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Isometric osteopathic manipulation influences on cervical ranges of motion and correlation with Osteopathic palpatory diagnosis: a randomized trial

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Contributorship :

CN performed design of the study, literature search, data collection and analysis and interpretation. RB participated to data collection and processing, analysis and interpretation. PJA participated in supervision, design of the study and critical review. ME participated in data processing, literature search, analysis and interpretation. All authors drafted the work or revised the manuscript, approved the final version and agree to be accountable for all aspect of the work.

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2 **Journal:** Complementary Therapies in Medicine

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5

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7 **Isometric osteopathic manipulation influences on cervical ranges of motion and**
8 **correlation with Osteopathic palpatory diagnosis: a randomized trial**

9

10 **ABSTRACT:**

11 **Introduction:** isometric manipulation is a current practice in osteopathy and treatment
12 benefits have been reported in the literature. Such benefits could be assessed using
13 experimental non-invasive cervical mobility measurements. The main objective was to
14 quantitatively measure the effects of isometric manipulation on principal and compensatory
15 cervical motions.

16 **Methods:** 101 healthy volunteers were included in this study. 51 healthy volunteers selected
17 randomly underwent the experimental protocol before and after isometric treatment and were
18 compared to 50 healthy volunteers who underwent a placebo treatment. Osteopathic diagnosis
19 was performed on each healthy volunteer before and after the treatment. The experimental
20 protocol included measurements by a motion capture system focusing on principal range of
21 motion and compensatory motions.

22 **Results:** in both the isometric and the placebo sample, respectively including 51 (age:
23 29.2±8.1, BMI: 22.2±3.5) and 50 healthy volunteers (age: 27.4±6.8, BMI: 22.9±2.8), a pre-
24 treatment diagnosis revealed a light cervical dysfunction in all subjects, mainly in levels C3
25 and C4. Altered ranges of motion thresholds (C3/C4 alterations) were identified: 113.2° for
26 flexion, 130.0° for rotation and 90.2° for lateral flexion.

27 After manipulations, the volunteers who underwent the isometric treatment presented a slight
28 increase in amplitude for lateral flexion ($p<0.04$), which was not found in the volunteers who
29 underwent the placebo treatment. Compensatory motions showed differences pre and post
30 isometric treatment without reaching significant values.

31 **Conclusion:** principal ranges of motion were found significantly higher after osteopathic
32 treatment when compared to the placebo treatment. Osteopathic palpatory diagnosis showed
33 significant correlation with range of motions before treatment.

34

35 **Keywords: rotation, spine, range of motion, musculoskeletal manipulations, therapeutics**

36 **Abbreviation:**

37 CNS: central nervous system

38 ROM: range of motion

39 MET: Muscle Energy Techniques

40 FRS: Flexion Rotation Side-Bending

41 ERS: Extension Rotation Side-Bending

42 RSD Rotation Side-Bending

43 **Introduction**

44

45 The cervical spine can be divided into two areas: the inferior cervical spine (C3–C7) and the
46 superior cervical spine (C0–C2). According to Watier ¹, the range of motion (ROM) of the
47 spine can be assessed in relation to every axis of the Cartesian space and each functional unit
48 can be evaluated in terms of range of motion. The complex structure of the functional unit of
49 the spine is the cause of principal motion coupling resulting in compensatory motions and
50 which can be explained by the osteoarticular surface. This coupling relates to an axial rotation
51 combined with a lateral flexion. In the inferior cervical spine, according to the orientation of
52 the zygapophysial articulation, the cervical translation has to be associated with a homolateral
53 rotation and a slight extension ².

54 A cervical mobility dysfunction is related to an osteopathic mobility concept ³. The concept of
55 somatic dysfunction can be defined as the expression of the functional pathology of the
56 articular complex, which leads to a loosening or a restriction of the physiological articular
57 mobility. Similarly such concept is associated in osteopathic practice to a pathological motor
58 barrier. As such, any factor (articulations and/or myofascial structures) that limits or restricts
59 the free motion of an articulation in the circumscribed limits could be considered as a
60 pathological motor barrier.

61 In isometric manipulation, the osteopath opposes the cervical spine against the motor
62 pathological barrier of the tensed muscle. The principle of reciprocal inhibition can be
63 applied, as muscle contraction is associated with a freeing of the antagonist muscle ^{4,5}. Thus,
64 during the stretch, the stimulation of the neuromuscular spindle is optimal, while during
65 maximum shortening, the muscle is totally at rest ⁶. The central nervous system (CNS) is then
66 faced with a paradoxical situation. In order to protect the system, the CNS decreases the
67 gamma activity, which reduces the pathological motor barrier. As a result of this action, a
68 normal tonicity level is progressively reached, thus freeing the articulation and decreasing the

69 associated pain ⁷.

70 The two main spinal palpation motion techniques can be defined as: active motion palpation
71 when the patient is asked to perform cardinal plane motions, and passive motion palpation,
72 which can itself be classified into two types. On the one hand, passive physiological
73 intervertebral motion palpation is when a vertebra is moved in relation to the lower vertebra
74 within physiological range. On the other hand, the translation motions associated with
75 physiological motions for which the segmental mobility is considered are assessed during a
76 passive palpation through accessory intervertebral motions.

77

78 Literature reviews highlight the lack of work presenting reproducibility testing of spinal
79 motion palpation techniques when comparing intersegmental excursion ⁸ presenting a rather
80 limited number of good reliability results and their limitations ⁹.

81 Higher reproducibility in cervical spine palpatory diagnosis was measured by Schoensee et al.
82 on asymptotic subjects (kappa: $k=0.81$, $k=0.72$) and Smith et al. ($k=0.3$ to 1.0) for intra
83 reliability measurement and for inter reliability (kappa was found to be around 0.45
84 depending on cervical level and population sample ⁹). Acceptable reliability was found in
85 motion study (kappa= 58%) ¹⁰.

86 Cervicalgia is defined as pain in the cervical spine and could have traumatic, hernia or
87 arthrosis origin. Physical therapy is one of the main treatments of cervicalgia. Proof of the
88 benefits of cervical osteopathic treatment in the long term is limited regarding chronic
89 cervicalgia, regardless of therapeutic management ¹¹. The level of evidence linked to chronic
90 neck pain for long-term cervical manipulation is limited, regardless of therapeutic
91 interventions and follow-up ¹¹. Cervical mobility measurements are difficult to carry out in
92 practice, especially when they are needed to evaluate the effects of treatment ¹².

93 The quantitative assessment of the benefits of osteopathic manipulations is still limited. Range

94 of motion measurements of head to thorax have been reported ¹³while differences in
95 techniques used for these measurements as well as reproducibility and inter-observer
96 variability vary ¹.

97 In this work, the non-invasive range of motion, derived from head to torso motion
98 acquisitions by CodaMotion system, is quantified before and after osteopathic isometric
99 treatment. Additionally, palpatory osteopathic diagnosis is performed and the correlation with
100 quantitative ROM before treatment is tested.

101 This study aims to assess the impact of isometric manipulation on the ranges of motion and
102 compensatory motions using a technique for which reproducibility has been tested.

103

104 **Methods:**

105 ***Participants***

106 Recruitment: 101 volunteers were recruited after publicity by email and fliers at different
107 locations around the research center. The experimentation took place in a specific room
108 dedicated to experimentation on healthy volunteers in the laboratory. This experimental
109 setting room received the approval of the Agence Régionale de Santé for experimentation on
110 healthy volunteers (N°2017-5).

111 Inclusion criteria included the ability to sign a consent form, age between 18 to 60 years, no
112 medical history regarding cervical spine and general good health. Gender ratio was insured as
113 a whole during inclusion.

114 Subjects were excluded when over 60 years old, when unable to give their consent and
115 whenever they had medical history in cervical spine. Exclusion criteria defined as reported in
116 medical records included severe cervical pathologies, bone fractures or cervical pains,
117 cervico-brachial neuralgia, cardiac or vascular pathologies, pulmonary, cephalic and visceral
118 pathologies, pregnancy or medical treatment implying drug treatment longer than one
119 complete month.

120 ***Osteopathic palpatory diagnosis***

121 The mechanism of pathological restriction is called type II dysfunction « *FRS* » (« *Flexion*
122 *Rotation Side-Bending* ») with lateral flexion and homolateral rotation. In osteopathy, somatic
123 dysfunction is defined as expressing a functional disorder of the articulation which leads to an
124 alteration or a loss of physiological articular mobility and which is associated with muscular
125 compensation. When a vertebra is assessed with motion coinciding with “*Flexion, Right*
126 *rotation and side-bending: FRS right dysfunction*”, muscular tensions (contraction of cervical
127 muscles) of the right multifidus muscle or right multifidus transversospinal (engaging right

128 rotation) and inter-transverse muscle (engaging right lateral flexion) prevent its motion. This
129 leads to the incapacity to perform a reverse motion of “*Extension. Left Rotation and side-*
130 *bending: restriction of ERS left*”. The angular values available in the few studies found in the
131 literature seem to show such motion interactions.

132 An osteopathic palpatory diagnostic ¹⁴ of each participant was performed before and after
133 each treatment in order to match the ROM measurements detailed in the next section. This
134 diagnostic consisted in the assessment of vertebrae mobility by the osteopath ¹⁴. The
135 osteopath tested each cervical level and performed a palpation of the cervical spine to note
136 possible deviations of the neutral position and select a vertebral level presenting a local
137 muscular density. Manipulating the participant, the osteopath induced one of the vertebral
138 rotations compared to the neutral or altered position of the normal vertebral apophysis and
139 noted the change/response of the tested cervical level. The osteopath noted the change in
140 position compared to the neutral position in the sagittal plane. Three combined diagnoses
141 were performed on each cervical level: flexion/extension, rotation and lateral flexions.

142 Regarding the flexion/extension diagnosis, from the neutral position, the osteopath induced
143 flexion and extension motions to find the higher muscular resistance. Once this resistance was
144 found, the combined rotation and lateral flexion were induced on the left and right sides to
145 find the higher muscular resistance (E-RS right/left or F-RS right/left).

146 Additionally, yes/no questions regarding cervical discomfort were asked before and after
147 treatment to measure cervical discomfort improvement.

148 ***Experimental layout***

149 The experimental layout has been described previously¹⁵, when testing the range of principal
150 and compensatory motions in healthy volunteers along with the reliability of the measurement
151 ^{16,17}. Briefly, the setup included a headband on which four opto-electrical sensors were fixed

152 while the subject was seated and fixed on a specifically designed chair (hip flexion set a 90°,
153 lumbar support to promote physiological lordosis). The sensors placed on an hemlet (Figure
154 1B) were part of a motion capture system CODA motion (Charnwood Dynamics Ltd.,
155 Rothley, UK), also composed of 3 video cameras acquiring the location (Z axis defined as the
156 caudal-cranial direction, X axis defined as the medio-lateral direction on the subject's left and
157 Y axis in the antero-posterior direction) of the sensors at a frequency of 100Hz and with a
158 resolution of 0.1mm. A specific chair with adjustable and foot lumbar support was used to
159 avoid pelvis and scapular waits motions, set the hip flexion to a 90° positioning, promote
160 physiological lordosis and free cervical and thoracic spine positioning (Figure 1A).

161 *Descriptions of the osteopathic isometric manipulation and the placebo manipulation*

162 Selection of the subjects' treatment (isometric or placebo) was performed randomly using a
163 specific Matlab script for treatment selection based on a random number generation. The
164 practitioner has a standardized practice (6 years of practice).

165 Muscle Energy Techniques (MET), including isometric manipulation, are defined as an active
166 technique involving direct positioning and indirect action, using an isometric contraction
167 against resistance¹⁸⁻²⁰ and completed by a muscular stretch.

168 In such techniques, the dysfunctional vertebra is set against the pathological motor barrier,
169 successively reversing the flexion, rotation and the dysfunctional side, in the three directions
170 of space. The patient performs an isometric contraction further than the motor barrier, in the
171 direction of the altered parameters (flexion, rotation, side), against the clinician's resistance.
172 During the loosening phase, the clinician looks for the new motor barrier (in the three
173 directions), then the former process is repeated a minimum of three times. The clinician is
174 thus isometrically contracting one or several hypertonic muscles with various progressively
175 increasing constraints^{18,19}.

176 Isometric manipulation is an active technique in which an isometric contraction is performed
177 against resistance. It consists in positioning the dysfunctional vertebrae against the
178 pathological motor barrier and successively reversing the orientation of the dysfunction in the
179 three planes of the space. The patient performs an isometric contraction away from the motor
180 barrier towards the lesioned orientation against the osteopath's barrier. During the relaxation
181 phase, the osteopath identifies the new motor barrier (in the three planes) and repeats this
182 same procedure at least three times.

183 The placebo treatment consists in cervical muscular palpation without specific relaxation.

184 *Kinematic/data analysis*

185 Data analysis was performed using Matlab scripts (The Mathworks, Natick, Massachusetts,
186 USA). Briefly, principal motion amplitudes were defined as the maximum amplitude of the
187 angle measured between the initial sensor location and the final one. The angular variations of
188 the 4 sensor positions were measured in each plane projection (XY, XZ, YZ). The angular
189 variations of the sensors for the flexion-extension motions (sagittal plane), axial rotation
190 (transverse plane) and flexion (frontal), were measured for each acquired time step. For each
191 motion, maximum amplitudes as well as standard deviations for 5 similar motions were
192 computed to avoid false motions or effects related to subject weariness. Compensatory
193 motions were defined as maximum amplitude on the two other planes at the same time as the
194 associated principal motions (Figure 2).

195 *Statistical analysis*

196 Group comparisons were performed using the Wilcoxon test and the influence of parameters
197 was tested using the ANOVA test. MANOVA tests were used to identify influencing
198 parameters in terms of results. ROC curve analyses were also performed in order to identify

199 the threshold between normal function and C3/C4 dysfunction. All statistics were
200 implemented on R software.

201

202 **Results:**

203 The sample includes 44 men and 57 women, divided into two groups with similar age ranges
204 (29.2 ± 8.1 and 27.4 ± 6.8), displaying normal size and weight ranges. Description of each group
205 (control and treatment) could be found in Table 1.

206

207 ***Osteopathic diagnosis***

208 The osteopathic diagnosis resulted in the identification of a dysfunctional level of the cervical
209 spine in all volunteers except 4, 55 having chronic cervicgia and 42 displaying a cervical
210 pathology in the osteopathic diagnosis (cervicgia and/or cervical rigidity and/or restriction
211 of associated mobility, without cervical-brachial neuralgia) on the day of the protocol. The
212 characteristics and dysfunctions found for each sample (isometric manipulation and placebo)
213 are reported in table 1. Subjects presented similar subject characteristics. More C4
214 dysfunctions and more “*Rotation Side-Bending*” (RSD) were found in isometric group than in
215 placebo group.

216 The main dysfunctions were found for C3 and C4 and the consequences of cervical
217 dysfunction on principal and compensatory motions were measured during pre-treatment
218 (table 2, figure 2). Subjects with no dysfunction presented higher ROM for extension and left
219 lateral flexion without reaching significant level and depending of the dysfunction level.
220 Significant differences between groups of healthy volunteers diagnosed with osteopathic
221 dysfunction by level of dysfunction were found for compensatory motions only for transverse
222 flexion extension, frontal rotations and sagittal and transverse flexions.

223 The identification of a threshold for dysfunction through ROC curve analysis for C3 and C4
224 level dysfunction resulted in a threshold of 113.2° for flexion, 130.0° for rotation and 90.2°
225 for lateral flexion.

226

227 ***ROM pre/post-isometric treatment differences compared to the placebo treatment***

228 The difference in pre and post treatment for the isometric and the placebo treatments are
229 reported in table 3. 66.7% of the subjects treated with isometric manipulation techniques
230 reported pain improvement, while 40% of the subjects declared a reduction in pain after the
231 placebo treatment. Significant differences were found between pre and post isometric
232 treatments for general flexions ($p=0.3$) and lateral flexions ($p<0.001$). When oriented, only
233 lateral flexions differ significantly between pre and post isometric treatments ($p=0.04$ and
234 $p=0.008$). For the placebo treatment, significant differences were found between pre and post
235 treatments for rotations ($p=0.007$). Time of motion between pre and post treatments differed
236 for flexion in both the isometric and the placebo treatments ($p<0.001$), and for rotation in the
237 case of the placebo treatment ($p<0.001$). For compensatory motions, sagittal flexions were
238 found to differ between pre and post isometric treatments without reaching significant values.
239 Regarding the placebo treatment, frontal flexion and transverse flexions were found to be
240 different pre and post treatment ($p<0.01$).

241

242 ***Isometric treatment benefits on dysfunctional levels in volunteers***

243 Significant differences in ROM were found for sub-groups of volunteers who underwent
244 isometric treatment with a dysfunction at level C3 and C4 for lateral flexion motions
245 ($p<0.001$), which was also found for left lateral flexion for both sub-groups ($p=0.02$). The
246 MANOVA analysis shows that both flexion and rotation are significantly influenced by age,

247 while other subject characteristics have limited impacts on their range of motion ($p=0.009$,
248 $F=7.78$).

249

250 **Discussion**

251 The main findings of this work are:

- 252 1) Differences observed in compensatory motions in case of dysfunctions of the cervical
253 level and threshold identification based on the analysis of the ROM.
- 254 2) Significant changes in the ROM of the main lateral flexion motion following the
255 isometric treatment compared to the placebo treatment.

256 ***Quantitative assessment of the ROM in osteopathic diagnosis***

257 The main dysfunctional level identified by the osteopathic diagnosis in this study is C3-C4.

258 The quantitative measurements of compensatory motions show that the level of dysfunction
259 changes the motion strategy, particularly the lateral flexion motion (transverse and sagittal),
260 transverse flexions and frontal rotation motions. Such measurements of the ROM could help
261 in understanding the dysfunction mechanisms. The threshold of the C3-C4 dysfunction has
262 been identified (113.2° for flexion, 130.0° for rotation and 90.2° for lateral flexion) despite
263 the limitations of the dysfunctions measured, which were not reported as disabling.

264 The sample did not show significant dysfunctional levels and the healthy volunteers were able
265 to perform all the required motions without issues. These characteristics lead to effective
266 improvements in range of motion in our result, even though these improvements were only
267 moderate. This could be explained by the fact that the sample does not suffer from major
268 cervicalgia.

269

270 ***Benefits of the isometric manipulation and changes in motion strategies after treatment***

271 Performing the isometric manipulation on the treated sample lead to a significant increase of
272 the angular measurements as far as the extension motion and the left lateral flexion are
273 concerned ($p < 0.04$). For the placebo treatment, a reduction of the ROM in right rotation was
274 found ($p = 0.052$). Our study reported few placebo effects. Such effects can be noticed by the

275 increase in cervical mobility due to persisting muscular tension (as uncorrected). This tension
276 reduces mobility in order to protect the cervical spine and avoid lesions, while the isometric
277 manipulation frees cervical mobility. Further indices could also be found in the literature ²¹².

278

279 *Change in motion strategy after treatment*

280 Despite the quantitative measurement of compensatory motions, no significant differences
281 were found in the measurements before and after treatment. Let us note that the cervical
282 coupled motion strategy can be explained by the anatomy of inclination of the articular facet.
283 Such results are thus not able to prove that the impact of osteopathic corrections on a cervical
284 dysfunction leads to any change in the cervical mobility strategy. These results could be due
285 to the difficulty to reliably measure the compensatory motions that have been highlighted by
286 the differences between the placebo group and the treated group. The standard deviations of
287 the compensatory motion are significant: the reproducibility of compensatory motion
288 measurements can be questioned. Additionally, the possibility of identifying subject groups
289 with a similar motion strategy could be considered on a wider population segment. However,
290 on specifically identified and selected individuals, a compensatory motion strategy and, in
291 particular, the modification of such a strategy could be noticed (figure 2).

292

293 Before treatment, right rotation mobility could be noted, a small motion in the right frontal
294 plane (the subject is slightly engaging the associated right lateral flexion), while for the left
295 rotation, the subject is engaging significant mobility in the left frontal plane. Thus, rotation in
296 the transversal plane leads to compensatory motions in the two other planes of the space,
297 more or less quickly (compensatory lateral flexion either directly or at the end of the main
298 motion), as well as changes in amplitude (angular value lower). After treatment, an increase
299 was found in the angular amplitude for the right and left rotations (transverse plane maximum

300 motion: 62° before treatment and 69° after, right rotation: 76° and 78° before and after
301 treatment respectively). Additionally, a standardisation of the compensatory motion in the
302 sagittal plane and an increase in the compensatory motion for the right lateral flexion
303 associated with the right rotation in the frontal plane.

304

305 Thus, to perform the required motion, the subject could be using different cervical motion
306 strategies from one rotation to another. Compensatory motions, while difficult to repeatedly
307 measure, could add to the description of motion strategy when performing a simple motion
308 task. This could lead to the proof of the non-unicity of the motion strategy when following
309 similar instructions which is behind the point of the present study. Then identifying groups
310 with subjects displaying a similar strategy could accentuate the changes in ROM after
311 treatment.

312

313 *Limitations*

314 The variability of the measured motion could be due to the differences between the
315 experimental setup and the protocols for motion amplitude measurement in the cervical
316 spine²²⁻²⁵. In our study, the voluntary subjects had to assume an anatomical position of
317 reference assessed by the CodaMotion system and initialised before each acquisition.
318 Osteopathic palpatory diagnosis was performed only after randomized choice of treatment so
319 the level dysfunction could differ between the two studied groups. The subjects were blinded
320 to treatment vs control. Additionally, gender difference could be questioned in our study, as
321 the randomisation of the treated healthy volunteers lead to a smaller number of men in the
322 treated sample. The treatments were all performed by the same osteopath, so the variability of
323 the method with different osteopaths has not been tested.

324 The reproducibility of the compensatory motions measurement could be improved by adding
325 a sound timing reference and adding virtual reality device ²³. Additionally, identifying groups
326 to define motion strategy by clustering from principal ROM could reduce deviations of such
327 measurements.

328

329 **Conclusion**

330 The main cervical dysfunction level found in the osteopathic diagnosis was C3-C4 and the
331 compensatory motions (transverse flexion/extension, frontal rotations and lateral flexions)
332 associated with the subjects with this diagnosis were found to differ significantly from the
333 compensatory motions of subjects with other dysfunctions. This osteopathic palpatory
334 diagnosis enables to identify a ROM threshold for C3-C4 alteration.

335 Performing a myotensive osteopathic action on a subject enables to improve cervical mobility,
336 decrease the restriction and the associated pain. Further work is needed to prove a
337 modification in motion strategy of the cervical spine after treatment, as the motion was found
338 to be more uniform in the three directions of space, while the non-unicity of the motion
339 strategy must be highlighted (when following similar instructions). The measurement of
340 compensatory motions could contribute to quantifying the diagnosis (guiding the osteopath
341 towards a specific level) and the benefits of osteopathic techniques on a sample presenting
342 cervical spine pathologies. The benefit to patient with cervicalgia could then be expected in
343 defining what is a normal range of motion and what is not as well as associate quantitative
344 range of motion value to the osteopathic diagnosis.

345

346

347 **Conflicts of interest**

348 The authors have no conflicts of interest to declare.

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423 **Tables:**

424 **Table 1:** Healthy volunteer characteristics by treatment group.

	Isometric	Placebo	
Subject characteristics	Sample (Female)	51(35)	50(22)
	Age (y.)	29.2±8.1	27.4±6.8
	Weight (Kg)	64.4±13.2	68±11.4
	Size (cm)	170±8.5	172.1±9.1
	BMI (Kg/m ²)	22.2±3.5	22.9±2.8
	Lifestyle (no practice)	39(3)	43(7)
Dysfunctions	C2 blocked (%) (extension)	1(1)	0
	C3 blocked (%) (extension)	23(2)	24(6)
	C4 blocked (%) (extension)	22(2)	8(1)
	C5 blocked (%) (extension)	2(0)	4(0)
	C6 blocked (%) (extension)	3(1)	5(0)
	C7 blocked (%) (extension)	0	5(3)
	RSD	35	20
RSG	16	26	

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430 **Table 2-** Principal and compensatory motions associated with the osteopathic diagnosis.
 431 Dysfunction influence - p value depicted : *** depicted $p < 0.001$, ** depicted $p < 0.01$, *
 432 depicted $p > 0.05$, depicted $p < 0.1$
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	No dysfunction	C2	C3	C4	C5	C6	C7	
Sample (Female)	4	1	47	30	6	8	5	
Isometric sample	0	1(1)	23(2)	22(2)	2(0)	3(1)	0	
Placebo sample	4	0	24(6)	8(1)	4(0)	5(0)	5(3)	
Age (y.)	25.8±28	24	28.9±7.6	28.2±7.3	24.3±2.2	29.6±10	29±10.8	
Weight (Kg)	70.5±67	54	66.6±13.3	64.6±11.7	66.3±11.6	69±11.2	65.8±11.5	
Size (cm)	178.5±166.6	169	167.1±26.5	164.5±31.4	146.7±65.2	153.7±58	172.6±3.6	
BMI (Kg/m2)	21.9±22.4	18.9	22.3±4.7	21.6±5.1	19.3±8.7	20.4±8.1	22±3.5	
Principal ROM	Flexion (°)	63.2±64	51.8	64.8±13	66.8±12.6	68.1±5.8	60.8±12.2	66.2±12.9
	Extension (°)	-70±59.8	-62.1	-59.8±9.3	-59.9±9.3	-57.6±11	-65.3±7.6	-62.6±3.7
	Right Rot. (°)	69.1±70.3	72.2	71.2±8.4	71.4±8	68±9	70.5±9.8	75.6±6.6
	Left Rot. (°)	-71.9±73.6	-84.1	-74±8.5	-74.6±6.9	-74.7±13.5	-75.2±9	-74.9±5.8
	Right Incl. (°)	42.2±43.6	36.6	42.4±6	43.3±9	45.6±6.2	44.5±11.3	48.3±5.2
	Left Incl. (°)	-48.3±45.3	-46.8	-44.4±5.6	-46.1±8.8	-48.6±7.5	-43.2±8.1	-44.6±2.6
Compensatory motions	Trans Flexion/Extension (°)	2.9±0.1*	2.3	0.7±3.7	0±4.3	4.1±7.2	-0.5±4.6	-1.3±3
	Front Flexion/Extension (°)	-8±2.3	3.4	2.5±4.1	3.5±4.9	0.1±5.6	3.1±1.6	2.2±2.5
	Sag. Right/Left Rot. (°)	6.6±15.3	-8.9	20±21.4	19.1±13.9	6.7±7.6	10.3±19.5	19.6±10.3
	Front. Right/Left Rot. (°)	-2.8±17.1*	-2.7	18.6±17.1	19.8±15.1	24±11	21.4±16.6	14.1±16.6
	Sag. Right/Left Incl. (°)	1.3±2.1*	26.4	-0.7±7.2	-3.5±6.9	-3.5±8.7	-4.3±7	-2.3±9.2
Trans. Right/Left Incl. (°)	9.9±16.4**	50.6	17.8±11.8	13.5±12.3	17.5±10.2	15±12.6	18.6±21.1	

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436 **Table 3** - Pre/post isometric/placebo treatment - Range of principal and compensatory
 437 motions. Comparison pre and post: p values- *** depicted $p < 0.001$. ** depicted $p < 0.01$, *
 438 depicted $p > 0.05$, depicted $p < 0.1$

	Pre- Isometri c	Post- isometric	P (95% CC I)	Pre- placebo	Post- placebo	P (95% CC I)	
Discomfort (yes/no)	34(66,7%)			20(40%)			
Flexion (°)	64.3± 13.7	66.5± 14.9		66.1± 10.4	66.8± 10.7		
Extension (°)	-59.9± 9.3	-60.6± 10.1		-61.5±9	-60±8		
Right Rot. (°)	69.9±8.4	70.5±9.7		72.5±7.8	71.4±7.3	0.052 (-0.01; 2.66)	
Left Rot. (°)	-74.6± 8.9	-73.7± 8.9		-74.1± 7.3	-73.7± 7.3		
Principal ROM	Right Incl. (°)	42.5±8.1	43.4±7.1	0.04 (-1.83; -0.05)	44±6.8	43.6±7.5	
	Left Incl. (°)	-44.5± 7.6	-46.4±7	0.008 (0.32; 2.97)	-46.1± 5.9	-46.7± 5.9	
	Flexion/extension (°)	124.2± 19.7	127.1± 20.1	0.03 (-5.2; -0.34)	127.6±1 3	126.7± 12.6	
Rotations (°)	144.5± 14.7	144.3± 16.3		146.6± 13.2	145.1± 11.6	0.007 (0.6; 3.04)	
Lateral flexions (°)	87±13.6	89.8±13	<0.001 (-3.89; -1.27)	90±11.1	90.4± 11.5		
Compensatory motions	Trans Flexion/Extension (°)	0.6± 5.38	0.81± 4.68		0.02± 4.22	1.05±4.4	
	Front Flexion/Extension (°)	2.87± 8.08	0.78± 7.68		4.13± 9.37	0.9±7.29	0.02 (0.43; 6.01)
	Sag. Right/Left Rot. (°)	29.95± 31.64	22.59± 36.25		15.23± 34.2	16.09± 24.98	
	Front. Right/Left Rot. (°)	-1.92± 8.6	-3.57±8.77		-1.07± 8.66	-2.82± 10.05	
	Sag. Right/Left Incl. (°)	1.17± 9.17	-0.26± 8.54	0.058 (-0.07; 2.88)	-0.58± 9.22	0.4±9.93	
Trans. Right/Left Incl. (°)	24.43± 21.5	25.23± 20.31		28.44± 20.19	26.35± 21.21	0.01 (0.77; 4.72)	
Mean Time Flex/Ext	388.3± 79.3	344.3± 84.2	<0.001 (28.07; 60.33)	377.1± 82.8	320.8± 75.4	<0.001 (32.75; 73.04)	

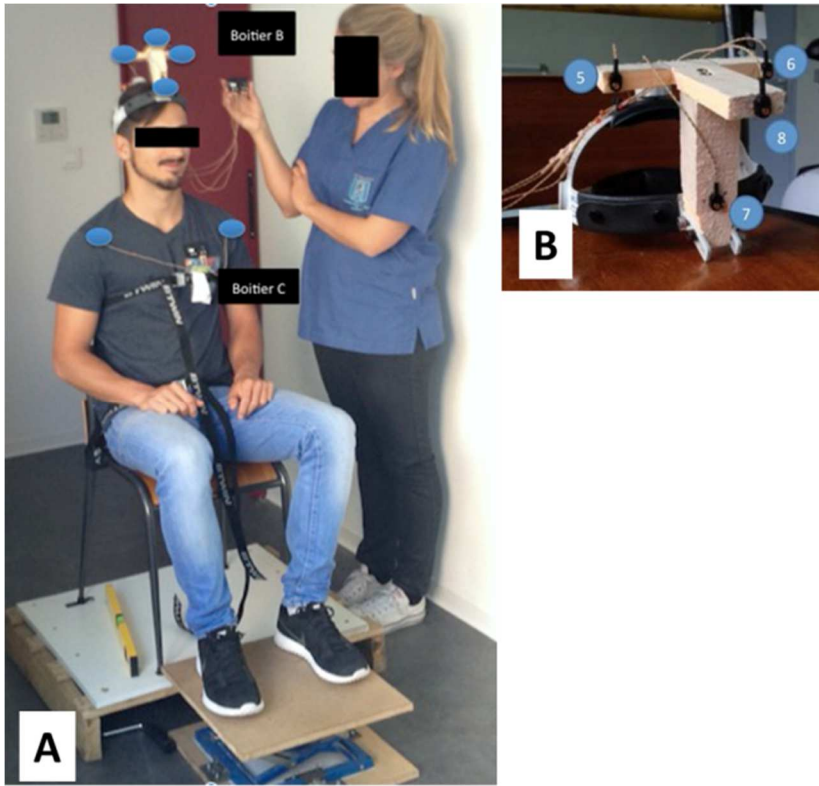
Mean Time Rot	312.7± 75.4	303.4± 83.6	293.7± 62.5	272.2± 60	<0.001 (13..36; 32..22)
Mean Time Incl.	299.2± 69.3	293.8± 72.1	284.1± 67.6	277.8± 66.1	

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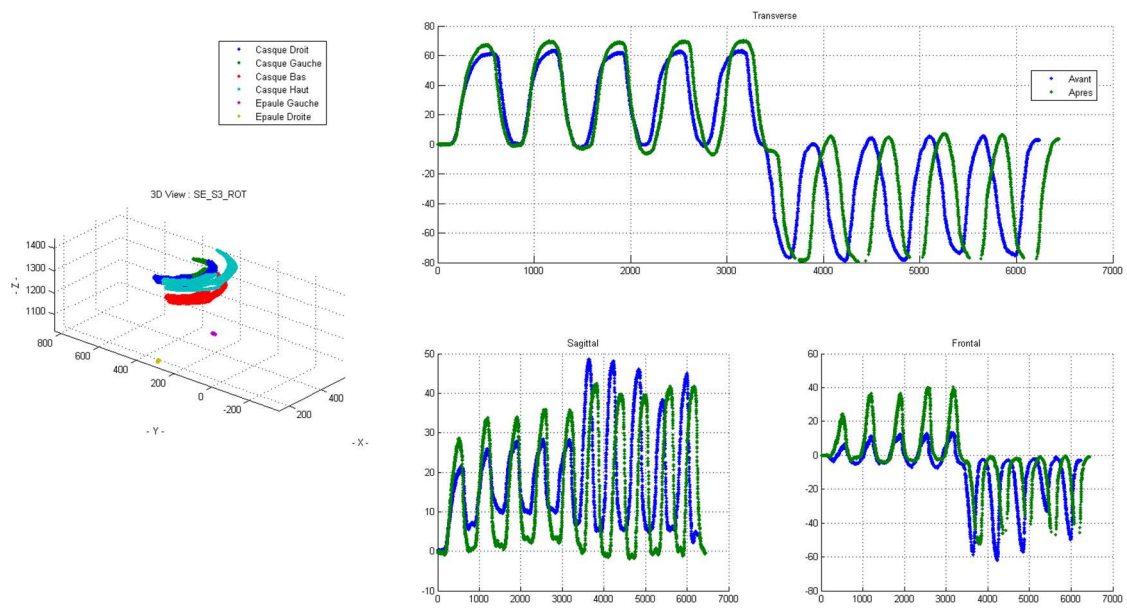
441 **Figures**

442 **Figure 1:** Acquisition setting and helmet with sensor used during the test.
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445 **Figure 2:** right and left rotations before and after osteopathic treatment.



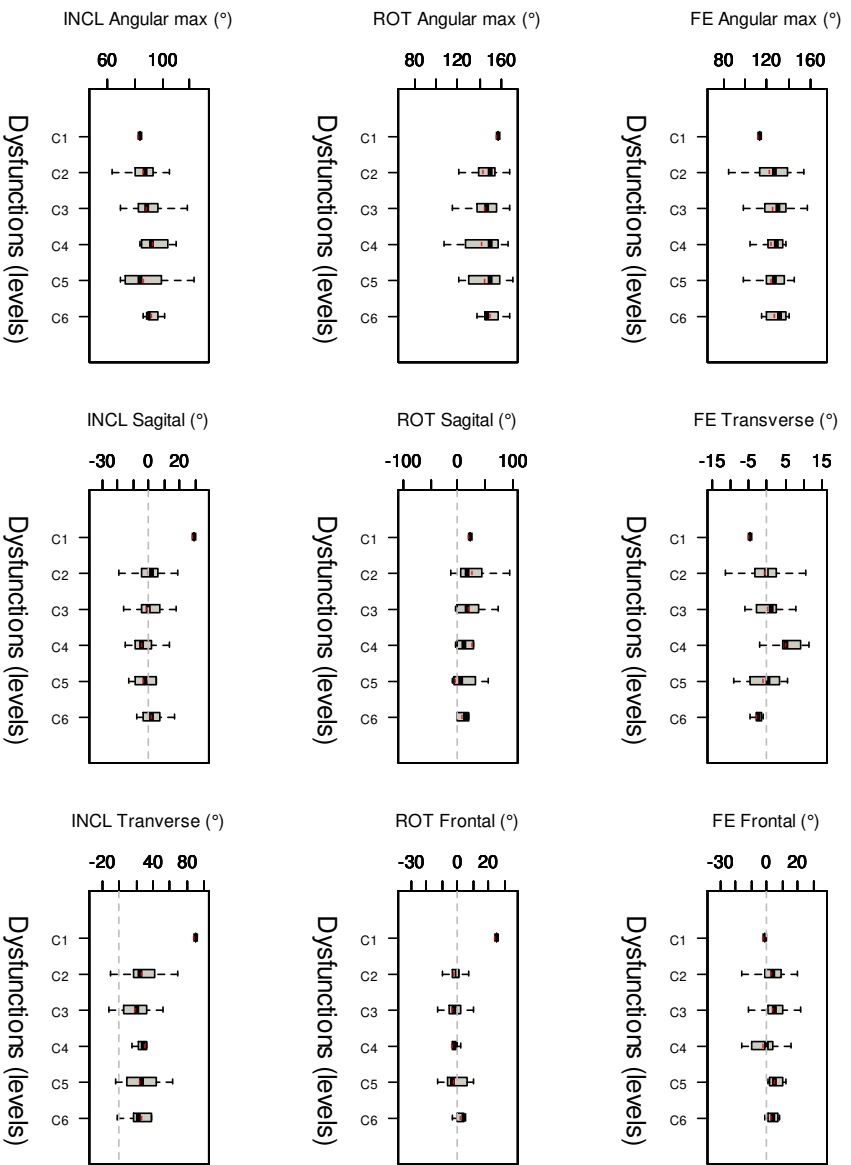
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450 **Figure 3:** principal and compensatory ranges of motion and compensatory motions according
 451 to levels of dysfunction and sample groups (healthy vs. pathological)
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