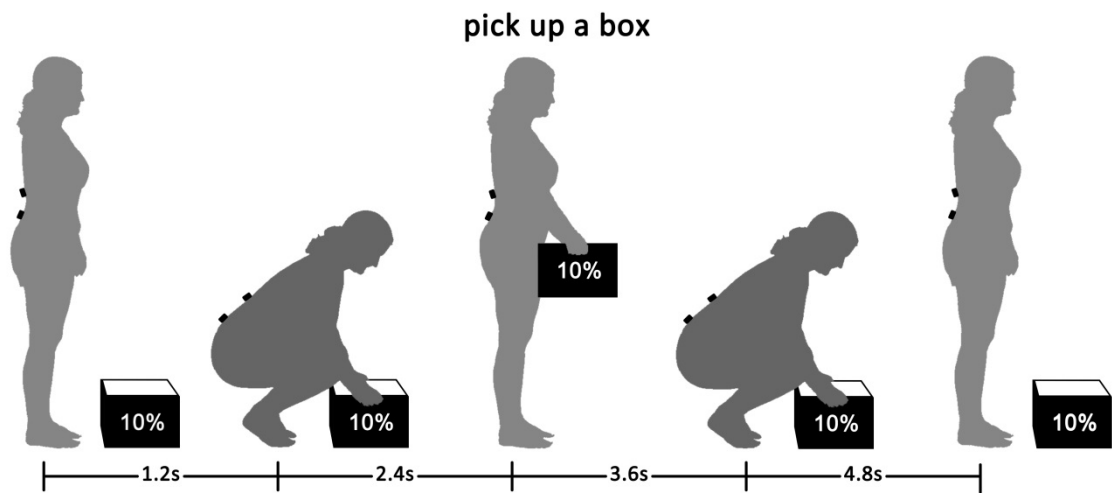
pick up a box

Fig 3.

Test procedure "Pick Up a Box". The nurses were guided with a metronome set at 50bpm. The box was loaded to ten percent of their body weight.
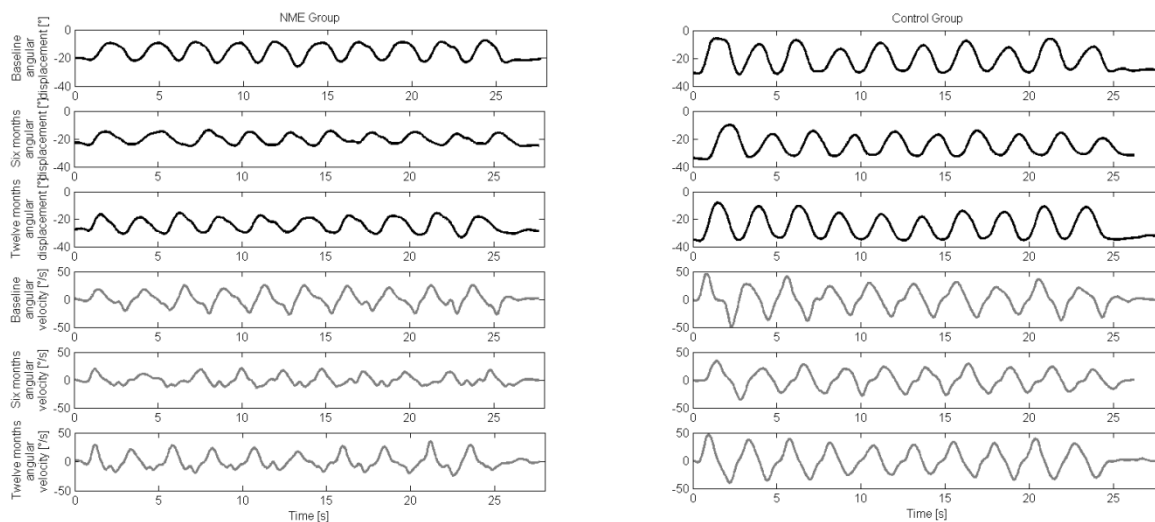
Fig 4. Angular displacement and velocity during Pick Up a Box

Angular displacement and velocity data from one participant from the NME group (left column) and control group (right column), at baseline, six months and twelve months. Determinism of angular displacement and velocity decreased from baseline to six and twelve months (left column) respectively increased (right column).

Abbreviations: NME – neuromuscular exercise

Example participant NME Group   Example participant Control Group

Angular Displacement   Angular Velocity   Angular Displacement   Angular Velocity
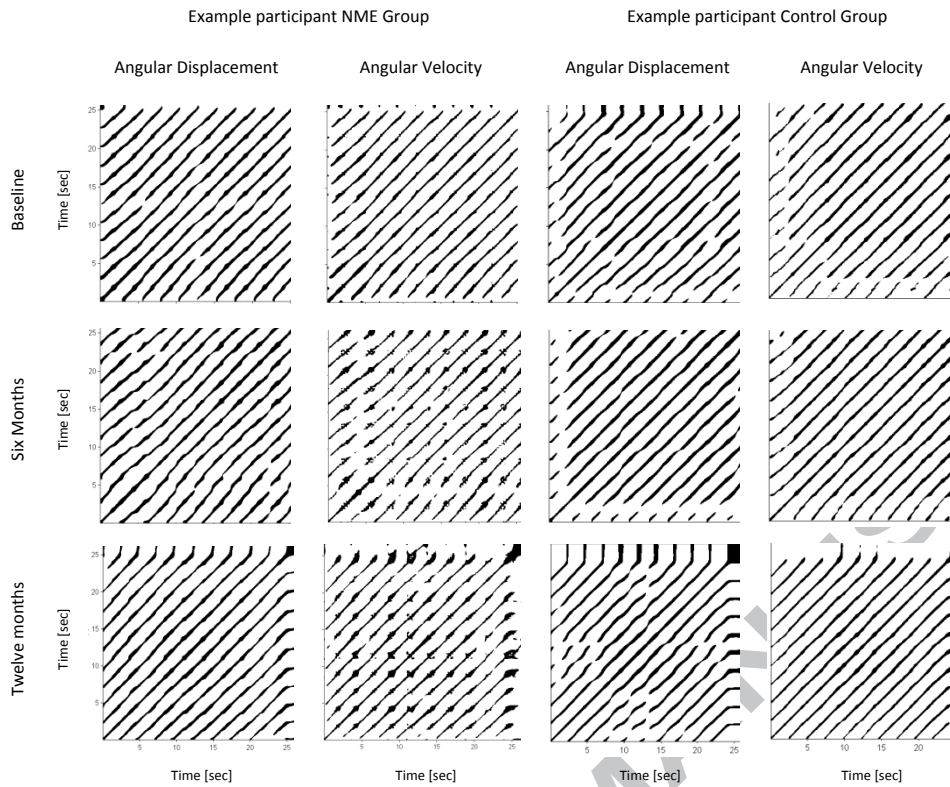

Fig 5. Recurrence plots for angular displacement and angular velocity

Angular displacement and velocity data from one participant from the NME group (left columns) and control group (right columns), at baseline, six months and twelve months. Determinism of angular displacement and velocity decreased from baseline to six and twelve months (left columns) respectively increased (right columns). All recurrent points derived from the phase space trajectories were moved into a two dimensional NxN-sized recurrence plot and are illustrated as black points, with N being the number of points in the original trajectory and expressed as time in seconds.

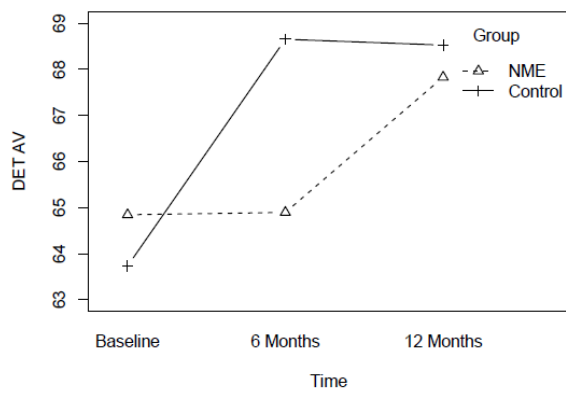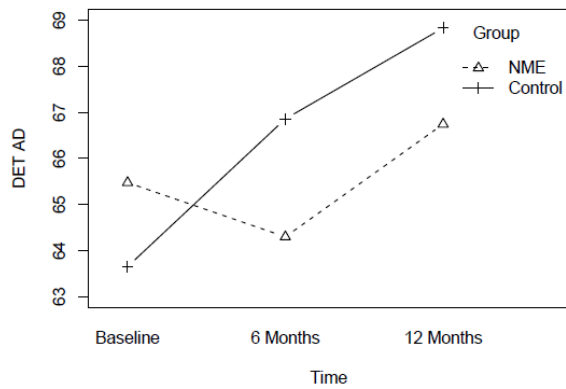Abbreviations: NME – neuromuscular exercise

Fig 6. Interaction plots for the primary outcomes across all time points

Abbreviations: AD – angular displacement; AV – angular velocity; DET – determinism; NME – neuromuscular exercise

The changes between the three time points indicate the treatment effect (the group-time interaction).

Inclusion Criteria	Excluison Criteria
Age between 30-55 years	Serious former back injury (fracture, back surgeries, disc protrusions)
Working at current job for at least 12 months	
	Chronic LBP defined by a physician
Suffering from LBP during the past four weeks, with a mean minimum intensity of two points on the numeric rating scale (NRS) (range 0-10 points)	Self-reported continuous LBP of seven months or longer duration
	Other diseases or symptoms that limit participation in moderate intensity NME
	Current engagement in NME more than once a week
	Pregnant or postpartum within the past twelve months

Table 1. Inclusion and Exclusion Criteria

Table 2 Input parameters used in recurrence quantification analysis

	Delay	Embedding Dimension	Distance	lmin	Epsilon
Angular Displacement	15	4	Euclidian	150	1.3σ
Angular Velocity	14	4	Euclidian	150	1.3σ

σ – Standard deviation of the reconstructed phase space trajectory; lmin - minimal length of diagonal line

Table 3 Descriptive characteristics of both groups

Group	n	Primary Outcomes		Covariates		
		DET AD	DET AV	LBP Intensity VAS (mm)	Age (years)	BMI
Baseline						
NME	42	65.5 ± 11.1	64.8 ± 11.4	34.0 ± 21.0	45.7 ± 7.8	26.7 ± (4.6)
Control	41	63.7 ± 9.7	63.7 ± 9.1	28.0 ± 21.1	46.7 ± 7.7	25.8 ± (3.6)
Six Months						
NME	31	64.3 ± 12.1	64.9 ± 12.1	25.2 ± 19.9		
Control	36	66.9 ± 9.6	68.7 ± 6.5	27.5 ± 19.0		
Twelve Months						
NME	31	66.7 ± 13.8	66.7 ± 13.8	21.3 ± 20.0		
Control	31	68.8 ± 7.0	68.8 ± 8.0	24.4 ± 22.7		

Abbreviations: AD – angular displacement; AV – angular velocity; BMI – body mass index; DET – determinism; LBP – low back pain; n – number of participants; VAS – visual analogue scale

All values are expressed as mean ± standard deviation

Table 4 Posterior distributions of treatment effects

Primary Outcome	Time points	Mean	95% HPDI
DET AD	**1 – 2**	**5.7**	**1.5 - 10**
	1 - 3	**4.7**	**0.1 – 9.2**
	2 - 3	-1.1	-5.7 – 3.6
DET AV	**1 - 2**	**5.8**	**1.8 – 9.6**
	1 - 3	1.9	-2.3 – 6.1
	2 - 3	-3.9	-8.2 – 0.3

Bold numbers indicate the 95%HDPI not crossing 0.

Abbreviations: 95% HPDI - 95% highest posterior density interval; AD – angular displacement; AV – angular velocity; DET – determinism

Appendix: Posterior Distributions

DET AD

Parameter	Timepoints	Mean	Standard Deviation	95% HPDI
Age		0.1	0.2	-0.2 – 0.4
BMI		0.2	0.3	-0.4 – 0.7
LBP intensity at baseline		0.0	0.1	-0.1 – 0.1
Group Effect	1	-1.9	2.6	-6.9 – 3.3
	2	3.9	2.7	- 1.4 – 9.1
	3	2.8	2.9	-2.7 – 8.3
v^2		0.8	0.2	0.5 – 1.2
τ^2		0.5	1.1	0.3 – 0.5
Time effects NME Group	1-2	-2.2	1.6	-5.3 – 0.8
	1-3	0.3	1.7	-3.0 – 3.5
	2-3	2.4	1.8	-0.8 – 5.8
Time effects Control Group	1-2	3.6	1.6	0.5 – 6.7
	1-3	5.0	1.8	1.8 – 8.2
	2-3	1.4	1.7	-1.9 – 4.6
Treatment Effect	1-2	5.7	2.3	1.5 – 10.0
	1-3	4.7	2.4	0.1 – 9.2
	2-3	-1.1	2.4	-5.7 – 3.6

DET AV

Parameter	Timepoints	Mean	Standard Deviation	95% HPDI
Age		-0.1	0.1	-0.4 – 0.2
BMI		0.1	0.3	-0.4 – 0.6
LBP intensity at baseline		0.0	0.1	-0.1 – 0.1
Group Effect	1	-1.4	2.4	-6.0 – 3.2
	2	4.4	2.5	- 0-5 – 9.2
	3	0.5	2.6	-4.7 – 5.5
v^2		0.7	0.2	0.5 – 1.1
τ^2		0.4	1.1	0.3 – 0.4
Time effects NME Group	1-2	-0.8	1.4	-3.4 – 1.9
	1-3	2.4	1.6	-0.4 – 7.2
	2-3	3.2	1.6	0.2 – 6.2
Time effects Control Group	1-2	5.0	1.5	2.3 – 7.7
	1-3	4.3	1.5	1.4 – 7.2
	2-3	-0.7	1.6	-3.7 – 2.3
Treatment Effect	1-2	5.8	2.0	1.8 – 9.6
	1-3	1.9	2.2	-2.3 – 6.1

27

	2-3	-3.9	2.2	-8.2 – 0.3

Bold numbers indicate the 95%HDPI not crossing 0.

Abbreviations: 95% HPDI - 95% highest posterior density interval; AD – angular displacement; AV – angular velocity; DET – determinism; v^2 – between subject variation; τ^2 – within subject variation

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