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Immediate effect of a spinal mobilisation intervention on muscle stiffness, tone and elasticity in subjects with lower back pain – A randomized cross-over trial.

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Background: Despite the lack of objective evidence, spinal manual therapies have been common practice for many years, particularly for treatment of lower back pain (LBP). This exploratory study measured and analysed the effect of a spinal mobilisation intervention on muscle tissue quality in LBP sufferers.

Methods: 40 people with LBP participated in a within-subject repeated measures cross-over study with intervention and control conditions. A myometer was used to assess the change in para-spinal muscle tissue quality before and after the intervention. Analysis considered the magnitude of muscle response together with individual covariates as potential contributors.

Results: A significant post intervention reduction was observed in muscle stiffness ($p = 0.012$, $\eta^2_{\text{partial}} = 0.15$), tone ($p = 0.001$, $\eta^2_{\text{partial}} = 0.25$) and elasticity ($p = 0.001$, $\eta^2_{\text{partial}} = 0.24$). Significant increases were seen in 2 variables post control: stiffness ($p = 0.004$, $\eta^2_{\text{partial}} = 0.19$), tone ($p = 0.006$, $\eta^2_{\text{partial}} = 0.18$) and a significant decrease in elasticity ($p < 0.000$, $\eta^2_{\text{partial}} = 0.3$). Significant contributing covariates include baseline stiffness, BMI, waist circumference and sex. Baseline stiffness and tone were significantly correlated to their response levels.

Conclusions: The significant reduction in all muscle tissue qualities following the intervention provide preliminary data for an evidence-based LBP therapeutic. Baseline stiffness, BMI, waist circumference and sex could act as significant contributors to magnitude of response. The results warrant further investigation into spinal mobilisation therapies to further build the objective evidence base.

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1 Introduction

2

3 Lower back pain (LBP) is one of the most common and economically debilitating pain
4 conditions globally. It is associated with decreased levels of spinal mobility, limited lumbar
5 muscle flexibility and altered spinal kinematics (Ferreira et al., 2009; Goertz et al., 2016;
6 Powers et al., 2008). The likely result of this, is reduced function of the lumbar spine and
7 increased stiffness. This can have an impact on body movement capability and lead to the
8 development of chronic problems with posture, coordination and range of motion (RoM)
9 (Shum et al., 2013, 2007). Manual therapy (MT) is a physical-based therapeutic reportedly
10 used for LBP treatment which targets musculoskeletal structures through several different
11 techniques (Bishop et al., 2015). Commonly reported benefits from MT-based techniques are
12 improvements in RoM, pain relief and muscle stiffness. However, these are often subjectively
13 assessed (Ferreira et al., 2009; George et al., 2006; Lopez-Lopez et al., 2015) with both positive
14 (Chiradejnant et al., 2003; George et al., 2006; Haas et al., 2014; Sterling et al., 2001) and
15 conflicting results (Assendelft et al., 2003; Childs et al., 2004; Goodsell et al., 2000; Stamos-
16 Papastamos et al., 2011; Thomson et al., 2009). These inconsistencies may be explained by
17 methodological differences as well as variability in individual responses to treatment (Childs
18 et al., 2004; Shum et al., 2013). Further, although commonly used in clinical practice to treat
19 musculoskeletal pain, there is limited understanding of the mechanisms responsible for the
20 reported benefits of MT (Goertz et al., 2016; Voogt et al., 2015). **The rationale to establish the
21 efficacy of such treatments is supported by the National Institute of Clinical Excellence,** given
22 their low risk of minor side effects and potential millions in economic savings (Carnes et al.,
23 2010; National Institute for Health and Care Excellence, 2016; Powers et al., 2008; Stamos-
24 Papastamos et al., 2011; Wong et al., 2016).

25

26 Spinal mobilisations is a MT technique used to treat such chronic pain (Chiradejnant et al.,
27 2003; Goodsell et al., 2000; Sterling et al., 2001; Thomson et al., 2009), typically applied in a
28 precise manner, using low velocity oscillatory movements to mobilise joints and passively
29 stretch soft tissues (Maitland et al., 2013; Piekarz and Perry, 2015). While objective research
30 on the efficacy of spinal mobilisations as an LBP treatment has been conducted in recent

31 years, more efficacy based evidence is needed (Piekarz and Perry, 2016), and a better
32 understanding of the response to such treatment is required.

33

34 Nonetheless, lower back muscle stiffness appears to be a meaningful contributor to reduced
35 mobility and has seen a growth in investigative literature (Edgecombe et al., 2013; Ferreira et
36 al., 2009). However, information about other aspects of muscle quality that collectively
37 contribute to mobility are lacking but are required to aid improved muscle condition
38 understanding (Kelly et al., 2018; Marusiak et al., 2012; Nair et al., 2016). The capacity of a
39 muscle to resist deformation, either by contraction or external force can be objectively
40 measured using a myometer to show stiffness or compliance. A muscle with higher stiffness
41 has a higher resistance to contraction (Viir et al., 2006). Muscle stiffness can be assessed by
42 palpation as well as characterised biomechanically. Muscle tone characterises the
43 background tension of the muscle in a resting state. Background tension is required to retain
44 stability, structure, and involuntary contractions. However, **hypertonicity** can cause high
45 intramuscular pressure and have a harmful effect on muscle recovery. Elasticity of a muscle
46 describes its ability to return to original shape after deformation and can be used as a
47 measure for mechanical stability and tissue changes (Kelly et al., 2018; Schneider et al., 2014).
48 In this study we seek to measure these tissue property changes to contribute to the
49 knowledge of the **effectiveness of spinal mobilisation in people with LBP** (Kelly et al., 2018;
50 Nair et al., 2016).

51

52 This study was an exploratory investigation of MT response and potential contributing factors.
53 We measured the change in stiffness, tone and elasticity in response to a spinal mobilisation
54 intervention within an LBP population to provide objective data for this. This is the first
55 scientific investigation of a 30-minute sustained spinal mobilisation intervention and
56 objective measures of muscular change. This is to provide a contribution to knowledge on MT
57 effectiveness and their beneficial mechanisms within LBP and provide recommendations for
58 further data collection to improve understanding.

59

60 We hypothesised that a reduction in paraspinal muscular stiffness and tone and increase in
61 elasticity after receiving a spinal mobilisation intervention could be objectively identified with
62 a validated protocol when compared to a sedentary scenario.

63 Methods

64 Participants

65 40 participants were recruited for this study (male: n = 18, female: n = 22) in a repeated-
66 measures cross-over study design, similar to previous investigations (Goodsell et al., 2000;
67 Jowsey and Perry, 2010; Pecos-Martín et al., 2017; Pentelka et al., 2012). Participants were
68 recruited through posters and word of mouth advertised at Edinburgh Napier University and
69 shared on social media.

70

71 Inclusion criteria for participation were: age range 18 to 80 and suffering from any form of
72 self-reported LBP (acute, chronic, diagnosed, undiagnosed, if pain was experienced in the
73 region between the 12th rib and the gluteal folds within the time of recruitment). Participants
74 were excluded if they responded positively to any absolute contraindications for spinal
75 therapy (Liebenson, 2007; Olson, 2009). These include: segment instability, infectious
76 disease, osteomyelitis, bone tumours, neurological deficit, upper motor neuron lesion, spinal
77 cord damage, or cervical arterial dysfunction. Participants responding positively to relative
78 contra-indications were asked to contact their GP and excluded based on severity. These
79 include: osteoporosis, spinal instability, rheumatoid arthritis, inflammatory disease, active
80 history of cancer, hypermobile syndrome, segment hypermobility, cardiovascular disease,
81 cervical anomalies, nerve root disorder, spinal surgery, respiratory problems, thrombosis,
82 open wounds, local infection and fractures or dislocations (Maitland et al., 2013). Ethical
83 approval was obtained from the Edinburgh Napier University Research Integrity Committee,
84 following the ethical guidelines stated by the Declaration of Helsinki.

85

86 Procedure

87 Participants attended a control and a spinal mobilisation intervention session one week apart,
88 at the same time of day for each session. All participants were informed about study details
89 and provided written consent. Participants were randomly allocated into one of two groups
90 via a random group generator, alternating the order of session type they received. All data
91 collection took place in the same treatment room and on the same standard physiotherapy
92 plinth. Ambient room temperature was controlled (20°-23° Celsius) for all sessions.

93

94 All participants completed the Oswestry Disability Index (ODI) (Fairbank and Pynsent, 2000)
95 prior to their first session to categorise their level of LBP (Chou and Huffman, 2007; Fritz et
96 al., 2011; Kamali and Shokri, 2012; Savigny P Watson P, Underwood M, Ritchie G , Cotterell
97 M, Hill D, Browne N, Buchanan E, Coffey P, Dixon P, Drummond C, Flanagan M, Greenough,C,
98 Griffiths M, Halliday-Bell J, Hettinga D, Vogel S, Walsh D., 2009). Anthropometric measures of
99 height, mass, waist circumference and sex were also recorded. These were taken as pre-
100 measures to investigate correlations as potential influencers on response and focus on muscle
101 tissue response as the main investigation.

102

103 The chartered physiotherapist performing the treatment had extensive experience in spinal
104 mobilisation therapy and as a working physiotherapist in practice at the time of the study.
105 They performed a 30-minute spinal mobilisation intervention, working at a specific rate
106 (0.37Hz) maintained by a metronome (on silent but within view of the therapist) set to the
107 equivalent 22 beats per minute. The physiotherapist worked at a grade lower than grade 1
108 and specific location (L1-L5), using posteroanterior (PA) mobilisations, oscillating the lumbar
109 vertebra, with both hands working on one side of the lumbar spine. Contact remained
110 consistent over the 30-minute period. These intervention parameters were based on previous
111 physiotherapy practice with anecdotal evidence of success within LBP. The intervention was
112 focussed on the lumbar spine to facilitate data collection.

113

114 Outcome measures for muscle stiffness, tone and elasticity were taken immediately before
115 and after both sessions, with participants lying prone. The intervention was performed on
116 one side of the lumbar spine (determined by pre-intervention stiffness values). The control
117 session involved no physical touch. The participant lay on the plinth and was encouraged to
118 relax for 30 minutes. The outcome measures were taken by the lead researcher who was not
119 involved in performing the intervention but was there to oversee the session.

120

121 Outcome measures

122 Measurements for para-spinal muscle stiffness, tone and elasticity were taken using a
123 myometer palpation device (MyotonPRO, Myoton Ltd., London UK). This previously validated
124 handheld device has been documented to give reliable results for muscle stiffness, tone and
125 elasticity (Bizzini and Mannion, 2003; Marusiak et al., 2012; Pruyn et al., 2015; Schneider et

126 al., 2014; Sohirad et al., 2017; Zinder and Padua, 2011). The myometer uses a series of low
127 force mechanical impulses (0.4N) registered as an oscillation in the form of an acceleration
128 signal. The muscle quality parameters are reported as a mean of these impulses along with
129 the coefficient of variation (CV), with recommended CV acceptance values of <3% (Kelly et al.,
130 2018; Schneider et al., 2014; Viir et al., 2006).

131

132 Measures were repeated 3 times on each side of the spine, to determine which side had
133 higher levels of stiffness and therefore the side to receive treatment. This was due to
134 literature suggesting that greater initial stiffness levels were more likely to respond with a
135 greater stiffness reduction (Childs et al., 2004; Shum et al., 2013). The location for
136 measurements were identified on both sides of the spine on a central point of the erector
137 spinae by asking the participant to lift their head and feet at the same time contracting their
138 back muscles. This spot was then marked to ensure pre- and post-measures were taken at the
139 same location. The distance and width from the base of the spine was measured to locate the
140 same spot for their 2nd session. The myometer was held perpendicular to the identified spot
141 and oscillations were sent through to the corresponding muscle.

142

143 Analysis

144 Analysis was exploratory and therefore carried out on each dependent variable (stiffness,
145 tone and elasticity) in separate 2-way repeated measure within participant ANOVAs to
146 determine any significant differences that occurred due to the independent variables;
147 condition (control and intervention) and time (pre- and post-). Covariates were assessed in
148 separate ANCOVAs to determine significant factors contributing to muscle changes. Due to
149 previously reported differences in male and female muscle characteristics (Granata et al.,
150 2002; Owens et al., 2007), the sex variable was investigated further with independent t-tests
151 and Pearson correlations, as well as within the ANCOVA analysis. All statistical analysis was
152 carried out using SPSS (version 23) with the alpha level set at 0.05.

153 Results

154 Pre- intervention anthropometric measures and ODI scores presented in table 1 for 40 LBP
155 participants and demonstrate a wide LBP population recruitment. Shapiro Wilk tests revealed

156 no normality violations in the dependent variable results. A post-hoc power calculation using
157 G-power (version 3.1) revealed an accepted power level of 0.91 (alpha = 0.05, sample size =
158 40, groups = 2, measurements = 3).

159

160 Muscle stiffness

161 A 2-way repeated measures ANOVA revealed a pre- to post- intervention significant main
162 effect interaction (between condition and time). Pairwise comparisons were used to
163 determine where specific differences lie in a pre- to post- comparison, revealing a significant
164 stiffness increase within the control and a significant decrease within the intervention (table
165 2, fig. 1).

166

167 ANCOVA was performed using all covariates to explore their interaction with the change in
168 stiffness post intervention. Change in stiffness was used as the dependent variable. Pre
169 intervention stiffness, BMI, ODI, waist circumference, height and sex were added as
170 covariates. A backward elimination was conducted based on highest p-value. The only
171 covariate remaining with significant influence was pre-intervention stiffness ($p = 0.002$) with
172 resultant model $R^2 = 0.22$ (adjusted = 0.2). There was a significant bivariate correlation
173 between pre intervention stiffness and change in stiffness (table 3). This results in a negative
174 correlation due to the reduction in stiffness seen in figure 1.

175

176 An independent t-test revealed a significant difference between male and female
177 intervention stiffness change ($p = 0.032$). Bivariate correlations for pre-intervention stiffness
178 and stiffness change carried out separately with male and female data displayed similar
179 trends (table 3).

180

181 Muscle tone

182 A 2-way repeated measures ANOVA revealed a pre- to post- intervention significant main
183 effect on muscle tone (condition) and the interaction (between condition and time). Pairwise
184 comparisons revealed a significant tone increase within the control group and a significant
185 tone decrease within the intervention group (table 2, fig. 2).

186

187 ANCOVA was performed using muscle tone as the dependent variable run in the same way as
188 above. BMI ($p = 0.048$), waist circumference ($p = 0.01$) and sex ($p = 0.005$) were found to be
189 significant contributors to tone change with resultant model $R^2 = 0.253$ (adjusted = 0.19).
190 There was a significant bivariate correlation between pre intervention tone and change of
191 tone (table 3), resulting in a negative correlation due to the reduction in tone (fig. 2).

192

193 An independent t-test revealed no significant difference between male and female tone
194 change ($p = 0.052$). Bivariate correlations for pre intervention tone and tone change
195 conducted separately with male and female data show different patterns (table 3).

196

197 Muscle elasticity

198 A 2-way repeated measures ANOVA revealed a pre- to post- intervention significant main
199 effect on muscle elasticity (time). Pairwise comparisons revealed a significant increase in
200 muscle logarithmic decrement within the control from pre- to post-intervention and a
201 significant increase within the intervention condition (table 2, fig. 3). This equates to a
202 decrease in muscle elasticity due to its inversely proportional relationship to muscle
203 decrement.

204

205 ANCOVA was performed using changes in elasticity as the dependent variable, in the same
206 way as above. There were no covariates with a significant influence on decrement change. A
207 bivariate correlation between pre-intervention decrement in elasticity and decrement change
208 was not significant (table 3).

209

210 An independent t-test revealed no significant difference between male and female elasticity
211 change ($p = 0.162$) and bivariate correlations for pre intervention decrement in elasticity and
212 decrement change conducted for male and female data displayed no pattern (table 3).

213 Discussion

214 The previously reported benefits of MT range from reduced pain, stiffness, fatigue and
215 improved RoM (Ferreira et al., 2009; Lopez-Lopez et al., 2015; Voogt et al., 2015). Greater
216 knowledge of the mechanistic changes occurring due to MT will benefit LBP management and

217 inform treatment recommendations. The findings from this study suggest that a reduction in
218 lower back para-spinal stiffness can be measured after a 30-minute treatment session and
219 could be determined by initial stiffness levels. These results are an indication of an immediate
220 effect on muscle tissue quality after this specific 30-minute spinal mobilisation treatment.
221 However, differences in specific clinical practices should be taken into consideration for the
222 application of results.

223

224 We show for the first time an immediate, objective and significant reduction in para-spinal
225 stiffness with a large effect size (table 2) after a 30-minute spinal mobilisation treatment (fig.
226 1), supported by previous literature (Ferreira et al., 2009; Fritz et al., 2011; Shum et al., 2013;
227 Wong et al., 2015). However, large SEM values could have resulted from the exploratory
228 nature of the study and the wide recruitment. This reduces the confidence of the findings;
229 therefore, we recommend this stiffness reduction is investigated further with distinct LBP
230 population groups to achieve more meaningful results. Since stiffness characterises the
231 muscle's ability to resist deformation, and is associated with pain and reduced mobility (Fritz
232 et al., 2011; Haas et al., 2014; Lopez-Lopez et al., 2015; Vicenzino et al., 2001), a reduction in
233 stiffness of these muscles may allow greater compliance to muscle contraction and therefore
234 improve movement fluidity (Ferreira et al., 2009). This study demonstrates the impact of lying
235 stationary for 30 minutes can have on stiffness, reinforcing the recommendation to reduce
236 sedentary behaviour, a known risk factor for developing LBP and chronic stiffness (Hartvigsen
237 et al., 2018; Naraoka et al., 2017).

238

239 Improved knowledge of muscular stiffness has been identified as crucial to understand
240 underlying mechanistic changes in therapeutic interventions and apply them effectively to
241 the populations at most need (Bailey et al., 2013; Kelly et al., 2018). Potential mechanisms
242 responsible have been suggested to involve the activation of somatosensory signals.
243 Mechanical induction of sensory nerves may cause adaptive signalling in the muscle spindles
244 (stretch receptors) affecting muscle fibre ability to respond to changes in shape (Pickar and
245 Bolton, 2012; Reed et al., 2014). Differences between the mechanical induction of muscle
246 stretch response verses an active muscle stretch response could be further investigated in an
247 MT and stretching study to help decipher the benefits of each. Information on significant
248 influencers on stiffness change, such as initial stiffness levels and anthropometric measures,

249 may help to inform these mechanistic theories through predictive modelling in large scale MT
250 studies.

251

252 While this exploratory study demonstrates the benefit of a single MT session, there is a lack
253 of statistical power describing the influencing factors and warrants further investigation. The
254 key influence of initial stiffness levels could be further investigated by taking into
255 consideration prior environmental influences on stiffness. As no significant differences were
256 found between the control and intervention condition pre-stiffness levels (fig. 1), it was
257 concluded that the protocol design had been successful in controlling for this. Further studies
258 investigating other stretching and movement related interventions may also contribute
259 insight into mechanistic changes and influencing factors.

260

261 Although the ANCOVA results showed that initial stiffness was a significant contributor to
262 stiffness response (and a significant correlation, table 3), results for sex as a covariate were
263 more complex. Sex did not account for the variance in stiffness within the ANCOVA model
264 and suggests that initial stiffness values have greater influence than sex on stiffness response,
265 supported by similar correlation trends for males and females (table 3). This could be further
266 investigated in a sex comparison study, given the known difference between male and female
267 muscle composition (Granata et al., 2002; Nair et al., 2016; Owens et al., 2007). It is important
268 to note that, while ODI, BMI, waist or height measurements do not contribute to stiffness
269 response, they could still influence the initial stiffness values. Though previous studies have
270 also found similar baseline and stiffness change correlations (Ferreira et al., 2009; Shum et
271 al., 2013) this correlation has not been defined objectively as a clinical predictor for
272 intervention response (Fritz et al., 2011; Nim et al., 2020; Wong et al., 2015). The availability
273 of objective measurement tools for muscle health, such as a myometer, will enable
274 monitoring of intervention effectiveness for types of responders, potentially developing
275 stiffness thresholds for responders.

276

277 Similar results for muscle tone (fig. 2) and stiffness indicate that both variables respond to the
278 intervention in a similar way. Pre- tone measures in the control and intervention conditions
279 were very similar with less variation than pre- stiffness measures. Muscle stiffness and tone
280 depict different aspects of muscle quality. The myometry form of muscle tone describes

281 resting muscle tension and is mechanically represented by the acceleration frequency of the
282 oscillations induced and recorded. The reduced variation in tone baseline and SEM values
283 compared to stiffness may be explained by its intrinsic nature (required for resting tension)
284 as oppose to responsive (Bizzini and Mannion, 2003; Schneider et al., 2014; Viir et al., 2006).

285

286 The ANCOVA results for tone response revealed BMI, waist circumference and sex as
287 contributing factors, different to the contributing factors for stiffness response. Comparison
288 of male and female trend lines demonstrated different patterns in their pre- intervention and
289 tone change correlations (table 3) supporting sex as a contributing factor to muscle tone in
290 the ANCOVA model. Though stiffness and tone display similar pattern changes in previous
291 studies (Gervasi et al., 2017; Nair et al., 2016), the resultant difference in contributing factors
292 between them may indicate key underlying differences in their response mechanisms. The
293 electrical signals responsible for muscle tone, though likely still influenced by adaptive
294 signalling, may result in a greater number of influencing factors compared to tissue stiffness.

295

296 A reduction in both tone and stiffness can be beneficial to populations with chronic pain and
297 limited movement (Chuang et al., 2012; Fröhlich-Zwahlen et al., 2014; Wong et al., 2015).
298 Hypertonia is associated with mobility restrictions and chronic pain in conditions such as
299 stroke and Parkinson's (Fröhlich-Zwahlen et al., 2014). It will therefore benefit clinicians to
300 monitor these variables and relate to functional output in rehabilitative interventions
301 together with changes in their patients' pain.

302

303 Elasticity results show a higher degree of variance compared to stiffness and tone (fig. 3)
304 which is consistent with previous literature (Gervasi et al., 2017; Schneider et al., 2014). An
305 increase in dissipation of mechanical energy (logarithmic decrement) equates to a lower level
306 of elasticity in the muscle and its ability to recover shape after deformation (Bailey et al.,
307 2013; Chuang et al., 2012). Both control and intervention conditions resulted in decreased
308 elasticity in this study, suggesting that both stationary relaxing and MT affected the elasticity
309 of para-spinal muscles in a similar way. A similar report (Schneider et al., 2014) found a
310 decrease in stiffness and tone and an increase in decrement after testing muscles in
311 weightlessness conditions. The reason for this is unclear and was suggested to be the result
312 of a relaxed state. The passive nature of the therapy may have resulted in an elasticity

313 decrease because of the participant lying still with no active movements. Therefore muscles
314 may require active movements to have an improved effect on elasticity and could be explored
315 in future studies with MT compared to exercise type therapies to investigate this further.

316

317 Limitations and Future Study

318 The results in reduced muscle stiffness and tone after a 30-minute MT intervention are
319 encouraging. This prospective study has provided promising preliminary data and warrants
320 further investigation to better understand the influencing factors to this muscular response
321 and the mechanisms responsible.

322

323 Though BMI was measured in this study, this variable does not give an accurate depiction of
324 muscle to fat ratio. Adipose tissue could be beneficial to measure in future studies as a
325 covariate due to potential influence on stiffness results (Fröhlich-Zwahlen et al., 2014).
326 Although the factorial, within-participant analysis should reduce this influence on stiffness
327 due to the relative change within each participant between groups, it would be beneficial to
328 accurately measure and investigate this variable.

329

330 Increasing the number of participants recruited with higher levels of pain, together with more
331 comprehensive methods to rate level of pain and post intervention pain, may assist in the
332 development of this area of research to investigate the relationship between pain and
333 stiffness. Physical activity levels were not controlled in this study and could be a factor in
334 baseline levels of stiffness, tone and elasticity (Nair et al., 2016). Therefore, more
335 investigation into potential lifestyle contributions to pain in LBP could give added information
336 about potential influences on spinal stiffness. The previously reported optimum number of
337 treatment sessions has been 12 (Ferreira et al., 2009; Haas et al., 2014), therefore, further
338 investigation into treatment dose and number of sessions would contribute to knowledge on
339 MTs.

340

341 Conclusions

342 The 30-minute spinal mobilisation intervention had a significant immediate effect on muscle
343 quality showing a stiffness and tone reduction in sufferers of LBP when compared to a control
344 intervention. Initial levels of stiffness contributed to reduction levels post intervention and

345 there was more variance in contributing factors for tone and elasticity. Although significant
346 differences between male and female stiffness results were found, sex was not a significant
347 contributor to stiffness reduction and likely affected initial baseline levels. Preliminary results
348 show an immediate muscular response after a MT intervention and further study could
349 investigate an accumulated effect after repeated sessions with further explanatory measures.

350

351 Clinical Relevance

- 352 • Findings reported of an exploratory investigation providing new objective evidence of
353 a spinal mobilisation intervention.
- 354 • Results reveal an immediate reduction in myometry measured muscle stiffness and
355 tone with baseline stiffness, waist circumference, BMI and sex as significant
356 contributors.
- 357 • Objective muscle data provided for an evidence-based contribution towards manual
358 therapy treatments.

359

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361 Lower back pain

362 Spinal mobilisations

363 Myometry

364 Muscle stiffness

365

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370

371 Declaration of Interest

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374 in study design, data collection and analysis.

375 References

- 376 Assendelft, W.J.J., Morton, S.C., Yu, E.I., Suttorp, M.J., Shekelle, P.G., 2003. Article Spinal
377 Manipulative Therapy for Low Back Pain. *Ann. Intern. Med.* 138, 871–881.
- 378 Bailey, L., Samuel, D., Warner, M., Stokes, M., 2013. Parameters Representing Muscle Tone,
379 Elasticity and Stiffness of Biceps Brachii in Healthy Older Males: Symmetry and Within-
380 Session Reliability Using the MyotonPRO. *J Neurol Disord* 02, 116.
381 <https://doi.org/10.4172/jnd.1000116>
- 382 Bishop, M.D., Torres-Cueco, R., Gay, C.W., Lluch-Girbés, E., Beneciuk, J.M., Bialosky, J.E.,
383 2015. What effect can manual therapy have on a patient’s pain experience? *Pain*
384 *Manag.* 5, 455–464. <https://doi.org/10.2217/pmt.15.39>
- 385 Bizzini, M., Mannion, A.F., 2003. Reliability of a new, hand-held device for assessing skeletal
386 muscle stiffness. *Clin. Biomech.* 18, 459–461. [https://doi.org/10.1016/S0268-
387 0033\(03\)00042-1](https://doi.org/10.1016/S0268-0033(03)00042-1)
- 388 Carnes, D., Mars, T.S., Mullinger, B., Froud, R., Underwood, M., 2010. Adverse events and
389 manual therapy: A systematic review. *Man. Ther.* 15, 355–363.
390 <https://doi.org/10.1016/j.math.2009.12.006>
- 391 Childs, M.J.D., Fritz, J.M., Flynn, T.W., Irrgang, J.J., Johnson, M.K.K., Majkowski, G.R., Delitto,
392 A., 2004. A clinical prediction rule to identify patients with low back pain most likely to
393 benefit from spinal manipulation: A validation study. *Ann. Intern. Med.* 141, 920–928.
394 <https://doi.org/10.1016/j.annint.2004.12.006> [pii]
- 395 Chiradejnant, A., Maher, C.G., Latimer, J., Stepkovitch, N., 2003. Efficacy of “therapist-
396 selected” versus “randomly selected” mobilisation techniques for the treatment of low
397 back pain: a randomised controlled trial. *Aust. J. Physiother.* 49, 233–241.
398 [https://doi.org/10.1016/S0004-9514\(14\)60139-2](https://doi.org/10.1016/S0004-9514(14)60139-2)
- 399 Chou, R., Huffman, L.H., 2007. Clinical Guidelines *Annals of Internal Medicine*
400 Nonpharmacologic Therapies for Acute and Chronic Low Back Pain : A Review of the
401 Evidence for an American Pain Society / American College of Physicians Clinical Practice
402 Guideline. *Ann. Intern. Med.* 147, 492–504.
- 403 Chuang, L.L., Wu, C.Y., Lin, K.C., Lur, S.Y., 2012. Quantitative mechanical properties of the
404 relaxed biceps and triceps brachii muscles in patients with subacute stroke: A reliability
405 study of the Myoton-3 myometer. *Stroke Res. Treat.* 2012.
406 <https://doi.org/10.1155/2012/617694>
- 407 Edgecombe, T.L., Kawchuk, G.N., Long, C.R., Pickar, J.G., 2013. The effect of application site
408 of spinal manipulative therapy (SMT) on spinal stiffness. *Spine J.* 15, 1332–1338.
409 <https://doi.org/10.1016/j.spinee.2013.07.480>
- 410 Fairbank, J., Pynsent, P., 2000. The Oswestry Disability Index. *Spine (Phila. Pa. 1976)*. 25,
411 2940–2952.
- 412 Ferreira, M.L., Ferreira, P.H., Latimer, J., Herbert, R.D., Maher, C., Refshauge, K., 2009.
413 Relationship between spinal stiffness and outcome in patients with chronic low back
414 pain. *Man. Ther.* 14, 61–67. <https://doi.org/10.1016/j.math.2007.09.013>
- 415 Fritz, J.M., Koppenhaver, S.L., Kawchuk, G.N., Teyhen, D.S., Hebert, J.J., Childs, J.D., 2011.

- 416 Preliminary investigation of the mechanisms underlying the effects of manipulation:
 417 exploration of a multivariate model including spinal stiffness, multifidus recruitment,
 418 and clinical findings. *Spine (Phila. Pa. 1976)*. 36, 1772–81.
 419 <https://doi.org/10.1097/BRS.0b013e318216337d>
- 420 Fröhlich-Zwahlen, A.K., Casartelli, N.C., Item-Glatthorn, J.F., Maffiuletti, N.A., 2014. Validity
 421 of resting myotonometric assessment of lower extremity muscles in chronic stroke
 422 patients with limited hypertonia: A preliminary study. *J. Electromyogr. Kinesiol.* 24,
 423 762–769. <https://doi.org/10.1016/j.jelekin.2014.06.007>
- 424 George, S.Z., Bishop, M.D., Bialosky, J.E., Zeppieri, G., Robinson, M.E., 2006. Immediate
 425 effects of spinal manipulation on thermal pain sensitivity: an experimental study. *BMC*
 426 *Musculoskelet. Disord.* 7, 1–10. <https://doi.org/10.1186/1471-2474-7-68>
- 427 Gervasi, M., Sisti, D., Amatori, S., Andrezza, M., Benelli, P., Sestili, P., Rocchi, M.B.L.,
 428 Calavalle, A.R., 2017. Muscular viscoelastic characteristics of athletes participating in
 429 the European Master Indoor Athletics Championship. *Eur. J. Appl. Physiol.* 117, 1739–
 430 1746. <https://doi.org/10.1007/s00421-017-3668-z>
- 431 Goertz, C.M., Xia, T., Long, C.R., Vining, R.D., Pohlman, K.A., DeVocht, J.W., Gudavalli, M.R.,
 432 Owens, E.F., Meeker, W.C., Wilder, D.G., 2016. Effects of spinal manipulation on
 433 sensorimotor function in low back pain patients - A randomised controlled trial. *Man.*
 434 *Ther.* 21, 183–190. <https://doi.org/10.1016/j.math.2015.08.001>
- 435 Goodsell, M., Lee, M., Latimer, J., 2000. Short-term effects of lumbar posteroanterior
 436 mobilization in individuals with low-back pain. *J. Manipulative Physiol. Ther.* 23, 332–
 437 342. [https://doi.org/10.1016/S0161-4754\(00\)90208-2](https://doi.org/10.1016/S0161-4754(00)90208-2)
- 438 Granata, K.P., Padua, D.A., Wilson, S.E., 2002. Gender differences in active musculoskeletal
 439 stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. *J.*
 440 *Electromyogr. Kinesiol.* 12, 127–135. [https://doi.org/10.1016/S1050-6411\(02\)00003-2](https://doi.org/10.1016/S1050-6411(02)00003-2)
- 441 Haas, M., Vavrek, D., Peterson, D., Polissar, N., Neradilek, M.B., 2014. Dose-response and
 442 efficacy of spinal manipulation for care of chronic low back pain: a randomized
 443 controlled trial. *Spine J.* 14, 1106–16. <https://doi.org/10.1016/j.spinee.2013.07.468>
- 444 Hartvigsen, J., Hancock, M.J., Kongsted, A., Louw, Q., Ferreira, M.L., Genevay, S., Hoy, D.,
 445 Karppinen, J., Pransky, G., Sieper, J., Smeets, R.J., Underwood, M., Buchbinder, R.,
 446 Cherkin, D., Foster, N.E., Maher, C.G., van Tulder, M., Anema, J.R., Chou, R., Cohen,
 447 S.P., Menezes Costa, L., Croft, P., Ferreira, M., Ferreira, P.H., Fritz, J.M., Gross, D.P.,
 448 Koes, B.W., Öberg, B., Peul, W.C., Schoene, M., Turner, J.A., Woolf, A., 2018. What low
 449 back pain is and why we need to pay attention. *Lancet* 391, 2356–2367.
 450 [https://doi.org/10.1016/S0140-6736\(18\)30480-X](https://doi.org/10.1016/S0140-6736(18)30480-X)
- 451 Jowsey, P., Perry, J., 2010. Sympathetic nervous system effects in the hands following a
 452 grade III postero-anterior rotatory mobilisation technique applied to T4: A randomised,
 453 placebo-controlled trial. *Man. Ther.* 15, 248–253.
 454 <https://doi.org/10.1016/j.math.2009.12.008>
- 455 Kamali, F., Shokri, E., 2012. The effect of two manipulative therapy techniques and their
 456 outcome in patients with sacroiliac joint syndrome. *J. Bodyw. Mov. Ther.* 16, 29–35.
 457 <https://doi.org/10.1016/j.jbmt.2011.02.002>

- 458 Kelly, J.P., Koppenhaver, S.L., Michener, L.A., Proulx, L., Bisagni, F., Cleland, J.A., 2018.
 459 Characterization of tissue stiffness of the infraspinatus, erector spinae, and
 460 gastrocnemius muscle using ultrasound shear wave elastography and superficial
 461 mechanical deformation. *J. Electromyogr. Kinesiol.* 38, 73–80.
 462 <https://doi.org/10.1016/j.jelekin.2017.11.001>
- 463 Liebenson, C., 2007. *Rehabilitation of the Spine: A Practitioner’s Manual*. Lippincott Williams
 464 and Wilkins.
- 465 Lopez-Lopez, A., Alonso Perez, J.L., González Gutierrez, J.L., La Touche, R., Lerma Lara, S.,
 466 Izquierdo, H., Fernández-Carnero, J., 2015. Mobilization versus manipulations versus
 467 sustain apophyseal natural glide techniques and interaction with psychological factors
 468 for patients with chronic neck pain: randomized controlled trial. *Eur. J. Phys. Rehabil.*
 469 *Med.* 51, 121–32. <https://doi.org/10.1155/2015/327307>
- 470 Maitland, G., Hengeveld, E., Banks, K., 2013. *Maitland’s Vertebral Mobilisations*, 8th ed.
 471 Elsevier Butterworth-Heinemann.
- 472 Marusiak, J., Jaskolska, A., Koszewicz, M., Budrewicz, S., Jaskolski, A., 2012. Myometry
 473 revealed medication-induced decrease in resting skeletal muscle stiffness in
 474 Parkinson’s disease patients. *Clin. Biomech.* 27, 632–635.
 475 <https://doi.org/10.1016/j.clinbiomech.2012.02.001>
- 476 Nair, K., Masi, A.T., Andonian, B.J., Barry, A.J., Coates, B.A., Dougherty, J., Schaefer, E.,
 477 Henderson, J., Kelly, J., 2016. ScienceDirect FASCIA SCIENCE AND CLINICAL
 478 APPLICATIONS : ORIGINAL RESEARCH STUDY Stiffness of resting lumbar myofascia in
 479 healthy young subjects quantified using a handheld myotonometer and concurrently
 480 with surface electromyography monitoring. *J. Bodyw. Mov. Ther.* 20, 388–396.
 481 <https://doi.org/10.1016/j.jbmt.2015.12.005>
- 482 Naraoka, Y., Katagiri, M., Shirasawa, T., 2017. Effectiveness of a 12-Week Program of Active
 483 and Passive Stretching in Improving Low Back and Neck Pain in Japanese Sedentary
 484 Men. *Health (Irvine. Calif.)*. 09, 493–505. <https://doi.org/10.4236/health.2017.93035>
- 485 National Institute for Health and Care Excellence, 2016. *Low back pain and sciatica in over*
 486 *16s: assessment and management (NG59)*. Nice 1–18.
- 487 Nim, C.G., Kawchuk, G.N., Schiøttz-Christensen, B., O’Neill, S., 2020. The effect on clinical
 488 outcomes when targeting spinal manipulation at stiffness or pain sensitivity: a
 489 randomized trial. *Sci. Rep.* 10, 1–10. <https://doi.org/10.1038/s41598-020-71557-y>
- 490 Olson, K., 2009. *Manual Physical Therapy of the Spine*, *Manual Physical Therapy of the*
 491 *Spine*. Elsevier Health Sciences. <https://doi.org/10.1016/B978-1-4160-4749-0.X5001-6>
- 492 Owens, E.F., DeVocht, J.W., Gudavalli, M.R., Wilder, D.G., Meeker, W.C., 2007. Comparison
 493 of Posteroanterior Spinal Stiffness Measures to Clinical and Demographic Findings at
 494 Baseline in Patients Enrolled in a Clinical Study of Spinal Manipulation for Low Back
 495 Pain. *J. Manipulative Physiol. Ther.* 30, 493–500.
 496 <https://doi.org/10.1016/j.jmpt.2007.07.009>
- 497 Pecos-Martín, D., de Melo Aroeira, A.E., Verás Silva, R.L., Martínez de Tejada Pozo, G.,
 498 Rodríguez Solano, L.M., Plaza-Manzano, G., Gallego-Izquierdo, T., Falla, D., 2017.
 499 Immediate effects of thoracic spinal mobilisation on erector spinae muscle activity and

- 500 pain in patients with thoracic spine pain: a preliminary randomised controlled trial.
 501 Physiother. (United Kingdom) 103, 90–97.
 502 <https://doi.org/10.1016/j.physio.2015.10.016>
- 503 Pentelka, L., Hebron, C., Shapleski, R., Goldshtein, I., 2012. The effect of increasing sets
 504 (within one treatment session) and different set durations (between treatment
 505 sessions) of lumbar spine posteroanterior mobilisations on pressure pain thresholds.
 506 Man. Ther. 17, 526–530. <https://doi.org/10.1016/j.math.2012.05.009>
- 507 Pickar, J.G., Bolton, P.S., 2012. Spinal manipulative therapy and somatosensory activation. J.
 508 Electromyogr. Kinesiol. 22, 785–794. <https://doi.org/10.1016/j.jelekin.2012.01.015>
- 509 Piekarcz, V., Perry, J., 2016. An investigation into the effects of a unilaterally applied lumbar
 510 mobilisation technique on peripheral sympathetic nervous system activity in the lower
 511 limbs. Man. Ther. 13, 492–499. <https://doi.org/10.1016/j.math.2007.05.015>
- 512 Piekarcz, V., Perry, J., 2015. An investigation into the effects of applying a lumbar Maitland
 513 mobilisation at different frequencies on sympathetic nervous system activity levels in
 514 the lower limb. Man. Ther. 23, 83–89. <https://doi.org/10.1016/j.math.2016.01.001>
- 515 Powers, C.M., Beneck, G.J., Kulig, K., Landel, R.F., Fredericson, M., 2008. Effects of a single
 516 session of posterior-to-anterior spinal mobilization and press-up exercise on pain
 517 response and lumbar spine extension in people with nonspecific low back pain. Phys.
 518 Ther. 88, 485–93. <https://doi.org/10.2522/ptj.20070069>
- 519 Pruyne, E.C., Watsford, M.L., Murphy, A.J., 2015. Validity and reliability of three methods of
 520 stiffness assessment. J. Sport Heal. Sci. 5, 476–483.
 521 <https://doi.org/10.1016/j.jshs.2015.12.001>
- 522 Reed, W.R., Long, C.R., Kawchuk, G.N., Pickar, J.G., 2014. Neural responses to the
 523 mechanical parameters of a high-velocity, low-amplitude spinal manipulation: Effect of
 524 preload parameters. J. Manipulative Physiol. Ther. 37, 68–78.
 525 <https://doi.org/10.1016/j.jmpt.2013.12.004>
- 526 Savigny P, Watson P, Underwood M, Ritchie G, Cotterell M, Hill D, Browne N, Buchanan E,
 527 Coffey P, Dixon P, Drummond C, Flanagan M, Greenough, C, Griffiths M, Halliday-Bell J,
 528 Hettinga D, Vogel S, Walsh D., K.S., 2009. Low Back Pain: early management of
 529 persistent non-specific low back pain. London Natl. Collab. Cent. Prim. Care R. Coll.
 530 Gen. Pract.
- 531 Schneider, S., Peipsi, A., Stokes, M., Knicker, A., Abeln, V., 2014. Feasibility of monitoring
 532 muscle health in microgravity environments using Myoton technology. Med. Biol. Eng.
 533 Comput. 53, 57–66. <https://doi.org/10.1007/s11517-014-1211-5>
- 534 Shum, G.L., Tsung, B.Y., Lee, R.Y., 2013. The immediate effect of posteroanterior
 535 mobilization on reducing back pain and the stiffness of the lumbar spine. Arch. Phys.
 536 Med. Rehabil. 94, 673–679. <https://doi.org/10.1016/j.apmr.2012.11.020>
- 537 Shum, G.L.K., Crosbie, J., Lee, R.Y.W., 2007. Movement coordination of the lumbar spine and
 538 hip during a picking up activity in low back pain subjects. Eur. Spine J. 16, 749–758.
 539 <https://doi.org/10.1007/s00586-006-0122-z>
- 540 Sohirad, S., Wilson, D., Waugh, C., Finnamore, E., Scott, A., 2017. Feasibility of using a hand-

541 held device to characterize tendon tissue biomechanics 1–9.

542 Stamos-Papastamos, N., Petty, N.J., Williams, J.M., 2011. Changes in bending stiffness and
543 lumbar spine range of movement following lumbar mobilization and manipulation. *J.*
544 *Manipulative Physiol. Ther.* 34, 46–53. <https://doi.org/10.1016/j.jmpt.2010.11.006>

545 Sterling, M., Jull, G., Wright, A., 2001. Cervical mobilisation : concurrent effects on pain ,
546 sympathetic nervous system activity and motor activity. *Man. Ther.* 6, 72–81.
547 <https://doi.org/10.1054/math.2000.0378>

548 Thomson, O., Haig, L., Mansfield, H., 2009. The effects of high-velocity low-amplitude thrust
549 manipulation and mobilisation techniques on pressure pain threshold in the lumbar
550 spine. *Int. J. Osteopath. Med.* 12, 56–62. <https://doi.org/10.1016/j.ijosm.2008.07.003>

551 Vicenzino, B., Paungmali, A., Buratowski, S., Wright, A., 2001. Specific manipulative therapy
552 treatment for chronic lateral epicondylalgia produces uniquely characteristic
553 hypoalgesia. *Man. Ther.* 6, 205–12. <https://doi.org/10.1054/math.2001.0411>

554 Viir, R., Laiho, K., Kramarenko, J., Mikkelsen, M., 2006. Repeatability of Trapezius Muscle
555 Tone Assessment By a Myometric Method. *J. Mech. Med. Biol.* 06, 215–228.
556 <https://doi.org/10.1142/S0219519406001856>

557 Voogt, L., de Vries, J., Meeus, M., Struyf, F., Meuffels, D., Nijs, J., 2015. Analgesic effects of
558 manual therapy in patients with musculoskeletal pain: A systematic review. *Man. Ther.*
559 20, 250–256. <https://doi.org/10.1016/j.math.2014.09.001>

560 Wong, A.Y.L., Parent, E.C., Dhillon, S.S., Prasad, N., Kawchuk, G.N., 2015. Do Participants
561 With Low Back Pain Who Respond to Spinal Manipulative Therapy Differ
562 Biomechanically From Nonresponders, Untreated Controls or Asymptomatic Controls?
563 *Spine (Phila. Pa. 1976)*. 40, 1329–1337.
564 <https://doi.org/10.1097/BRS.0000000000000981>

565 Wong, A.Y.L., Parent, E.C., Prasad, N., Huang, C., Chan, K.M., Kawchuk, G.N., 2016. Does
566 experimental low back pain change posteroanterior lumbar spinal stiffness and trunk
567 muscle activity? A randomized crossover study. *Clin. Biomech.* 34, 45–52.
568 <https://doi.org/10.1016/j.clinbiomech.2016.03.006>

569 Zinder, S., Padua, D., 2011. Reliability, validity, and precision of a handheld myometer for
570 assessing in vivo muscle stiffness. *J. Sport Rehabil.* 1–8.
571 <https://doi.org/10.2307/2992450>

572