Comparative analysis and relationship of tensiomyographic and isokinetic muscle contractile assessments of rectus abdominis and erector spinae in bodybuilding trainees with nonspecific low back pain

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Background: Bodybuilding training places a significant load on the lumbar region, making it prone to nonspecific low back pain (NSLBP). This study aimed to examine the associations between tensiomyography (TMG) parameters—contraction time (Tc), relaxation time (Tr), delay time (Td), maximum displacement (Dm), and sustain time (Ts)—and isokinetic performance measures, including peak torque (PT) and work per repetition (WR), in trunk muscles of bodybuilding trainees with NSLBP. Methods: A total of 150 participants were allocated to control group ($n = 60$) and NSLBP group ($n = 90$). Pain severity from NSLBP was evaluated using the Numerical Pain Rating Scale and the Roland-Morris Disability Questionnaire. Muscle function in the rectus abdominis and erector spinae of the trunk was assessed using TMG and an isokinetic dynamometer.

Results: This study revealed that the parameters assessed using TMG and isokinetic equipment were lower or indicated greater weakness in the NSLBP group compared to the control group. Tc, Tr, and Td showed negative correlations with PT and WR, whereas Dm and Ts were positively associated. The NSLBP group demonstrated significantly longer Tc, Tr, and Td, along with lower Dm, Ts, PT, and WR values. These findings suggest that TMG variables, which assess muscle function at rest, are associated with the torque parameters measured by isokinetic dynamometry during movement. Bodybuilding trainees with a history of NSLBP exhibit impairments in both static and dynamic muscle function, indicating the need for stability-focused interventions during training.

1 Title page

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5 **in bodybuilding trainees with nonspecific low back**
6 **pain**

7 Short title: "TMG and isokinetic dynamometry"

8

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Abstract

38   **Background:** Bodybuilding training places a significant load on the lumbar region, making it prone to

39   nonspecific low back pain (NSLBP). This study aimed to examine the associations between

40   tensiomyography (TMG) parameters—contraction time (Tc), relaxation time (Tr), delay time (Td),

41   maximum displacement (Dm), and sustain time (Ts)—and isokinetic performance measures, including peak

42   torque (PT) and work per repetition (WR), in trunk muscles of bodybuilding trainees with NSLBP.

43   **Methods:** A total of 150 participants were allocated to control group ($n = 60$) and NSLBP group ($n = 90$).

44   Pain severity from NSLBP was evaluated using the Numerical Pain Rating Scale and the Roland-Morris

45   Disability Questionnaire. Muscle function in the rectus abdominis and erector spinae of the trunk was

46   assessed using TMG and an isokinetic dynamometer.

47   **Results:** This study revealed that the parameters assessed using TMG and isokinetic equipment were lower

48   or indicated greater weakness in the NSLBP group compared to the control group. Tc, Tr, and Td showed

49   negative correlations with PT and WR, whereas Dm and Ts were positively associated. The NSLBP group

50   demonstrated significantly longer Tc, Tr, and Td, along with lower Dm, Ts, PT, and WR values. These

51   findings suggest that TMG variables, which assess muscle function at rest, are associated with the torque

52   parameters measured by isokinetic dynamometry during movement. Bodybuilding trainees with a history

53   of NSLBP exhibit impairments in both static and dynamic muscle function, indicating the need for stability-

54   focused interventions during training.

55

56   **Keywords:** Nonspecific low back pain, Trunk flexor, Trunk extensor, Contraction time, Maximum

57   displacement

58

Introduction

60   Nonspecific low back pain (NSLBP) is the most prevalent form of low back pain (LBP), accounting for

61   approximately 90–95% of all cases (Howarth et al., 2024; Imamura et al., 2016; Jiang et al., 2024). Unlike

62   specific LBP, NSLBP lacks a clear pathological cause and is often linked to risk factors such as obesity,

63   sedentary lifestyles, repetitive trunk flexion and rotation, and improper heavy lifting (Alshehri et al., 2024).

64   These multifactorial influences contribute to the onset and persistence of NSLBP (Maher et al., 2017;

65   Shmagel et al., 2016).

66   Bodybuilding has become a popular activity across age groups, focusing on physical aesthetics through

67   intensive resistance training (Huebner et al., 2022). In essence, bodybuilding involves stimulating the body

68 through various weight training methods to achieve an ideal level of development, thereby promoting

69 physical and mental self-fulfillment (Huebner et al., 2022). Despite its benefits, bodybuilding carries a high

70 risk of musculoskeletal injuries, including muscle strains, tendinitis, and NSLBP (Jiang et al., 2024). These

71 risks are exacerbated when training exceeds an individual's physiological capacity (Chaput et al., 2011).

72 The hypertrophic effects of resistance training are primarily attributed to the enlargement of fast-twitch

73 muscle fibers (Huebner et al., 2022; Gehrig et al., 2010). While initial studies employed invasive muscle

74 biopsies (Loell et al., 2011), recent advancements favor non-invasive assessment techniques (Kandwal et

75 al., 2024). Among these, tensiomyography (TMG) and isokinetic dynamometry are widely recognized for

76 their reliability in evaluating muscle function. Unlike MRI and surface EMG-which are costly or susceptible

77 to noise (Campanini et al., 2020), TMG and isokinetic tests offer selective, non-invasive, and repeatable

78 measures of muscle contractility (Toskić et al., 2019). These methods offer the advantage of selectively

79 evaluating specific muscles, high versatility, and the capability for continuous measurements. Furthermore,

80 the scientific assessment of variables derived from these tools has facilitated their widespread application

81 in various practical settings (Tous-Fajardo et al., 2010).

82 TMG assesses muscle contractile properties via external stimulation without requiring voluntary

83 contraction, enabling the analysis of muscle hypertrophy and atrophy through five key parameters, offering

84 a thorough assessment of static muscle function (Lohr et al., 2018). Its reliability and precision have made

85 it widely utilized in both research and clinical practice. Conversely, isokinetic dynamometry evaluates

86 muscle strength across controlled velocities and contraction modes, allowing the analysis of torque and

87 power output. By measuring the muscle moments' ratio, it is possible to identify potential issues within the

88 targeted muscle groups (Yahia et al., 2011). Isokinetic measurements are well-regarded for their reliability

89 and precision (Mueller et al., 2011; Paul & Nassis, 2015) and are frequently utilized for assessing dynamic

90 strength to understand the mechanical profiles of skeletal muscles, including those of the trunk regions (Van

91 Damme et al., 2013).

92 Despite their independent clinical applications, the correlation between TMG and isokinetic measures

93 has not been thoroughly explored. Furthermore, limited research has examined trunk muscle characteristics

94 related to NSLBP in bodybuilding populations. Therefore, this study aimed to investigate the presence of

95 NSLBP in individuals who engage in regular and periodic weight training. The participants were

96 categorized based on the presence or absence of NSLBP, and the study also aimed to analyze potential

97 differences in TMG and isokinetic muscle contractility between the groups.

98

Materials & Methods

100 *Participants*

101   To identify cases of NSLBP, a standardized clinical assessment protocol was implemented. This process
102   included a structured interview, physical examination, and red flag screening, based on established
103   guidelines for diagnosing NSLBP (Delitto et al., 2012; Maher et al., 2017). All 150 participants were young
104   adults (aged 19–25 years) who had engaged in bodybuilding training for at least one year, with a minimum
105   training frequency of four sessions per week. Each participant underwent an individual assessment
106   conducted by a licensed physical therapist specializing in musculoskeletal disorders. The clinical interview
107   collected information on the presence, onset, duration, and characteristics of LBP. Participants were
108   specifically asked about pain location, intensity, aggravating and relieving factors, and possible training-
109   related causes. Any reports of radiating pain, numbness, tingling, or muscle weakness in the lower
110   extremities were documented for differential diagnosis. A standardized physical examination assessed
111   lumbar range of motion, local tenderness, and pain provocation during movement. Neurological screening
112   included muscle strength, sensory function, and deep tendon reflexes. Special tests such as the straight leg
113   raise and Slump test were performed to evaluate possible neural involvement. Participants were also
114   screened for red flag symptoms indicative of serious pathology, including a history of malignancy,
115   unexplained weight loss, prolonged corticosteroid use, recent trauma, persistent night pain, or fever.
116   Individuals presenting with any red flag indicators were excluded from the NSLBP group and referred for
117   further medical evaluation such as herniated disc, spondylolysis, spondylolisthesis, spinal stenosis, or facet
118   joint syndrome. Additionally, exclusion criteria included smoking, alcohol consumption, current
119   pharmacological or physical therapy treatment, or any surgical procedures within one year before
120   enrollment.

121   Sample size estimation was performed using G*Power software (version 3.1.9.7, Heinrich-Heine-
122   University Software, Germany with the following parameters: effect size = 0.5, $\alpha = 0.05$, power = 0.95,
123   and allocation ratio = 1 (Kang, 2021). A minimum of 174 participants was determined to be necessary; 208
124   were recruited to accommodate a 20% attrition rate (Sedgwick, 2013). Of the 208 participants initially
125   recruited for the study, 58 were excluded due to not meeting the inclusion criteria or for personal reasons.
126   After applying exclusion criteria, 150 participants were enrolled and assigned to either the control ($n = 60$)
127   or NSLBP ($n = 90$) group. Throughout the one-month experiment, there were no dropouts from either the
128   CON group or the NSLBP group, leading to the final analysis based on data from 60 participants in the
129   CON group and 90 in the NSLBP group.

130

131   ***Experimental design***

132   This case-control study was conducted from March to December 2024. The study followed the Transparent
133   Reporting of Evaluations with Nonrandomized Designs statement (Des Jarlais et al., 2004) and complied
134   with the Sex and Gender Equity in Research guidelines (Heidari et al., 2016). The investigation adhered to

135   the ethical standards outlined in the declaration of Helsinki (Williams, 2008). Ethical approval was granted

136   by the Institutional Review Board of Hanseo University (HS22-05-03). Prior to participation, all subjects

137   received detailed explanations of the study's purpose and procedures and provided written informed

138   consent. Double blinding was maintained throughout data collection. Daily logs were used to monitor

139   dietary intake and physical activity to control for external variables.

140

141   ***Measurement methods***

142   *Body composition and demographics*

143   Age and sex were self-reported. Height was measured using a digital stadiometer (BMS 330, BioSpace,

144   Seoul, Korea), and body composition was assessed using Dual-Energy X-ray Absorptiometry (DEXA),

145   whole-body scan (TSX-303A, Toshiba Medical Systems Corporation, Tokyo, Japan) with participants in a

146   supine position after a 10-hour fasting period. The DEXA scan was performed quickly to minimize

147   radiation exposure (Jee, 2019; Smith-Bindman, 2010). Body mass index was also calculated using the

148   weight-to-height ratio formula. Waist and hip circumferences were measured using standardized protocols

149   to calculate the waist-to-hip ratio (Park et al., 2024).

150

151   *Pain intensity related to NSLBP*

152   NSLBP was operationally defined as non-specific, localized low back pain in the absence of neurological

153   deficits, serious structural pathology, or red flag symptoms. The participants' pain intensity levels were

154   evaluated using the Numerical Pain Rating Scale (NPRS; 0–10 cm). On this scale, 0 indicates "no pain,"

155   while 10 represents "the worst imaginable pain." Participants were instructed to select the number that best

156   described their current pain. The NPRS has been demonstrated to be a reliable, valid, and responsive tool

157   for measuring pain intensity in individuals with chronic LBP (Ibrahim et al., 2020; Sarafadeen et al., 2020).

158   In this study, the level of pain-related disability associated with NSLBP was also evaluated using the

159   Roland-Morris Disability Questionnaire (RMDQ), a self-reported assessment tool (Roland & Morris,

160   1983). The RMDQ is concise and easy for patients to complete, demonstrating strong validity, internal

161   consistency, and responsiveness (Roland & Fairbank, 2000; Stratford et al., 1996). The RMDQ consists of

162   24 items, each qualified with the phrase "because of my back pain," specifically attributing the disability

163   to back pain experienced in the past 24 hours (Ren & Kazis, 1998). Scores are calculated by summing up

164   the number of items checked. The total score ranges from 0 (no disability) to 24 (maximum disability)

165   (Roland & Fairbank, 2000). In this study, the Cronbach's α coefficient between the duration of NSLBP and

166   the NPRS was found to be 0.866, while the coefficient between the duration of NSLBP and the RMDQ was

167   analyzed as 0.703.

168

169   *Measurement for calorie input and output*

170   All participants were instructed on how to use a dietary camera AI system (DoingLab Inc., Seoul, Korea)

171   to photograph the meals they prepared for consumption each day (Park et al., 2024). The system

172   automatically calculated the calorie intake from the images, and these data were transmitted daily to a

173   designated researcher for evaluation. The data were then analyzed weekly, with the average of the data

174   from the final 4 weeks used for analysis. Additionally, participants' daily physical activity levels were

175   recorded and quantified using the International Physical Activity Questionnaire - Short Form (Cheng,

176   2016). Participants completed the questionnaire each week during the experimental period, based on their

177   physical activity records. Daily calorie expenditure was calculated using metabolic equivalent-minutes, and

178   the data were used to compute the average weekly physical activity levels, which were subsequently

179   analyzed based on the accumulated data.

180

181   *Tensiomyographic trunk muscle tone measures*

182   A digital TMG displacement sensor (TMG-BMC Ltd., Ljubljana, Slovenia) with a spring constant of 0.17

183   N/mm was positioned perpendicular to the muscle belly of the rectus abdominis (RA) at approximately 5

184   cm intervals on both the left and right sides of the navel (Park et al., 2024) as shown in Fig.1A. Additionally,

185   it was placed on the lumbar erector spinae (ES) at the interspace between the L3 and L4 vertebrae (Lohr &

186   Medina-Porqueres, 2021) as shown in Fig.1B. Two adhesive electrodes (AxelGaard Manufacturing Co.

187   Ltd., Pals Platinum Neuro-Stimulation Electrodes, Model 895,220, 50 × 50 mm) were positioned

188   equidistant from the sensor, with an inter-electrode distance of 3 cm.

189   Near here Fig. 1

190

191   The optimal measurement point, located at the thickest part of the muscle bulk approximately 2 cm lateral

192   to the dorsal midline, was identified through visual orientation and palpation during both voluntary and

193   elicited contractions (Lohr et al., 2020). Once the optimal measurement point was located, the sensor and

194   electrode positions were marked with a dermatological pen to ensure precise relocation (Lohr & Medina-

195   Porqueres, 2021). A single square-wave monophasic 1 ms stimulation pulse was delivered using an

196   electrical stimulator (TMG–S1, TMG-BMC Ltd., Ljubljana, Slovenia) with an initial stimulation current of

197   30 mA. To determine the individual maximal twitch response amplitude, the stimulation current was

198   progressively increased by 10 mA increments (Piqueras-Sanchiz et al., 2020). Inter-stimulus interval of $\geq$

199   10 sec was maintained between successive measurements to prevent fatigue and potentiation. The two

200   highest twitch responses observed on the displacement graph for each participant were recorded and

201   averaged for subsequent analysis (Tous-Fajardo et al., 2010). The primary variables under consideration

202   are the maximum displacement (Dm), which measures the maximum distance (in mm) the muscle moves

203 during contraction, and the contraction time (Tc), which represents the time (ms) it takes for the muscle to

204 contract from 10% to 90% of Dm. Stimulation commenced at an initial intensity of 20 mA and was

205 incrementally raised by 10 mA steps until the maximum Dm value was achieved as shown in Fig. 1C.

206 Before conducting the measurements, participants were instructed to rest in bed for 5 min to ensure muscle

207 relaxation. Subsequently, the recorded values were documented and subjected to analysis. In addition, this

208 study examined sustain time (Ts), relaxation time (Tr), and delay time (Td). Td refers to the time taken to

209 reach 10% of the maximum Dm. Ts represents the duration the muscle stays in the contraction phase at

210 50% of Dm before entering the relaxation phase. Tr indicates the time it takes for the muscle to transition

211 from 90% of Dm to 50% during relaxation (Dahmane et al., 2001). Lastly, Vc, the contraction velocity for

212 the muscle, was calculated as Dm / (Tc + Td). The right and left values of all variables were presented, and

213 then all were averaged and analyzed.

214

215 *Isokinetic trunk muscle concentric contraction measures*

216 Isokinetic trunk extension and flexion (TEF) tests were utilized to evaluate the moments of the trunk

217 muscles, as outlined by García-Vaquero and colleague (2020). These tests were performed using an

218 isokinetic dynamometer (Fig. 2A), which maintains a constant speed during muscle contractions, enabling

219 precise and reliable measurements of force and performance. From a practical perspective, isokinetic

220 dynamometer-based muscle assessment methods are considered valid and highly reliable (Warneke et al.,

221 2025), with correlation coefficients of 0.93–0.99 for peak force values and 0.91–0.96 for total workload

222 values (Ben Moussa Zouita et al., 2018; Guilhem et al., 2014). Trunk flexion typically exhibits a range of

223 motion between 40° and 60° (Fig. 2B), with an average of 45°, whereas trunk extension generally ranges

224 from 20° to 35° (Fig. 2C), with an average of around 25° (Morini et al., 2008).

225   Near here Fig. 2

226

227   In this study, participants completed a comprehensive stretching and warm-up routine prior to testing.

228 The TEF assessments were conducted using the HUMAC®/NORM™ Testing and Rehabilitation System

229 (CSMi, Stoughton, MA, USA). During the isokinetic TEF concentric contraction tests, participants stood

230 with their iliac crests aligned to the dynamometer axis and stabilized using knee, lumbar, and chest pads to

231 ensure proper alignment and minimize extraneous movements. The testing protocol began with an

232 isokinetic resistance set at 90°/sec, during which participants performed 4 practice repetitions followed by

233 8 test repetitions. After a 1-min rest interval, the resistance was adjusted to 30°/sec, and participants

234 performed an additional 4 practice repetitions followed by 4 test repetitions. For analysis, the study focused

235 on key metrics, including peak torque (PT) and peak torque normalized to body weight (PTBW), as well as

236 work per repetition (WR) and work per repetition normalized to body weight (WRBW).

237

238 ***Statistical analysis***

239 Statistical analysis was conducted using GraphPad Prism 10.4.2 software (GraphPad Software, Boston,

240 MA, USA). Descriptive statistics, including the mean and standard deviation, were used to summarize the

241 data. The normality of variable distribution was assessed using the Kolmogorov–Smirnov test before

242 analysis. For variables that did not meet normality assumptions, homogeneity was evaluated using the

243 Mann-Whitney U test. The analysis was carried out in three key steps. First, Cronbach's α was calculated

244 to assess the internal validity of the questionnaire used in this study. Second, Pearson correlation analysis

245 was performed to examine the relationship between TMG and isokinetic muscle function, with a correlation

246 matrix created for clarity. Correlation coefficients were classified as excellent (≥ 0.90), good (0.75–0.90),

247 average (0.50–0.75), or poor (< 0.50) (Koo & Li, 2016). Third, to compare TMG and isokinetic muscle

248 function between CON and NSLBP groups, an independent t-test was used for normally distributed data,

249 while the Mann-Whitney U test was applied to non-normally distributed data. Effect sizes for parametric

250 measures were categorized as small (0.2), moderate (0.5), or large (0.8), while for non-parametric measures,

251 thresholds of 0.1, 0.3, and 0.5 were used, following Fritz et al. (2012). Statistical significance was set at p

252 ≤ 0.05.

253

254 # Results

255 ***Demographic and physical characteristics***

256 As shown in Table 1, there was no statistically significant difference in age between the CON and NSLBP

257 groups.

258 <div align="center">Near here Table 1</div>

259   Regarding sex distribution, the CON group consisted of 36 males and 24 females, while the NSLBP

260 group included 62 males and 28 females. When sex was quantified (male = 1, female = 2) for statistical

261 comparison, no significant difference was observed between the groups. None of the participants reported

262 smoking or alcohol consumption. In addition, there was no significant difference in training duration

263 between the groups. As also shown in Table 1, the basal metabolic rate, daily dietary intake, and physical

264 activity level were not significantly different between the two groups. The groups were classified based on

265 the presence or absence of NSLBP, and a quantitative analysis of its duration including NPRS and RMDQ

266 scores revealed a significant difference between the groups.

267

268 ***Relationships between TMG and isokinetic TEF measures***

269 As illustrated in Fig. 3A, the Tc of the RA exhibited significant negative correlations with flexor PT (r = -

270   0.459), extensor PT (r = -0.425), flexor WR (r = -0.420), and extensor WR (r = -0.438). Similarly, the Tc

271   of the ES showed significant negative correlations with flexor PT (r = -0.421), extensor PT (r = -0.331),

272   flexor WR (r = -0.259), and extensor WR (r = -0.340) at 90°/sec. The Tr of the RA displayed significant

273   negative correlations with flexor PT (r = -0.361), extensor PT (r = -0.356), flexor WR (r = -0.225), and

274   extensor WR (r = -0.293), while the Tr of the ES showed significant negative correlations with flexor PT

275   (r = -0.401), extensor PT (r = -0.339), flexor WR (r = -0.349), and extensor WR (r = -0.394). The Td of the

276   RA was significantly negatively correlated with flexor PT (r = -0.461), extensor PT (r = -0.380), flexor WR

277   (r = -0.408), and extensor WR (r = -0.342). In addition, the Td of the ES exhibited significant negative

278   correlations with flexor PT (r = -0.397), extensor PT (r = -0.248), and extensor WR (r = -0.353), except for

279   flexor WR (r = -0.126, p = 0.124). In contrast, the Dm of the RA demonstrated significant positive

280   correlations with flexor PT (r = 0.256), extensor PT (r = 0.277), flexor WR (r = 0.266), and extensor WR

281   (r = 0.305). Likewise, the Dm of the ES showed significant positive correlations with flexor PT (r = 0.281),

282   extensor PT (r = 0.316), flexor WR (r = 0.200), and extensor WR (r = 0.228). Additionally, the Ts of the

283   RA exhibited significant positive correlations with flexor PT (r = 0.296), extensor PT (r = 0.301), flexor

284   WR (r = 0.232), and extensor WR (r = 0.223), like the Dm. The Ts of the ES exhibited significant positive

285   correlations with flexor PT (r = 0.336), extensor PT (r = 0.209), flexor WR (r = 0.308), and extensor WR

286   (r = 0.195). Examining the characteristics among these variables, it was observed that the PT and WR of

287   the TEF muscles at 90°/sec were higher when the Tc, Tr, and Td were shorter or lower, whereas they were

288   lower when Tc, Tr, and Td of the RA and ES were longer or higher. Meanwhile, the PT and WR of the TEF

289   muscles were lower when the Dm and Ts of the RA and ES were lower, but higher when Dm and Ts were

290   higher.

291   Near here Fig. 3

292   As shown in Fig. 3B, the Tc of the RA exhibited significant negative correlations with flexor PT (r = -

293   0.403), extensor PT (r = -0.414), flexor WR (r = -0.315), and extensor WR (r = -0.287). The Tc of the ES

294   showed significant negative correlations with flexor PT (r = -0.170), extensor PT (r = -0.326), flexor WR

295   (r = -0.269), and extensor WR (r = -0.348) at 30°/sec. The Tr of the RA displayed significant negative

296   correlations with extensor PT (r = -0.281), flexor WR (r = -0.220), and extensor WR (r = -0.195), except

297   for flexor PT (r = -0.154, p = 0.060). The Tr of the ES showed significant negative correlations with extensor

298   PT (r = -0.323), flexor WR (r = -0.235), and extensor WR (r = -0.294), except for flexor PT (r = -0.096, p

299   = 0.244). The Td of the RA exhibited significant negative correlations with flexor PT (r = -0.271), extensor

300   PT (r = -0.341), flexor WR (r = -0.401), and extensor WR (r = -0.332). In contrast, the Td of the ES showed

301   significant negative correlations with flexor PT (r = -0.204) and extensor PT (r = -0.293), except for flexor

302   WR (r = -0.155, p = 0.058) and extensor WR (r = -0.064, p = 0.437). Meanwhile, The Dm of the RA

303   demonstrated significant positive correlations with extensor PT (r = 0.277), flexor WR (r = 0.266), and

304   extensor WR (r = 0.305), except for flexor PT (r = 0.045, p = 0.582). The Dm of the ES also showed

305   significant positive correlations with flexor PT (r = 0.204), extensor PT (r = 0.254), flexor WR (r = 0.177),

306   and extensor WR (r = 0.202) at 30°/sec. The Ts of the RA was significantly positively correlated with flexor

307   PT (r = 0.167), extensor PT (r = 0.402), and extensor WR (r = 0.341), except for flexor WR (r = 0.144, p =

308   0.078). The Ts of the ES exhibited significant positive correlations with flexor PT (r = 0.222), extensor PT

309   (r = 0.288), flexor WR (r = 0.220), and extensor WR (r = 0.198). Analyzing the relationships among these

310   variables, it was observed that the PT and WR of the TEF muscles at 30°/sec were higher when the Tc, Tr,

311   and Td of the RA and ES were shorter or lower, whereas they were lower when Tc, Tr, and Td were longer

312   or higher. Conversely, the PT and WR of the TEF muscles were lower when the Dm and Ts were lower but

313   higher when Dm and Ts were higher. The validity of these findings was further confirmed through a

314   correlation matrix, examining multiple variables across each row and column between TMG measures and

315   isokinetic measures at 90°/sec and at 30°/sec.

316

317   ***Differences of TMG values***

318   As depicted in Table 2, the Tc of the RA was greater on both the left and right sides in the NSLBP group

319   than in the CON group, with a comparable pattern observed in the mean Tc. The Tc of the ES was higher

320   on both sides in the NSLBP group compared to the CON group, exhibiting a similar trend in the mean Tc.

321   The Dm of the RA was lower on both sides in the NSLBP group compared to the CON group, with a similar

322   pattern observed in the mean Dm. The Dm of the ES was lower on both sides in the NSLBP group than in

323   the CON group, showing a comparable trend in the mean Dm. The Ts of the RA was significantly lower on

324   both sides in the NSLBP group compared to the CON group, with a similar pattern observed in the mean

325   Ts. The Ts of the ES was also significantly lower on both sides in the NSLBP group than in the CON group,

326   exhibiting a comparable trend in the mean Ts.

327   Near here Table 2

328   The Tr and Td of the RA were significantly higher on both sides in the NSLBP group compared to the

329   CON group, with a similar pattern observed in the mean Tr and Td. The Tr and Td of the ES were also

330   significantly higher on both sides in the NSLBP group than in the CON group, exhibiting a comparable

331   trend in the mean Tr and Td. However, these differences were associated with a small effect size (≤ 0.1).

332   Meanwhile, as shown in Fig. 4A, the Vc of the RA was significantly lower in the NSLBP group compared

333   to the CON group. Similarly, the Vc of the ES was also significantly lower in the NSLBP group than in the

334   CON group (Fig. 4B).

335   Near here Fig. 4

336

337 *Differences of isokinetic TEF torques*

338 As demonstrated in Table 3, the PT of the trunk flexor measured at 90°/sec was lower in the NSLBP group

339 compared to the CON group, with a similar pattern observed in PTBW. Likewise, the PT of the trunk

340 extensor was significantly lower in the NSLBP group than in the CON group, showing a comparable trend

341 in the PTBW. Meanwhile, the WR and WRBW of the trunk flexor were lower in the NSLBP group

342 compared to the CON group, but the differences were not statistically significant. In contrast, the WR and

343 WRBW of the trunk extensor were significantly lower in the NSLBP group than in the CON group.

344   Near here Table 3

345

346   As shown in Fig. 5A, the ratio of the PT of the trunk extensor to that of the trunk flexor was significantly

347 lower in the NSLBP group compared to the CON group, indicating that the trunk extensor in the NSLBP

348 group exhibited lower moments during force production. At 30°/sec, the PT and PTBW of the trunk flexor,

349 as shown in Table 3, were lower in the NSLBP group compared to the CON group. However, a statistically

350 significant difference was observed only in PTBW. In contrast, both the PT and PTBW of the trunk extensor

351 were significantly lower in the NSLBP group than in the CON group. Similarly, the WR and WRBW of

352 the trunk flexor were lower in the NSLBP group than in the CON group, though the difference was not

353 statistically significant. However, the WR and WRBW of the trunk extensor were significantly lower in the

354 NSLBP group. Additionally, as illustrated in Fig. 5B, the ratio of PT of the trunk extensor to that of the

355 trunk flexor was significantly lower in the NSLBP group, indicating reduced trunk extensor moment in this

356 group compared to the CON group.

357   Near here Fig. 5

358

359 **Discussion**

360 *Relationships between TMG factors and isokinetic TEF measures*

361 The primary aim of this study was to investigate the relationship between TMG and isokinetic measures in

362 the trunk muscles of bodybuilding trainees with and without NSLBP. Among the 150 participants, a

363 preliminary questionnaire indicated that 90 participants (60%) had NSLBP. However, a more detailed

364 assessment using the NPRS and RMDQ revealed that some degree of NSLBP was also present in the CON

365 group. This study has focused on TMG, an advanced method for assessing muscle function by measuring

366 radial displacement in response to electrical stimulation. Although TMG has operated on a similar

367 fundamental principle as mechanomyography, it is specifically designed for stimulated muscle contractions

368 and utilizes a unique mechanical sensor to detect radial displacement (Macgregor et al., 2018). However,

369 since TMG evaluated muscle properties in a static state, its role in assessing dynamic muscle function has

370   not been clearly established. Therefore, this study aimed to examine the relationship between TMG
371   parameters and variables obtained from isokinetic dynamometry, a widely used tool in sports medicine
372   area, to determine the functional significance of the five key components of TMG. The findings of this
373   study revealed significant negative correlations between the Tc, Tr, and Td of the RA and ES with PT and
374   WR of the trunk flexor and extensor.

375   When analyzing the general patterns of variables derived from TMG, the Tc of the RA and ES muscles
376   typically appears shorter in healthy muscles, whereas weaker muscles exhibit a relatively prolonged
377   response time (Bibrowicz et al., 2024). As shown in the results of this study, a shorter Tc, as observed in
378   datasets, reflects well-maintained neuromuscular control and responsiveness in the CON group, whereas a
379   prolonged Tc may indicate muscle fatigue, weakness, or impaired neuromuscular function in the NSLBP
380   group. Tr, defined as the time between 90% and 50% of muscle relaxation, reflects the speed of muscle
381   relaxation. A shorter Tr indicates faster muscle relaxation, which is generally associated with a normal
382   physiological state. In contrast, a prolonged Tr may suggest increased muscle fatigue, potential muscle
383   damage, or excessive muscle tension as similar results of this study. Td, defined as the time between the
384   electrical impulse and 10% of the contraction, represents neuromuscular response time. A shorter Td
385   indicates an appropriate neuromuscular response, whereas a prolonged Td suggests delayed neural
386   conduction or impaired muscle responsiveness (Simunič et al., 2011). As observed in the results of this
387   study, the shorter Td in the CON group indicates better neuromuscular control and responsiveness, whereas
388   the relatively prolonged Td in the NSLBP group may suggest muscle fatigue, weakness, or impaired
389   neuromuscular function. These findings suggest that when Tc, Tr, and Td of the RA and ES, as measured
390   by TMG in a static state, are slower or lower, the trunk flexor and extensor muscles can exhibit normal
391   muscle function during dynamic trunk contractions. Conversely, Dm and Ts of the RA and ES of TMG
392   parameters exhibited significant positive correlations with PT and WR of trunk flexor and extensor
393   performance. For Dm, a higher Dm reflects reduced muscle tension or increased flexibility, while a lower
394   Dm suggests heightened muscle stiffness or an increased risk of potential injury (Reeves et al., 2005;
395   García-García et al., 2013). It is not uncommon for Tc and Dm to change at uneven rates. In such cases, we
396   propose that the change in Tc, independent of Dm, is primarily influenced by variations in the contraction
397   rate, as indicated by Vc (Valencic & Knez, 1997). Ts, defined as the duration for which a twitch is sustained,
398   is measured as the time between 50% of Dm on either side of the twitch curve. A prolonged Ts reflects an
399   improved capacity to sustain muscle contraction, while a shorter Ts suggests increased muscle fatigue or
400   reduced endurance (Tous-Fajardo et al., 2010). In the present study, the CON group exhibited a longer Ts,
401   indicating superior neuromuscular control and responsiveness, whereas the shorter Ts observed in the
402   NSLBP group may suggest muscle fatigue, weakness, or neuromuscular dysfunction. Eventually, higher or
403   longer values of Dm and Ts, as measured by TMG, may indicate that the trunk flexor and extensor muscles

404   exhibit normal muscle function during dynamic contractions.

405   The relationship between contractile properties and geometric changes during muscle contraction has
406   been analyzed using real-time brightness mode ultrasound to track instantaneous variations in
407   gastrocnemius muscle fascicle length (Simunič et al., 2011). Dick & Wakeling (2017) simultaneously
408   measured torque and geometric changes, revealing that tension is generated in synchronization with fascicle
409   length alterations. Furthermore, surface mechanomyography has been shown to effectively capture muscle
410   fiber expansion during contraction, demonstrating a strong correlation between mechanomyography
411   amplitude, torque oscillations, and fascicle length variations. These findings reinforce the concept that
412   muscle functions as a near-constant volume system, where fiber shortening is accompanied by thickening,
413   as reflected in muscle surface displacement and tendon tension (Macgregor et al., 2018). Moreover, while
414   TMG enables accurate and efficient muscle assessment, studies investigating the factors contributing to
415   muscle strength variations within TMG and their relationship with variables obtained through isokinetic
416   dynamometry remain limited. In other words, investigating the relationship between muscle surface
417   displacement tracking and isokinetic muscle contraction characteristics, and applying this approach to
418   NSLBP patients, could have potential applications in both sports' performance and rehabilitation. Based on
419   the previous studies, this study an analysis of the relationships among these variables revealed that at an
420   isokinetic angular velocity of 90°/sec, PT and WR of the TEF muscles were higher when T_c, T_r, and T_d
421   were shorter or lower, whereas PT and WR were lower when T_c, T_r, and T_d of the RA and ES were longer
422   or higher. Conversely, PT and WR of the TEF muscles were lower when D_m and T_s of the RA and ES were
423   lower but increased when D_m and T_s were higher. Similarly, at an isokinetic angular velocity of 30°/sec,
424   PT and WR of the TEF muscles were higher when T_c, T_r, and T_d of the RA and ES were shorter or lower
425   and decreased when these parameters were longer or higher. Ultimately, it was observed that the correlation
426   patterns varied slightly depending on changes in isokinetic angular velocity.

427

428   *Distinctive features of TMG factors and isokinetic TEF torques*

429   When individuals experience LBP, they naturally attempt to minimize discomfort by reducing their range
430   of motion and exerting less force. Non-specific LBP most commonly occurs when lifting heavy objects
431   such as bodybuilding training, and if left unaddressed, it may progress to chronic pain or structural
432   deformities (Price, 2021). As discussed earlier, TMG and isokinetic dynamometry are closely associated
433   and can be effectively utilized during the early stages of NSLBP. The findings of this study demonstrated
434   their utility in identifying the characteristics of individuals with and without NSLBP, thereby facilitating
435   appropriate interventions. In this study, the NSLBP group demonstrated significantly prolonged T_c, T_r, and
436   T_d values for the RA and ES, whereas D_m, T_s, and V_c for both muscles were significantly reduced than
437   those of the CON group. Moreover, the NSLBP group exhibited significantly lower PT and WR in trunk

438   flexor and extensor, with a more pronounced deficit observed in the trunk extensor compared to the trunk

439   flexor. These findings suggest potential neuromuscular impairments in individuals with NSLBP (de

440   Oliveira Meirelles et al., 2020), highlighting the importance of targeted interventions to improve trunk

441   muscle function in the bodybuilding trainees.

442   Since LBP is inherently subjective and variable, accurately assessing its influencing factors—such as

443   physical, psychological, emotional, and environmental conditions—is crucial (Bláfoss et al., 2019). In this

444   study, although participants in the CON group reported no LBP prior to group classification, responses

445   from the back pain-related questionnaires revealed the presence of underlying, subclinical symptoms

446   indicative of potential LBP. According to previous studies, the primary causes of sports injuries include

447   excessive training, improper training methods, anatomical limitations, lack of flexibility, and muscle

448   imbalances, with lower back injury related to weight training consistently ranking among the top two injury

449   sites for weightlifters—accounting for 23% to 59% of all injuries—and most often associated with the squat

450   or deadlift (Ross et al., 2023). In the context of bodybuilding, injuries are often attributed to inadequate

451   exercise techniques, insufficient knowledge, poor instruction from trainers, and excessive tension (Bonilla

452   et al., 2022). In addition, among the various causes of back pain, weightlifters are commonly diagnosed

453   with muscle strains, ligament sprains, degenerative disc disease, disc herniation, spondylolysis,

454   spondylolisthesis, or lumbar facet syndrome. Standard treatments often fail to fully alleviate pain or prevent

455   recurrence. Since most athletes aim to continue weightlifting, effective management should emphasize

456   lifting-specific modifications, including improved technique and addressing mobility and muscular

457   imbalances (Ross et al., 2023). Bodybuilding is a form of physical training that systematically stimulates

458   the body through various methods to achieve optimal development, ultimately fostering both physical and

459   mental self-fulfillment. Given these characteristics, bodybuilding plays a significant role in the occurrence

460   and prevention of exercise-related injuries (Mangano et al., 2015). Considering the results of previous

461   studies alongside the findings of the present study, it is evident that training for bodybuilding places a

462   significant load on the muscles surrounding the trunk.

463   TMG and isokinetic dynamometry, both historically and currently utilized, provide valuable insights for

464   developing effective treatment strategies for the LBP patients (Park, 2020). Given that the trunk flexor and

465   extensor play a fundamental role in spinal support, integrating these two assessment tools to measure both

466   static and dynamic trunk muscle function may yield more clinically relevant findings, ultimately benefiting

467   patient outcomes. Even based on the results of this study alone, distinct characteristics were identified in

468   the static muscle function parameters measured by TMG when comparing the trunk muscles of patients

469   with lower back pain to those of healthy young participants without back pain. The primary variable in

470   TMG, Dm, measures the maximum muscle displacement during contraction, where a lower Dm may

471   indicate increased stiffness, muscle rigidity, or injury risk, while a higher Dm suggests lower muscle tension

472   or greater flexibility (Reeves et al., 2005; García-García et al., 2013). In this study, the Dm values derived

473   from the abdomen and back muscles were lower in the NSLBP group, while higher values were observed

474   in the CON group, aligning with the findings of previous studies (Yeom et al., 2023). Typically, Tc is

475   shorter in the absence of muscular impairments; however, it tends to be prolonged in the presence of muscle

476   fatigue, weakness, or neuromuscular control deficits (Bibrowicz et al., 2024). Consistent with the findings

477   of this study, Tc of the RA and ES was shorter on both the left and right sides in the CON group compared

478   to the NSLBP group, with a similar trend observed in the mean Tc. According to various studies, Ts

479   represents the duration for which Tc is maintained. A shorter Ts may indicate muscle fatigue or reduced

480   contraction endurance, whereas a longer Ts is considered indicative of better contractile capacity (Tous-

481   Fajardo et al., 2010). In the results of this study, the Ts values derived from the RA and ES were

482   significantly lower in the NSLBP group compared to the CON group, suggesting diminished muscle

483   function associated with lower back pain. Tr represents the time it takes for the muscle to transition from

484   90% to 50% of its maximal displacement during relaxation (Poggesi et al., 2005). A prolonged Tr may

485   indicate increased fatigue, muscle damage, or excessive tension, whereas a shorter Tr suggests quick

486   relaxation, typically reflecting a normal state. In this study, the Tr values derived from the abdomen and

487   back muscles were longer in the NSLBP group, while shorter values were observed in the CON group,

488   consistent with the findings of previous studies. In addition, Td represents the time required to reach 10%

489   of the Dm (Dahmane et al., 2001). A prolonged Td may indicate delayed nerve conduction or impaired

490   muscle response, whereas a shorter Td reflects an appropriate neuromuscular response time (Simunič et al.,

491   2011). In this study, the Td values derived from the RA and ES were longer in the NSLBP group, while

492   shorter values were observed in the CON group, aligning with the findings of previous studies. Meanwhile,

493   the Vc of a muscle, calculated as Dm/(Tc + Td), is considered an indicator of muscle health, with lower

494   values suggesting potential issues within the muscle group and higher values indicating healthier muscles

495   (Valencic & Knez, 1997). In this study, the Vc values derived from the RA and ES were lower in the

496   NSLBP group compared to the CON group, confirming impairments in the RA and ES muscles that

497   constitute the trunk.

498   The isokinetic dynamometer revealed the degree of development of trunk extensors relative to trunk

499   flexors in the healthy control group without back pain (Yahia et al., 2011; Merati et al., 2004). In this study,

500   the PT and PTBW of the trunk flexor measured at 90°/sec were lower in the NSLBP group compared to the

501   CON group. Similarly, the PT and PTBW of the trunk extensor were significantly lower in the NSLBP

502   group than in the CON group. However, while WR and WRBW were lower in the NSLBP group compared

503   to the CON group, no significant differences were found in the flexors, whereas significant differences were

504   observed only in the extensors. These trends were similar at an isokinetic angular velocity of 30°/sec,

505   suggesting that NSLBP has a more pronounced detrimental effect on the trunk extensors than on the flexors.

506   These findings reflect the high activation of the ES muscles during multi-joint strength training exercises,

507   such as squats and deadlifts, commonly incorporated into exercise training programs (Cormie et al., 2011).

508   The flexion-to-extension ratio in all muscle groups serves as a valuable indicator for assessing muscle

509   damage or the potential risk of injury. Ben Moussa Zouita et al. (2018) reported that the maximum torque

510   ratio between the flexor and extensor muscles serves as an indicator of muscular joint balance. In this

511   regard, Merati et al. (2004) reported that at 90°/sec, the trunk flexion-to-extension ratio in a pain-free control

512   group of children was 0.89, whereas it was 1.00 in a group with low back pain. Similarly, Lee et al. (2012)

513   found that at 60°/sec, the trunk flexion-to-extension ratio in middle-aged adults with LBP was 0.57.

514   Conversely, Yahia et al. (2011) reported that at 90°/sec, the ratio was 0.85 in a group without chronic lumbar

515   pain, while it was 1.34 in those with chronic lumbar pain. Cohen et al. (2002) observed that at 60°/sec, the

516   ratio was 0.82 in a healthy control group but increased to 1.31 in individuals with LBP. The findings of our

517   study contrast with those of Merati et al. (2004) and Lee et al. (2012) but align more closely with the results

518   reported by Yahia et al. (2011) and Cohen et al. (Cohen et al., 2002). Specifically, at 90°/sec, the CON

519   group exhibited a trunk flexion-to-extension ratio of 0.96 ± 0.18, whereas in the NSLBP group, it was 1.20

520   ± 0.36, showing a statistically significant difference between groups ($Z = -4.421$, $p = 0.001$, $\eta^2 = 0.133$).

521   This finding suggests that individuals with NSLBP have weaker extensor muscles relative to flexor muscles.

522   Similarly, at 30°/sec, the CON group demonstrated a flexion-to-extension ratio of 1.02 ± 0.28, while the

523   NSLBP group showed a ratio of 1.32 ± 0.49 ($Z = -3.843$, $p = 0.001$, $\eta^2 = 0.112$), further confirming that in

524   the presence of low back pain, the extensor muscles are weaker compared to the flexor muscles.

525   Ultimately, this study confirmed that trunk flexor and extensor muscle characteristics assessed using

526   TMG and isokinetic dynamometry effectively reflect the differences between bodybuilding trainees with

527   and without NSLBP. Specifically, the findings revealed an inverse relationship between the PT and WR of

528   the TEF muscles and the parameters Tc, Tr, and Td. Higher PT and WR values were associated with lower

529   Tc, Tr, and Td, whereas lower PT and WR values corresponded to higher Tc, Tr, and Td. Additionally, a

530   direct relationship was observed between PT, WR, and Dm and Ts, with higher PT and WR values linked

531   to increased Dm and Ts, and lower PT and WR values associated with decreased Dm and Ts. Furthermore,

532   individuals with NSLBP exhibited distinct muscle characteristics compared to healthy controls. They

533   demonstrated higher Tc, Tr, and Td values and lower Dm and Ts values in the RA and ES muscles.

534   Isokinetic strength assessments further indicated that the NSLBP group had reduced trunk flexor and

535   extensor strength compared to the control group, with extensor muscle weakness being more pronounced

536   than flexor muscle weakness.

537   However, our study has several limitations. First, the participants were exclusively bodybuilding trainees,

538   which may limit the generalizability of the findings. Second, the study was conducted on young adults in

539   their twenties who attended a single training center, and the relatively small sample size further restricts the

540 applicability of the results to a broader population. Considering these limitations, future research should

541 aim to examine the characteristics of non-invasive assessment tools across a more diverse and larger

542 population from multiple locations to enhance the validity and applicability of the findings.

543

Conclusions

545 Nonetheless, it is essential to recognize that this study has certain limitations, this study found a consistent

546 relationship between muscle tone using a TMG and the assessment of trunk flexor and extensor using an

547 isokinetic dynamometer. Additionally, it demonstrated a specific alteration in distinguishing between

548 impaired and unimpaired trunks' muscles due to NSLBP.

549

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552

References

554 **Alshehri MA, van den Hoorn W, Klyne DM, Hodges PW. 2024.** Coordination of hip and spine in

555   individuals with acute low back pain during unstable sitting. *The Spine Journal: Official Journal of*

556   *the North American Spine Society* **24(5):**768–782. https://doi.org/10.1016/j.spinee.2023.12.001

557 **Ben Moussa Zouita A, Ben Salah FZ, Dziri C, Beardsley C. 2018.** Comparison of isokinetic trunk flexion

558   and extension torques and powers between athletes and nonathletes. *Journal of Exercise*

559   *Rehabilitation* **14(1):** 72–77. https://doi.org/10.12965/jer.1835126.563

560 **Bibrowicz K, Szurmik T, Kurzeja P, Bibrowicz B, Ogrodzka-Ciechanowicz K. 2024.** Pelvic tilt and

561   stiffness of the muscles stabilising the lumbo-pelvic-hip (LPH) complex in tensiomyography

562   examination. *PloS one* **19(10):** e0312480. https://doi.org/10.1371/journal.pone.0312480

563 **Bláfoss R, Aagaard P, Andersen LL. 2019.** Physical and psychosocial work environmental risk factors

564   of low-back pain: protocol for a 1 year prospective cohort study. *BMC Musculoskeletal*

565   *Disorders* **20(1):** 626. https://doi.org/10.1186/s12891-019-2996-z

566 **Bonilla DA, Cardozo LA, Vélez-Gutiérrez JM, Arévalo-Rodríguez A, Vargas-Molina S, Stout JR,**

567   **Kreider RB, Petro JL. 2022.** Exercise Selection and Common Injuries in Fitness Centers: A

568   Systematic Integrative Review and Practical Recommendations. *International Journal of*

569   *Environmental Research and Public Health* **19(19):**12710. https://doi.org/10.3390/ijerph191912710

570 **Campanini I, Disselhorst-Klug C, Rymer WZ, Merletti R. 2020.** Surface EMG in Clinical Assessment

571   and Neurorehabilitation: Barriers Limiting Its Use. *Frontiers in Neurology* **11:**934.

572   https://doi.org/10.3389/fneur.2020.00934

573   **Chaput JP, Klingenberg L, Rosenkilde M, Gilbert JA, Tremblay A, Sjödin A. 2011.** Physical activity
574   plays an important role in body weight regulation. *Journal of Obesity* 360257.
575   https://doi.org/10.1155/2011/360257

576   **Cheng HLH. 2016.** A simple, easy-to-use spreadsheet for automatic scoring of the international physical
577   activity questionnaire (IPAQ) short form. https://doi.org/10.13140 /RG.2.2.21067.80165

578   **Cohen P, Chantraine A, Gobelet C, Ziltener JL. 2002.** Influence de la position de test sur l'évaluation
579   isocinétique lombaire [Influence of testing position on lumbar isokinetic measurements]. *Annales de*
580   *readaptation et de medecine physique : revue scientifique de la Societe francaise de reeducation*
581   *fonctionnelle de readaptation et de medecine physique* **45(1):**12–18. https://doi.org/10.1016/s0168-
582   6054(01)00167-2

583   **Cormie P, McGuigan MR, Newton RU. 2011.** Developing maximal neuromuscular power: part 2 -
584   training considerations for improving maximal power production. *Sports Medicine (Auckland, N.Z.)*
585   **41(2):**125–146. https://doi.org/10.2165/11538500-000000000-00000

586   **Dahmane R, Valenčič V, Knez N, Eržen I. 2001.** Evaluation of the ability to make non-invasive
587   estimation of muscle contractile properties on the basis of the muscle belly response. *Medical &*
588   *Biological Engineering & Computing* **39(1):**51–55. https://doi.org/10.1007/BF02345266

589   **de Oliveira Meirelles F, de Oliveira Muniz Cunha JC, da Silva EB. 2020.** Osteopathic manipulation
590   treatment versus therapeutic exercises in patients with chronic nonspecific low back pain: A
591   randomized, controlled and double-blind study. *Journal of Back and Musculoskeletal*
592   *Rehabilitation 33***(3):**367–377. https://doi.org/10.3233/BMR-181355

593   **Delitto A, George SZ, Van Dillen LR, Whitman JM, Sowa G, Shekelle P, Godges JJ. 2012.** Low back
594   pain. *Journal of Orthopaedic & Sports Physical Therapy* **42(4):**A1–A57.
595   https://doi.org/10.2519/jospt.2012.0301

596   **Des Jarlais DC, Lyles C, Crepaz N, TREND Group. 2004.** Improving the reporting quality of
597   nonrandomized evaluations of behavioral and public health interventions: the TREND
598   statement. *American Journal of Public Health* **94(3):**361–366. https://doi.org/10.2105/ajph.94.3.361

599   **Dick TJM, Wakeling JM. 2017.** Shifting gears: dynamic muscle shape changes and force-velocity
600   behavior in the medial gastrocnemius. *Journal of Applied Physiology (Bethesda, Md.:*
601   *1985)* **123(6):**1433–1442. https://doi.org/10.1152/japplphysiol.01050.2016

602   **Fairbank JCT, Pynsent PB. 2000.** The Oswestry Disability Index. *Spine* **25(22):**2940–2953.
603   https://doi.org/10.1097/00007632-200011150-00017

604   **Fritz CO, Morris PE, Richler JJ. 2012.** Effect size estimates: current use, calculations, and
605   interpretation. *Journal of Experimental Psychology. General* **141(1):**2–18.
606   https://doi.org/10.1037/a0024338

607 **García-García O, Cancela-Carral JM, Martínez-Trigo R, Serrano-Gómez V. 2013.** Differences in the
608   contractile properties of the knee extensor and flexor muscles in professional road cyclists during the
609   season. _Journal of Strength and Conditioning Research_ **27(10):**2760–2767.
610   https://doi.org/10.1519/JSC.0b013e31828155cd

611 **García-Vaquero MP, Barbado D, Juan-Recio C, López-Valenciano A, Vera-Garcia FJ. 2020.**
612   Isokinetic trunk flexion-extension protocol to assess trunk muscle strength and endurance: Reliability,
613   learning effect, and sex differences. _Journal of Sport and Health Science_ **9(6):**692–701.
614   https://doi.org/10.1016/j.jshs.2016.08.011

615 **Gehrig SM, Koopman R, Naim T, Tjoakarfa C, Lynch GS. 2010.** Making fast-twitch dystrophic muscles
616   bigger protects them from contraction injury and attenuates the dystrophic pathology. _The American_
617   _Journal of Pathology_ **176(1):**29–33. https://doi.org/10.2353/ajpath.2010.090760

618 **Guilhem G, Giroux C, Couturier A, Maffiuletti NA. 2014.** Validity of trunk extensor and flexor torque
619   measurements using isokinetic dynamometry. _Journal of Electromyography and Kinesiology: Official_
620   _Journal of the International Society of Electrophysiological Kinesiology_ **24(6):**986–993.
621   https://doi.org/10.1016/j.jelekin.2014.07.006

622 **Heidari S, Babor TF, De Castro P, Tort S, Curno M. 2016.** Sex and Gender Equity in Research: rationale
623   for the SAGER guidelines and recommended use. _Research Integrity and Peer Review_ **1:**2.
624   https://doi.org/10.1186/s41073-016-0007-6

625 **Howarth SJ, McCreath Frangakis E, Hirsch S, De Carvalho D. 2024.** Evaluating Test–Retest
626   Reliability and Measurement Error of the Lumbar Flexion Relaxation Ratio Within and Between Days.
627   _Measurement in Physical Education and Exercise Science_ **28(4):**401-410.
628   https://doi.org/10.1080/1091367X.2024.2377101

629 **Huebner M, Arrow H, Garinther A, Meltzer DE. 2022.** How Heavy Lifting Lightens Our Lives: Content
630   Analysis of Perceived Outcomes of Masters Weightlifting. _Frontiers in Sports and Active Living_
631   **4:**778491. https://doi.org/10.3389/fspor.2022.778491

632 **Ibrahim AA, Akindele MO, Bello B, Kaka B. 2020.** Translation, Cross-cultural Adaptation, and
633   Psychometric Properties of the Hausa Versions of the Numerical Pain Rating Scale and Global Rating
634   of Change Scale in a Low-literate Population with Chronic Low Back Pain. _Spine_ **45(8):**E439–E447.
635   https://doi.org/10.1097/BRS.0000000000003306

636 **Imamura M, Alfieri FM, Filippo TR, Battistella LR. 2016.** Pressure pain thresholds in patients with
637   chronic nonspecific low back pain. _Journal of Back and Musculoskeletal Rehabilitation_ **29(2):**327–
638   336. https://doi.org/10.3233/BMR-150636

639 **Jee YS. 2019.** The effect of high-impulse-electromyostimulation on adipokine profiles, body composition
640   and strength: A pilot study. _Isokinetics and Exercise Science_ **27(3):**163-176.

641   https://doi.org/10.3233/IES-183201

642   **Jiang Y, Xu Y, Kong X, Zhao E, Ma C, Lv Y, Xu H, Sun H, Gao X. 2024.** How to tackle non-specific

643   low back pain among adult patients? A systematic review with a meta-analysis to compare four

644   interventions. *Journal of Orthopaedic Surgery and Research* **19(1):**1. https://doi.org/10.1186/s13018-

645   023-04392-2

646   **Kandwal A, Sharma YD, Jasrotia R, Kit CC, Lakshmaiya N, Sillanpää M, Liu LW, Igbe T, Kumari**

647   **A, Sharma R, Kumar S, Sungoum C. 2024.** A comprehensive review on electromagnetic wave based

648   non-invasive glucose monitoring in microwave frequencies. *Heliyon* **10(18):**e37825.

649   https://doi.org/10.1016/j.heliyon.2024.e37825

650   **Kang H. 2021.** Sample size determination and power analysis using the G*Power software. *Journal of*

651   *Educational Evaluation for Health Professions* **18:**17. https://doi.org/10.3352/jeehp.2021.18.17

652   **Koo TK, Li MY. 2016.** A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for

653   Reliability Research. *Journal of Chiropractic Medicine* **15(2):**155–163.

654   https://doi.org/10.1016/j.jcm.2016.02.012

655   **Lee HJ, Lim WH, Park JW, Kwon BS, Ryu KH, Lee JH, Park YG. 2012.** The Relationship between

656   Cross Sectional Area and Strength of Back Muscles in Patients with Chronic Low Back Pain. *Annals*

657   *of Rehabilitation Medicine* **36(2):**173–181. https://doi.org/10.5535/arm.2012.36.2.173

658   **Loell I, Helmers SB, Dastmalchi M, Alexanderson H, Munters LA, Nennesmo I, Lindroos E, Borg K,**

659   **Lundberg IE, Esbjörnsson M. 2011.** Higher proportion of fast-twitch (type II) muscle fibres in

660   idiopathic inflammatory myopathies - evident in chronic but not in untreated newly diagnosed

661   patients. *Clinical Physiology and Functional Imaging* **31(1):**18–25. https://doi.org/10.1111/j.1475-

662   097X.2010.00973.x

663   **Lohr C, Medina-Porqueres I. 2021.** Immediate effects of myofascial release on neuromechanical

664   characteristics in female and male patients with low back pain and healthy controls as assessed by

665   tensiomyography. A controlled matched-pair study. *Clinical Biomechanics (Bristol,*

666   *Avon)* **84:**105351. https://doi.org/10.1016/j.clinbiomech.2021.105351

667   **Lohr C, Braumann KM, Reer R, Schroeder J, Schmidt T. 2018.** Reliability of tensiomyography and

668   myotonometry in detecting mechanical and contractile characteristics of the lumbar erector spinae in

669   healthy volunteers. *European Journal of Applied Physiology* **118(7):**1349–1359.

670   https://doi.org/10.1007/s00421-018-3867-2

671   **Lohr C, Schmidt T, Braumann KM, Reer R, Medina-Porqueres I. 2020.** Sex-Based Differences in

672   Tensiomyography as Assessed in the Lower Erector Spinae of Healthy Participants: An Observational

673   Study. *Sports Health* **12(4):**341–346. https://doi.org/10.1177/1941738120917932

674   **Macgregor LJ, Hunter AM, Orizio C, Fairweather MM, Ditroilo M. 2018.** Assessment of Skeletal

675   Muscle Contractile Properties by Radial Displacement: The Case for Tensiomyography. *Sports*
676   *Medicine (Auckland, N.Z.)* **48(7):**1607–1620. https://doi.org/10.1007/s40279-018-0912-6

677 **Maher C, Underwood M, Buchbinder R. 2017.** Non-specific low back pain. *Lancet (London, England)*
678   **389(10070):**736–747. https://doi.org/10.1016/S0140-6736(16)30970-9

679 **Mangano T, Cerruti P, Repetto I, Trentini R, Giovale M, Franchin F. 2015.** Chronic tendonopathy as
680   a unique cause of non traumatic triceps tendon rupture in a (risk factors free) bodybuilder: A case
681   report. *Journal of Orthopaedic Case Reports* **5(1):**58–61. https://doi.org/10.13107/jocr.2250-
682   0685.257

683 **Merati G, Negrini S, Carabalona R, Margonato V, Veicsteinas A. 2004.** Trunk muscular strength in
684   pre-pubertal children with and without back pain. *Pediatric Rehabilitation* **7(2):**97–103.
685   https://doi.org/10.1080/13638490310001654754

686 **Morini S, Ciccarelli A, Cerulli C, Giombini A, Di Cesare A, Ripani M. 2008.** Functional anatomy of
687   trunk flexion-extension in isokinetic exercise: muscle activity in standing and seated
688   positions. *Journal of Sports Medicine and Physical Fitness* **48(1):**17–23.

689 **Mueller S, Mayer P, Baur H, Mayer F. 2011.** Higher velocities in isokinetic dynamometry: A pilot study
690   of new test mode with active compensation of inertia. *Isokinetics and Exercise Science* **19(2):**63-70.
691   https://doi.org/10.3233/IES-2011-0398

692 **Park S. 2020.** Theory and usage of tensiomyography and the analysis method for the patient with low back
693   pain. *Journal of Exercise Rehabilitation* **16(4):**325–331. https://doi.org/10.12965/jer.2040420.210

694 **Park S, Kim YC, Jee YS. 2024.** Plank exercise improves respiratory capacity through positive changes in
695   body composition, abdominis function, and autonomic nerves' activities. *European Journal of Sport*
696   *Science* **24(3):**330-340. https://doi.org/10.1002/ejsc.12086

697 **Paul DJ, Nassis GP. 2015.** Testing strength and power in soccer players: the application of conventional
698   and traditional methods of assessment. *Journal of Strength and Conditioning Research* **29(6):**1748–
699   1758. https://doi.org/10.1519/JSC.0000000000000807

700 **Piqueras-Sanchiz F, Martín-Rodríguez S, Pareja-Blanco F, Baraja-Vegas L, Blázquez-Fernández J,**
701   **Bautista IJ, García-García Ó. 2020.** Mechanomyographic measures of muscle contractile properties
702   are influenced by electrode size and stimulation pulse duration. *Scientific Reports* **10(1):**8192.
703   https://doi.org/10.1038/s41598-020-65111-z

704 **Poggesi C, Tesi C, Stehle R. 2005.** Sarcomeric determinants of striated muscle relaxation kinetics. *Pflugers*
705   *Archive: European Journal of Physiology* **449(6):**505–517. https://doi.org/10.1007/s00424-004-1363-
706   5

707 **Price JW. 2021.** Osteopathic model of the development and prevention of occupational musculoskeletal
708   disorders. *Journal of Osteopathic Medicine* **121(3):**287–305. https://doi.org/10.1515/jom-2020-0060

709 **Reeves ND, Maganaris CN, Ferretti G, Narici MV. 2005.** Influence of 90-day simulated microgravity
710 on human tendon mechanical properties and the effect of resistive countermeasures. *Journal of*
711 *Applied Physiology (Bethesda, Md.: 1985)* **98(6):**2278–2286.
712 https://doi.org/10.1152/japplphysiol.01266.2004

713 **Ren XS, Kazis L. 1998.** Are patients capable of attributing functional impairments to specific
714 diseases? *American Journal of Public Health* **88(5):**837–838. https://doi.org/10.2105/ajph.88.5.837

715 **Roland M, Fairbank J. 2000.** The Roland-Morris Disability Questionnaire and the Oswestry Disability
716 Questionnaire. *Spine* **25(24):**3115–3124. https://doi.org/10.1097/00007632-200012150-00006

717 **Roland M, Morris R. 1983.** A study of the natural history of low-back pain. Part II: development of
718 guidelines for trials of treatment in primary care. *Spine* **8(2):**145–150.
719 https://doi.org/10.1097/00007632-198303000-00005

720 **Ross R, Han J, Slover J. 2023.** Chronic Lower Back Pain in Weight Lifters: Epidemiology, Evaluation,
721 and Management. *JBJS Reviews* **11(6):**e22.00228. https://doi.org/10.2106/JBJS.RVW.22.00228

722 **Sarafadeen R, Ganiyu SO, Ibrahim AA. 2020.** Effects of spinal stabilization exercise with real-time
723 ultrasound imaging biofeedback in individuals with chronic nonspecific low back pain: a pilot
724 study. *Journal of Exercise Rehabilitation* **16(3):**293–299. https://doi.org/10.12965/jer.2040380.190

725 **Sedgwick P. 2013.** Sample size: how many participants are needed in a trial? *BMJ (Clinical research*
726 *ed.)* **346:**f1041. https://doi.org/10.1136/bmj.f1041

727 **Shmagel A, Foley R, Ibrahim H. 2016.** Epidemiology of Chronic Low Back Pain in US Adults: Data
728 From the 2009-2010 National Health and Nutrition Examination Survey. *Arthritis Care &*
729 *Research* **68(11):**1688–1694. https://doi.org/10.1002/acr.22890

730 **Simunič B, Degens H, Rittweger J, Narici M, Mekjavić IB, Pišot R. 2011.** Noninvasive estimation of
731 myosin heavy chain composition in human skeletal muscle. *Medicine and Science in Sports and*
732 *Exercise* **43(9):**1619–1625. https://doi.org/10.1249/MSS.0b013e31821522d0

733 **Smith-Bindman R. 2010.** Is computed tomography safe? *New England Journal of Medicine* **363(1):**1–4.
734 https://doi.org/10.1056/NEJMp1002530

735 **Stratford PW, Binkley J, Solomon P, Finch E, Gill C, Moreland J. 1996.** Defining the minimum level
736 of detectable change for the Roland-Morris questionnaire. *Physical Therapy* **76(4):**359–368.
737 https://doi.org/10.1093/ptj/76.4.359

738 **Toskić L, Dopsaj M, Stanković V, Marković M. 2019.** Concurrent and predictive validity of isokinetic
739 dynamometry and tensiomyography in differently trained women and men. *Isokinetics and Exercise*
740 *Science* **27(1):**31-39. https://doi.org/10.3233/IES-185152

741 **Tous-Fajardo J, Moras G, Rodríguez-Jiménez S, Usach R, Doutres DM, Maffiuletti NA. 2010.** Inter-
742 rater reliability of muscle contractile property measurements using non-invasive

743   tensiomyography. *Journal of Electromyography and Kinesiology: Official Journal of the International*

744   *Society of Electrophysiological Kinesiology* **20(4):**761–766.

745   https://doi.org/10.1016/j.jelekin.2010.02.008

746 **Valencic V, Knez N. 1997.** Measuring of skeletal muscles' dynamic properties. *Artificial*

747   *Organs* **21(3):**240–242. https://doi.org/10.1111/j.1525-1594.1997.tb04658.x

748 **Van Damme BB, Stevens VK, Van Tiggelen DE, Duvigneaud NN, Neyens E, Danneels LA. 2013.**

749   Velocity of isokinetic trunk exercises influences back muscle recruitment patterns in healthy

750   subjects. *Journal of Electromyography and Kinesiology: Official Journal of the International Society*

751   *of Electrophysiological Kinesiology* **23(2):**378–386. https://doi.org/10.1016/j.jelekin.2012.10.015

752 **Warneke K, Keiner M, Wallot S, Siegel SD, Günther C, Wirth K, Puschkasch-Möck S. 2025.** The

753   Impact of Sample Size on Reliability Metrics Stability in Isokinetic Strength Assessments: Does Size

754   Matter? *Measurement in Physical Education and Exercise Science* 1-12.

755   https://doi.org/10.1080/1091367X.2025.2494998

756 **Williams JR. 2008.** The Declaration of Helsinki and public health. *Bulletin of the World Health*

757   *Organization* **86(8):**650–652. https://doi.org/10.2471/blt.08.050955

758 **Yahia A, Jribi S, Ghroubi S, Elleuch M, Baklouti S, Habib Elleuch M. 2011.** Evaluation of the posture

759   and muscular strength of the trunk and inferior members of patients with chronic lumbar pain. *Joint*

760   *Bone Spine* **78(3):**291–297. https://doi.org/10.1016/j.jbspin.2010.09.008

761 **Yeom S, Jeong H, Lee H, Jeon K. 2023.** Effects of Lumbar Stabilization Exercises on Isokinetic Strength

762   and Muscle Tension in Sedentary Men. *Bioengineering (Basel, Switzerland)* **10(3):**342.

763   https://doi.org/10.3390/bioengineering10030342

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765 **Table Legends**

766

Table 1 Demographic and physical characteristics.

Items	Groups		Z	p	η²
	CON (n = 60)	NSLBP (n = 90)			
Age (years)	21.9 ± 1.0	22.0 ± 1.6	-0.476	0.634	0.003
Sex†	1.4 ± 0.4	1.3 ± 0.4	-1.117	0.264	0.008
Stature (cm)	170.8 ± 8.6	172.1 ± 8.5	-0.722	0.470	0.006
Weight (kg)	68.7 ± 12.1	70.9 ± 12.8	-1.040	0.298	0.008
Muscle mass (kg)	29.9 ± 6.9	31.0 ± 6.6	-0.946	0.344	0.007
Fat mass (kg)	15.7 ± 3.5	15.1 ± 5.1	-1.249	0.212	0.004
Percent fat (%)	23.4 ± 6.4	21.9 ± 7.5	-1.638	0.101	0.010
Lean mass (kg)	52.2 ± 10.7	51.7 ± 8.6	-0.146	0.884	0.001
Body mass index (kg/m²)	23.6 ± 2.6	23.9 ± 2.7	-0.616	0.538	0.002
Waist-to-hip ratio	0.8 ± 0.1	0.8 ± 0.1	-0.649	0.516	0.002
Basal metabolic rate (kcal)	1544.3 ± 244.6	1586.7 ± 243.8	-1.109	0.267	0.007
Diet level (kcal)	2390.7 ± 311.0	2440.1 ± 266.5	-0.794	0.427	0.007
PA level (MET·min/week)	2110.1 ± 742.0	2201.5 ± 726.4	-0.599	0.549	0.004
Training duration (years)	3.1 ± 0.7	2.9 ± 1.1	-1.649	0.099	0.011
LBP duration (month)	0.1 ± 0.2	4.8 ± 2.2	-10.542	0.001	0.624
NPRS (scores)	0.6 ± 0.3	4.7 ± 1.0	-10.447	0.001	0.843
RMDQ (scores)	0.7 ± 0.2	7.7 ± 3.2	-10.372	0.001	0.648

† represents sex, with '1' and '2' indicating male and female. CON, control group; NSLBP, nonspecific low back pain group; PA, physical activity; LBP, low back pain; NPRS, Numerical pain rating scale; RMDQ, Roland-Morris disability questionnaire.

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Table 2 Comparative results of tensiomyograpic features between groups.

Items	Groups		Z	p	η²
	CON (n = 60)	NSLBP (n = 90)			
Tc at left rectus abdominis	20.8 ± 7.9	30.3 ± 10.3	-5.247	0.001	0.196
Tc at right rectus abdominis	20.4 ± 8.1	29.8 ± 11.1	-5.141	0.001	0.175
mean Tc of rectus abdominis	20.6 ± 7.7	30.0 ± 10.4	-5.308	0.001	0.194
Tc at left erector spinae	21.2 ± 8.3	27.1 ± 7.0	-4.426	0.001	0.132
Tc at right erector spinae	20.9 ± 7.3	27.0 ± 8.3	-4.239	0.001	0.124
mean Tc of erector spinae	21.0 ± 7.1	27.1 ± 6.9	-4.685	0.001	0.154
Dm at left rectus abdominis	4.3 ± 1.7	3.2 ± 1.3	-3.699	0.001	0.112
Dm at right rectus abdominis	4.1 ± 1.8	3.1 ± 1.4	-3.022	0.003	0.081
mean Dm of rectus abdominis	4.2 ± 1.7	3.2 ± 1.3	-3.458	0.001	0.098
Dm at left erector spinae	5.8 ± 3.1	4.0 ± 1.9	-2.945	0.003	0.117
Dm at right erector spinae	5.9 ± 3.1	3.9 ± 1.9	-3.693	0.001	0.134
mean Dm of erector spinae	5.8 ± 3.1	3.9 ± 1.8	-3.395	0.001	0.128
Ts at left rectus abdominis	106.6 ± 28.1	88.9 ± 22.2	-3.729	0.001	0.111
Ts at right rectus abdominis	107.1 ± 34.2	89.7 ± 25.6	-3.046	0.002	0.079
mean Ts of rectus abdominis	106.9 ± 27.8	89.3 ± 21.1	-3.342	0.001	0.115
Ts at left erector spinae	103.5 ± 17.0	94.6 ± 22.9	-3.131	0.002	0.042
Ts at right erector spinae	104.3 ± 17.3	95.1 ± 29.5	-2.369	0.018	0.031
mean Ts of erector spinae	103.9 ± 16.5	94.9 ± 23.0	-3.054	0.002	0.044
Tr at left rectus abdominis	88.6 ± 17.9	106.2 ± 22.3	-5.147	0.001	0.149
Tr at right rectus abdominis	88.2 ± 17.2	105.6 ± 20.6	-5.381	0.001	0.166
mean Tr of rectus abdominis	88.4 ± 17.1	105.9 ± 21.1	-5.335	0.001	0.162
Tr at left erector spinae	102.5 ± 17.6	110.8 ± 13.6	-3.354	0.001	0.066
Tr at right erector spinae	100.3 ± 27.4	108.6 ± 17.4	-2.482	0.013	0.034
mean Tr of erector spinae	101.4 ± 18.1	109.7 ± 12.8	-3.158	0.002	0.068
Td at left rectus abdominis	7.7 ± 3.3	9.5 ± 2.8	-3.378	0.001	0.080
Td at right rectus abdominis	7.7 ± 3.1	9.3 ± 2.5	-3.115	0.002	0.067
mean Td of rectus abdominis	7.7 ± 3.0	9.4 ± 2.5	-3.666	0.001	0.083
Td at left erector spinae	7.3 ± 3.1	9.5 ± 3.4	-4.301	0.001	0.104
Td at right erector spinae	7.1 ± 3.6	9.6 ± 4.1	-3.514	0.001	0.083
mean Td of erector spinae	7.2 ± 3.2	9.6 ± 3.5	-4.063	0.001	0.104
Vc of rectus abdominis	0.1 ± 0.1	0.1 ± 0.1	-5.212	0.001	0.158
Vc of erector spinae	0.2 ± 0.1	0.1 ± 0.1	-4.630	0.001	0.165

All values represent mean ± standard deviation. CON, control group; NSLBP, nonspecific low back pain group; Tc, contraction time; Dm, maximum displacement; Ts, sustain time; Tr, relaxation time; Td, delay time; Vc, contraction velocity.

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Table 3 Comparative results of isokinetic moments between groups.

Items	Groups		Z	_p_	η²
	CON (_n_ = 60)	NSLBP (_n_ = 90)			
Values at 90°/sec (Nm)					
Flexor PT	216.5 ± 83.5	182.7 ± 51.5	-2.406	0.016	0.060
Flexor PTBW	319.7 ± 118.2	271.9 ± 99.8	-2.858	0.004	0.046
Extensor PT	224.5 ± 65.5	159.8 ± 48.0	-6.399	0.001	0.248
Extensor PTBW	332.1 ± 94.6	247.1 ± 82.4	-5.772	0.001	0.187
Flexor WR	190.8 ± 83.0	179.6 ± 57.8	-0.098	0.922	0.006
Flexor WRBW	278.8 ± 110.4	259.1 ± 91.4	-0.568	0.570	0.009
Extensor WR	199.9 ± 98.0	162.8 ± 59.8	-2.129	0.033	0.053
Extensor WRBW	290.3 ± 130.7	232.9 ± 86.6	-2.826	0.005	0.066
Values at 30°/sec (Nm)					
Flexor PT	190.5 ± 39.1	177.6 ± 53.3	-1.470	0.141	0.017
Flexor PTBW	281.3 ± 55.4	252.1 ± 66.7	-2.561	0.010	0.050
Extensor PT	195.3 ± 58.3	140.9 ± 35.3	-6.177	0.001	0.254
Extensor PTBW	287.4 ± 79.7	203.5 ± 56.7	-6.302	0.001	0.277
Flexor WR	183.0 ± 62.2	169.0 ± 48.6	-0.923	0.356	0.016
Flexor WRBW	268.7 ± 80.0	244.9 ± 77.6	-1.682	0.092	0.022
Extensor WR	191.0 ± 91.0	144.6 ± 28.0	-2.509	0.012	0.122
Extensor WRBW	278.7 ± 119.5	210.0 ± 53.5	-3.419	0.001	0.134

All values represent mean ± standard deviation. CON, control group; NSLBP, nonspecific low back pain group; PT, peak torque; PTBW, peak torque % body weight; WR, work per repetition; WRBW, work per repetition % body weight.

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773 **Figure Legends**

774

775 **Figure 1.** Tensiomyographic rectus abdominis and erector spinae measurement scene

776

777 **Figure 2.** Isokinetic trunk flexor/extensor measurement scene

778

779 **Figure 3.** Correlation matrix of multiple variables across each row and column between TMG and
780 isokinetic measures. In A, a deeper shade of grey indicates a higher positive correlation (+1), while a shift
781 towards red hues suggests a negative correlation (-1) between TMG and isokinetic factors at 90°/sec. In B,
782 a deeper shade of grey signifies a higher positive correlation (+1), whereas a shift towards green hues
783 indicates a negative correlation (-1) between TMG and isokinetic measures at 30°/sec. Tc, contraction time;
784 Dm, maximum displacement; Ts, sustain time; Tr, relaxation time; Td, delay time; RA, rectus abdominis;
785 ES, erector spinae; PT, peak torque; PTBW, peak torque % body weight; WR, work per repetition; WRBW,
786 work per repetition % body weight.

787

788 **Figure 4.** Differences of Vc (contraction velocity) in rectus abdominis and erector spinae factors. CON,
789 control group; NSLBP, nonspecific low back pain; ***, $p < 0.001$ between groups.

790

791 **Figure 5.** Differences of trunk extensor / flexor peak torques' ratio at isokinetic 90°/sec and 30°/sec. CON,
792 control group; NSLBP, nonspecific low back pain; ***, $p < 0.001$ between groups.

793

Figure 1

Figure 1

Tensiomyographic rectus abdominis and erector spinae measurement scene
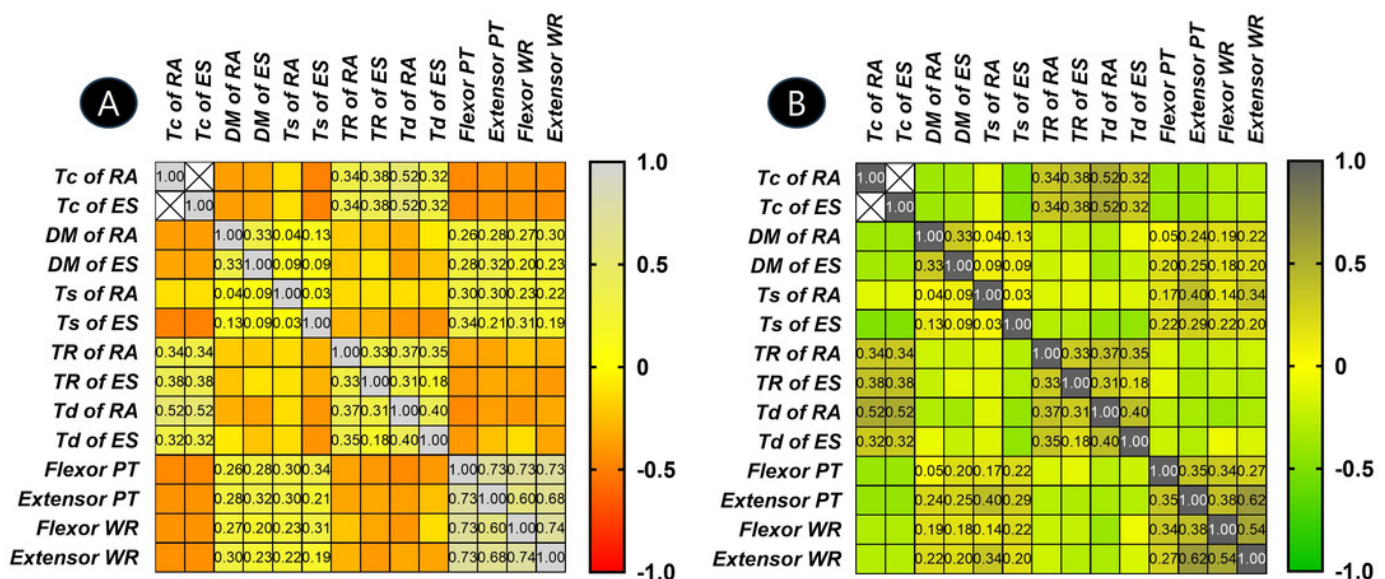
Figure 2

Figure 2

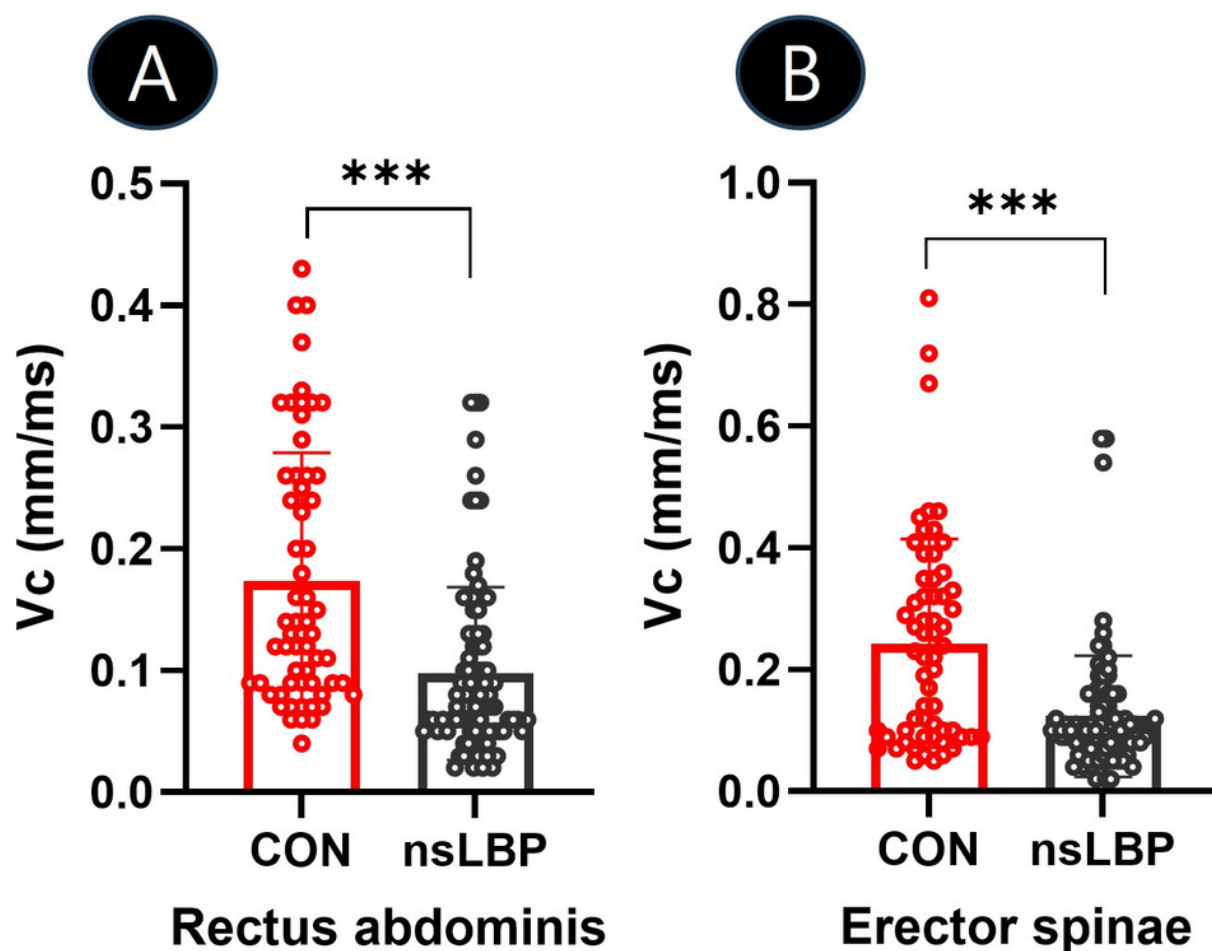Isokinetic trunk flexor/extensor measurement scene

Figure 3

Figure 3

Correlation matrix of multiple variables across each row and column between TMG and isokinetic measures. In A, a deeper shade of grey indicates a higher positive correlation (+1), while a shift towards red hues suggests a negative correlation (-1) between TMG and isokinetic factors at 90°/sec. In B, a deeper shade of grey signifies a higher positive correlation (+1), whereas a shift towards green hues indicates a negative correlation (-1) between TMG and isokinetic measures at 30°/sec. Tc, contraction time; Dm, maximum displacement; Ts, sustain time; Tr, relaxation time; Td, delay time; RA, rectus abdominis; ES, erector spinae; PT, peak torque; PTBW, peak torque % body weight; WR, work per repetition; WRBW, work per repetition % body weight.

Figure 4

Figure 4

Differences of Vc (contraction velocity) in rectus abdominis and erector spinae factors. CON, control group; NSLBP, nonspecific low back pain; ***, $p < 0.001$ between groups.

Figure 5

Figure 5

Differences of trunk extensor / flexor peak torques' ratio at isokinetic 90°/sec and 30°/sec.

CON, control group; NSLBP, nonspecific low back pain; ***, $p < 0.001$ between groups.