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Effects Of Pre-Competitive Preparation Period On The Isokinetic Muscular Characteristics In World Class Handball Players

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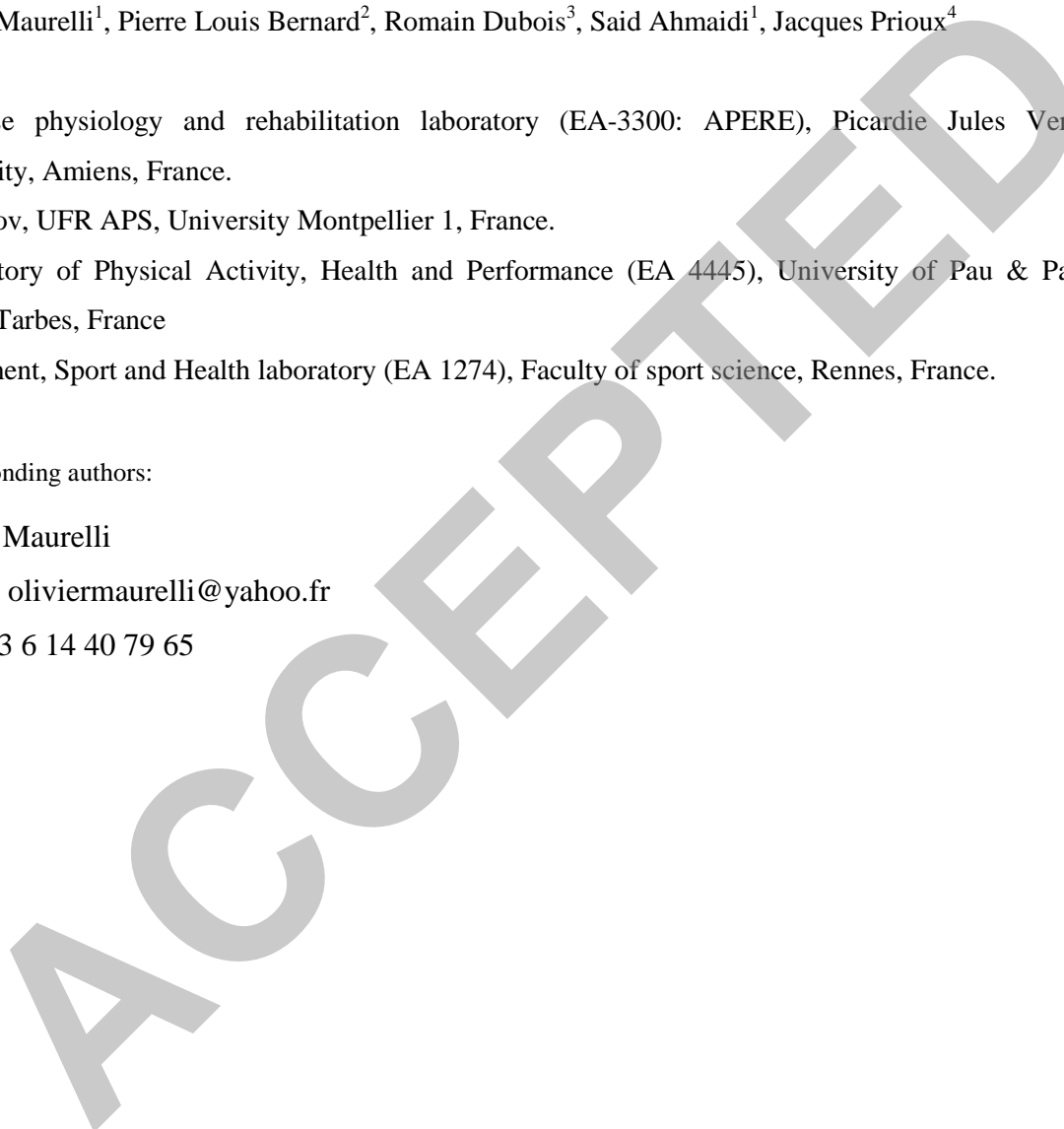
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Abstract

The aim of this study was to describe the effects of eight weeks of pre-competitive period preparation (Pc2P) on the isokinetic muscular characteristics in world-class handball players. Nineteen male professional players (age: 26.6 ± 5.4 years) participated in the study. Two bilateral isokinetic tests of knee joint flexors (H; Hamstring) and extensors (Q; Quadriceps) were performed before and after Pc2P to determine the peak torque (PT), the mean power (MP) and the ratios (agonist/antagonist, dominant/non-dominant and combined). For the PT, Q at low angular velocity ($60^\circ.s^{-1}$) in concentric mode revealed no significant increase for the dominant nor non-dominant legs. For H, results showed a significant increase for both legs ($p < 0.001$). At the higher angular velocity ($240^\circ.s^{-1}$), Q was significantly increased for the dominant ($p < 0.005$) and non-dominant legs ($p < 0.002$) as well as H for both sides ($p < 0.001$). Eccentric mode ($30^\circ.s^{-1}$) showed a significant increase for dominant ($p < 0.005$) and non-dominant legs ($p < 0.01$). For MP, results showed significant increase at low angular velocity ($p < 0.003$) and high angular velocity ($p < 0.01$) for both legs. In eccentric mode, values showed a significant increase following Pc2P for dominant ($p < 0.001$) and non-dominant legs ($p < 0.02$). The ratios showed significant increase for the agonist/antagonist ratio (AAR) at $60^\circ.s^{-1}$ for dominant leg ($p < 0.003$) as well as the non-dominant leg ($p < 0.01$). At $240^\circ.s^{-1}$ the values showed a significant difference for both side ($p < 0.02$). From an injury risk perspective, in addition to optimizing performance, these results demonstrated that eight weeks of Pc2P increased the maximum strength and muscle power of international handball players, even if the ratios of the knee joint muscles did not change during this period.

Key words: elite handball; muscular profile of the lower limbs; preseason period.

28

29 INTRODUCTION

30 Handball is played by two teams of seven players on a court measuring 40 by 20 meters
31 during matches of two periods lasting 30 minutes. The average actual play time is $52.36 \pm$
32 5.92 minutes for an elite men's team (41) with field players moving for more than 60% of the
33 total playing time with an average distance of 4370 ± 702 m (44). Their activity consists of a
34 succession of actions such as jumps, sprints, offensive and defensive duels, shooting, and
35 changes of direction which are followed by random recoveries (35,40,45). These actions place
36 high neuromuscular demand on the body, primarily on the lower limbs, and are repeated
37 throughout the match; therefore, they are critical to performance (35).

38 Actions like duels require the production of maximum strength, whereas others, such as
39 explosive actions, require a high rate of strength development and power (27) with
40 contraction times of less than 250 ms (2). Given the demand on the lower limb neuromuscular
41 system, the investigation of knee muscle functioning adaptations in handball players is
42 necessary (14). To assess these adaptations, several tests exist such as the one-repetition
43 maximum (1-RM) test, vertical jump tests (squat jump or counter movement jump),
44 electromyography assessments (EMG) and isokinetic testing. EMG and isometric test
45 measurements from Thorlund et al. (51) have found that muscle and joint stress in elite
46 handball players are side effects of fatigue following a game. Compared to others, the
47 isokinetic dynamometer provides valid and reproducible measurements (7,12) to assess knee
48 joint strength (13,34). Although the isokinetic device was initially utilized for muscular
49 rehabilitation (11), it has become a reference for the exploration and research of strength as
50 well as injury prevention in sports (9,15,20,22,34). Few studies have used an isokinetic
51 dynamometer in handball players. Gonzales-Ravé (26) and Holm (31) have analyzed
52 muscular profiles in elite male and female handball players to study isokinetic strength in
53 order to optimize performance (26) and to prevent the cruciate ligaments rupture, respectively

54 (31). A handball season consists of two distinct periods : a pre-competitive preparation period
55 (Pc2P) of six to eight weeks and a competition period of nine months (10,28,29). Pc2P
56 usually focuses on developing technical and tactical skills in addition to the physical qualities
57 needed to optimize performance for the competitive period (6). Pc2P also provides insight
58 into the repeated stresses on muscles, which occur throughout the season and result in fatigue
59 setting in gradually (24). In team sports, few authors have studied Pc2P. Although certain
60 studies have analyzed the physical and physiological changes in competitive soccer
61 (24,33,46) and rugby players (6), few studies have referred to changes in isokinetic strength
62 values in the lower limbs. Only Orchard et al. (43) specifically analyzed the changes in peak
63 torque (PT) and the strength of quadriceps (Q) and hamstrings (H) in Australian soccer
64 players. To date, no studies have investigated the effects of Pc2P on muscle adaptations in
65 world-class handball players. However, the monitoring of isokinetic strength and muscle
66 power before and after Pc2P, through the measuring of PT and mean power (MP) of Q and H,
67 could be used to illustrate its effects in handball players and to reorient if necessary training
68 methods during this time. Furthermore, the analysis of available dominant/non-dominant
69 (DNDR), agonist/antagonist (AAR) and combined ratios (CR) would accurately assess the
70 muscular characteristics of each player, permitting injury prevention. The aim of our study
71 was then to analyze the effects of a Pc2P, with duration of eight weeks, on the isokinetic
72 muscle profile of the lower limbs in world-class handball players. We hypothesized that Pc2P
73 would be an appropriate period to develop the isokinetic muscular performance, allowing
74 athletes to begin the competitive period with optimized strength and power levels.

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77

78

79 **METHODS**

80 *Experimental approach to the problem*

81 To achieve the purpose of our study, the handball players were monitored before and
82 after Pc2P. All subjects were familiar with the isokinetic tests. Before and after Pc2P, these
83 tests were always carried out at the same time of the day and in the same order for all the
84 subjects. On the day of evaluation, after a standardized breakfast for all studied players,
85 measurements of body mass and fat free mass were carried out. Afterwards, the subjects then
86 performed an isokinetic test.

87 Pc2P lasted eight weeks and was organized to optimize performance at the end of this
88 period (Figure 1). The cardio-respiratory function was the main focus of 16 sessions (17.8%
89 of the total volume) on the whole of Pc2P. The training included three separate phases (Table
90 1). The first phase, with a duration of two weeks, focused on aerobic capacity development
91 (65-80% of maximum heart rate (HRmax)) began (i) with continuous training sessions and
92 (ii) ended with fartlek sessions. During the first phase, subjects performed three sessions per
93 week. The second phase of cardio-respiratory training, with a duration of four weeks, focused
94 on maximum aerobic power development (85 to 100% HRmax). This phase was based at the
95 beginning on long and medium interval training and at the end on short interval training.
96 During this phase, subjects performed two sessions per week. Finally, during the two-week
97 third phase of cardio-respiratory training, subjects performed only one session of maximum
98 sprint training with a short recovery.

99

100 *** FIGURE 1 HERE ***

101

102 *** TABLE 1 HERE ***

103

104 The technical and tactical training aspects of handball received the most attention with
105 46 sessions, accounting for 51.1% of the training volume of Pc2P. A psychomotor emphasis
106 during these sessions allowed for the improvement of the general and specific motor skills of
107 handball player (coordination, agility, lateralization, segmental dissociation). This focus
108 represented 11 sessions for 12.2% of the total volume. Finally, muscle strengthening was also
109 utilized during 17 sessions (Table 2), with 18.9% of the total training volume of Pc2P. During
110 the first two weeks of training, focused on endurance of strength, the intensity of the lower
111 limb strength training ranged from 40 to 60% of one-repetition maximum (1-RM). Three
112 sessions per week were dedicated to this training. In the next phase of a duration of four
113 weeks, focused on hypertrophy and maximal strength, the intensity of lower limb strength
114 training intensities was 70 to 90% 1-RM. During this phase, players made two sessions per
115 week. The number of sessions was deliberately limited to two per week, in order to account
116 for the training load in handball, which emphasizes in particular the use of the lower body. In
117 the final two-week phase, focused on power, players dedicated to weight training
118 characterized by a intensity from 50 to 60% 1-RM at the rate of two sessions per week.

119

120 ***

TABLE 2 HERE

121

122 **Subjects**

123 Nineteen male handball players, either French or foreign and belonging to the
124 professional league 1 (France), were recruited for the study. The players had a training
125 experience (7.6 ± 1.3 years) of the highest level of expertise in France. Mean values (\pm SD) of
126 age, height, weight and body fat were respectively 26.6 ± 5.4 years, 189.5 ± 5.1 cm, $91.8 \pm$
127 12.5 kg and $10.2 \pm 2.2\%$. Inclusion criteria were the following: being a male and being under
128 contract for a minimum of three years. The exclusion criteria were chronic or acute diseases

129 of the knee and/or lower limbs and pain in the knee and/or lower limbs at testing,
130 contraindicating maximal concentric and eccentric exercise. All subjects have written
131 informed consent to participate in the experiment in accordance with the Declaration of
132 Helsinki. The study protocols were approved by the Ethics Committee of the local university
133 and were carried out in agreement with the head doctor and validated by the medical
134 committee of the club.

135

136 **Procedures**

137 *Isokinetic tests*

138 Subjects were evaluated using a Biodex Isokinetic Dynamometer 3® System (Biodex
139 Corporation, Shirley, NY) with gravity correction. Two bilateral tests of knee joint flexors
140 (H) and extensors (Q) were performed before and after Pc2P in concentric and eccentric
141 mode. The warm-up and set-up procedure for the subjects were the same prior to and
142 following Pc2P. Before the tests, the subjects warmed-up on a cycle ergometer for five
143 minutes by cycling against a load of 60 watts (W) at 90 rotations.min⁻¹. This warm-up was
144 followed by active dynamic stretching of the psoas, Q, H and gastrocnemius muscles. The
145 range of motion during the test was 70°, from -10° to 60° angle, between the femur and the
146 tibia to limit hamstring resistance during the extension. The length of the lever arm was
147 individually determined, depending of the height of each players and the resistance pad was
148 placed two fingers above the medial malleolus. The tests were carried out bilaterally in a
149 sitting position with a hip flexion angle of 110°, a trunk and waist strap, and the upper limbs
150 crossed on the trunk. Each subject was placed in a comfortable position that did not limit knee
151 movement. The height and depth of the seat relative to the dynamometer's rotational axis and
152 the length of the lever arm relative to the rotational axis were stored in the computer program

153 (Biodex Medical, Inc.) to standardize the test's conditions. During testing, subjects were
154 verbally encouraged by the same experimenter and gripped the sides of the seat for support.

155 Each test was preceded by a standardized warm-up of two sets of five repetitions at $60^{\circ}.s^{-1}$
156 ¹ in concentric mode separated by one minute of recovery, following the three minutes of the
157 initial cycling warm-up. The protocol started with an evaluation in the concentric/concentric
158 modes on the dominant leg, beginning with a series of five repetitions at $60^{\circ}.s^{-1}$, followed by
159 one minute of recovery, then a new series of five repetitions at $240^{\circ}.s^{-1}$. After one minute of
160 recovery, evaluation of H at $30^{\circ}.s^{-1}$ in eccentric mode concluded the first part of the test.
161 During the following five-minute recovery, the subjects were set up for evaluation of the non-
162 dominant leg following the same procedure (47).

163 The values of PT and the MP, expressed in absolute values and normalized by body
164 weight, were used to calculate DNDR and AAR at $60^{\circ}.s^{-1}$ and $240^{\circ}.s^{-1}$ in concentric mode. In
165 addition, the evaluation in eccentric mode allowed us to calculate CR from the H values
166 measured at $30^{\circ}.s^{-1}$ in eccentric mode and the Q values measured at $240^{\circ}.s^{-1}$ in concentric
167 mode.

168

169 *Testing one-repetition maximum (1-RM)*

170 The one-repetition maximum test was measured after a standardized warm-up, which
171 began with cardio-respiratory activation (aerobic capacity training at 70-75% of HRmax) and
172 then an articular mobilization of lower limbs (ankles, knees and hips). Subsequently, subjects
173 began with two sets of 8-10 repetitions at 50% and 60% of 1-RM. Following this, subjects
174 then performed successive 1-RM starting at about 75% of 1-RM and increased by 5% until
175 reaching 1-RM. There was a rest interval of two to three minutes between the sets. Each
176 subject had two attempts on the last performance to be executed (5).

177

178 *Testing maximal aerobic velocity (MAV)*

179 The 20 meters shuttle run test was originally designed by Leger and Lambert (38). The
180 test is based on the completion of repeated shuttle runs between two lines placed 20 meters
181 apart. The running speed is incremental and dictated by audio signals from a tape recorder.
182 The aim of the test is to complete as many shuttle runs as possible.

183

184 *Anthropometrics measures*

185 Body mass was measured with the players wearing light indoor clothing and no shoes,
186 using a Tanita Body Composition Analysis (TBF-3000) (Tanita Corporation, Tokyo, Japan).
187 Percentage of fat mass was estimated from four skinfolds thicknesses (biceps, triceps, sub-
188 scapular, and supra-iliac), according to the method of Durnin and Rahaman (19). Fat free
189 mass (FFM) was estimated as the difference between measured body mass and estimated
190 body fat.

191

192 **Statistical analyses**

193 All data is presented as means \pm standard deviation (SD). After conducting a test of
194 normality, the non-parametric Wilcoxon test for paired data was used to analyze the influence
195 of Pc2P on PT, MP, DNDR, AAR and CR. The significance level was set at $p < 0.05$. When
196 significant differences were found, effect size (ES) was assessed from the Cohen's d. ES of
197 0.20-0.60, 0.61-1.19 and ≥ 1.20 considered small, moderate and large respectively (32).

198

199 **RESULTS**

200 *Peak torque*

201 In concentric mode at $60^\circ \cdot s^{-1}$, the comparison of PT before and after Pc2P showed no
202 significant difference in Q for the dominant and non-dominant legs. For H, PT increased
203 significantly for both legs ($p < 0.001$). At $240^\circ \cdot s^{-1}$, the results showed that Q was significantly

204 increased for the dominant ($p < 0.005$) and non-dominant legs ($p < 0.002$) as well as H for
205 both sides ($p < 0.001$). In eccentric mode at $30^\circ \cdot s^{-1}$, results showed a significant increase for
206 dominant ($p < 0.005$) and non-dominant legs ($p < 0.01$) (Figure 2). The Cohen's d. ES were -
207 0.35 (small) in H for dominant and -0.25 (small) for non-dominant legs at $60^\circ \cdot s^{-1}$. At $240^\circ \cdot s^{-1}$,
208 ES were -0.27 (small) and -0.34 (small) respectively for Q for dominant and non-dominant
209 legs. For H, ES were -0.48 (small) for dominant and -0.44 (small) for non-dominant legs. At
210 $30^\circ \cdot s^{-1}$ in eccentric, for H, ES were -0.27 (small) for dominant and -0.21 (small) for non-
211 dominant leg.

212

213 ***

FIGURE 2 HERE

214

215 *Mean power*

216 In concentric mode at $60^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$ our results showed a significant increase of
217 Q for the dominant side ($p < 0.003$) and non-dominant side ($p < 0.001$). For H, the values
218 showed a significant increase for dominant side ($p < 0.001$) at $60^\circ \cdot s^{-1}$ and $240^\circ \cdot s^{-1}$. For non-
219 dominant side, our results showed a significant increase ($p < 0.003$) at $60^\circ \cdot s^{-1}$ and ($p < 0.01$)
220 at $240^\circ \cdot s^{-1}$. In eccentric mode, we observed a significant increase in MP of H for the dominant
221 ($p < 0.001$) and non-dominant legs ($p < 0.02$) (Figure 3). At $60^\circ \cdot s^{-1}$ the Cohen's d. ES were -
222 0.26 (small) in Q for dominant leg and -0.24 (small) for non-dominant leg. For H, ES were -
223 0.30 (small) for dominant and -0.14 (small) for non-dominant leg. At $240^\circ \cdot s^{-1}$, ES were -0.24
224 (small) for Q for dominant leg and -0.23 (small) for non-dominant leg. For H, ES were -0.29
225 (small) for the dominant leg and -0.17 (small) for the non-dominant leg. At $30^\circ \cdot s^{-1}$ in
226 eccentric, for H, ES were -0.29 (small) for dominant leg and -0.17 (small) for non-dominant
227 leg.

228

229 ***

FIGURE 3 HERE

230

231 *Dominant/non-dominant, agonist/antagonist and combined ratios*

232 At $60^{\circ}.s^{-1}$ and $240^{\circ}.s^{-1}$, the results for DNDR in concentric mode showed no
233 significant change for both legs. Our results for AAR showed significant difference at $60^{\circ}.s^{-1}$
234 for dominant leg ($p < 0.003$) and non-dominant leg ($p < 0.01$). At $240^{\circ}.s^{-1}$ values showed
235 significant difference for both legs ($p < 0.02$). Lastly, CR showed no significant change
236 (Table 3). The Cohen's d. ES for AAR at $60^{\circ}.s^{-1}$ were -0.32 (small) for dominant leg and -
237 0.08 (small) for non-dominant leg. At $240^{\circ}.s^{-1}$, ES were -0.45 (small) for dominant leg and -
238 0.16 (small) for non-dominant leg.

239

240 ***

TABLE 3 HERE

241

242 **DISCUSSION**

243 This study set out to investigate the influence of Pc2P on the isokinetic muscular
244 characteristics of the knee joint in world-class handball players. The results showed a
245 significant impact of Pc2P on the development of MP in Q and H in concentric mode for the
246 two velocities (60 and $240^{\circ}.s^{-1}$) and for both legs. The Pc2P effects were slightly more limited
247 in Q, since no increase in PT was observed in concentric contraction at $60^{\circ}.s^{-1}$ for the
248 dominant and the non-dominant leg.

249 These results can be explained in different ways. Firstly, the duration of Pc2P (eight
250 weeks) appeared to be sufficient to induce a significant improvement in the majority of
251 strength and power values of H, and to a lesser extent of Q. Secondly, these results may be
252 explained by the Pc2P training, as a relatively large share of training sessions (18.9%) were
253 dedicated to building muscle. The gain in strength and power after Pc2P may also be
254 explained by the muscle deconditioning in these world-class handball players during the five

255 weeks of training interruption preceding Pc2P. Indeed, Marquez and Badillo (39) indicated a
256 significant decrease in the strength of handball throws after seven weeks of training
257 interruption and Andersen et al. (3) reported lower isokinetic strength in sedentary adults after
258 a 12-week period of inactivity. The significant increases noted above were observed despite
259 the need to manage the optimal development of both strength and endurance qualities
260 alongside technical and tactical sessions (51.1%) as well as preparation matches (n = 8) that
261 coincided with Pc2P. The effects of the concurrent development of these two major muscle
262 functional qualities have also been the subjects of several studies. Some studies have shown
263 that strength gains are inhibited by the addition of endurance training sequences
264 (18,30,48,50), mainly due to a physiological interference between two signaling pathways.
265 One pathway stimulates growth factors like IGF-1, thereby optimizing protein synthesis and
266 thus the increase in strength and hypertrophy: mTOR (mammalian/mechanistic target of
267 rapamycin). The other stimulates the metabolism of carbohydrates and fatty acids: AMPK
268 (metabolic activated protein kinase) (23), which inhibits mTOR and thus limits these training
269 responses (17,42). To limit the negative effects of concurrent training in strength and
270 endurance, a recent literature review (25) recommended not exceeding two to three endurance
271 sessions per week, avoiding long-term running, and always placing the power session before
272 the endurance session. These potential interferences may explain in part the lack of significant
273 change in the low angular velocity strength values for Q and not for H. H was not impacted
274 by these interferences thanks to regular sessions that included muscle strengthening of the
275 posterior chain, and also by multiple positions of knee flexion found in handball.

276 The reduction of the number of strengthening exercises involving the anterior muscle
277 chain in the thighs might be another possible explanation. We adapted the session contents
278 and indirectly favored limited loading on Q, as this muscle group is already highly solicited in
279 handball. The results are consistent with the previous studies. Reilly and Thomas (46) showed

280 that a six-week Pc2P did not significantly improve strength in the knee joint muscles of
281 soccer players, while Dudley and Djamil (18) observed a significant improvement in muscle
282 strength in the knee joint in a population of trained men and women, but only at high angular
283 velocity.

284 Pc2P is a complex period, and training programs are dictated by the demands of the
285 sport. Physical qualities will be developed according to the priorities set. Yet overall, too few
286 studies have investigated the Pc2P influence on knee strength gains (33) and further studies
287 are needed. The significant increase in PT of H and Q at high angular velocity ($240^{\circ} \cdot s^{-1}$) can
288 be explained by the repetition of explosive actions in handball (35). Compared with other
289 team sports such as rugby, handball training includes a high number of different types of
290 practice sessions (including technical and tactical play as well as game on a half-sized court)
291 from the first week of Pc2P for players to improve their specific motors skills, such as passing
292 and shooting. A professional team, mainly composed of international players, participated in
293 46 handball-specific sessions during Pc2P. In each session, many actions were executed at
294 high intensity. The study carried out by Behm and Sale (8) found that the greatest strength
295 gains were observed at velocities close to the training velocity. These results observed at high
296 intensity reported that the significant effects on the isokinetic strength expressed at high
297 angular velocity are due to the combination of strength training sessions and specific activity
298 sessions of Pc2P (21). The results of our study were, however, more pronounced for the
299 power values, which are in agreement with the training program (Table 1). During Pc2P, the
300 objective was primarily to develop power indices and not maximal strength. This objective is
301 in agreement with the need for movements at high angular velocities in most team sports
302 practiced at the highest level. These movements are systematically repeated during matches,
303 especially during sprints involving the knee joint at velocities in the range of $600-700^{\circ} \cdot s^{-1}$
304 (48). Regular high-speed segmental movements during handball activity support the motor

305 adaptations at high velocities (21).

306 Pc2P is also a key period for strengthening vulnerable muscle groups. In order to
307 prevent injury, H strengthening is systematically included in the strength-building sessions.
308 This may explain the significant increase in PT of H at low angular velocity ($60^{\circ} \cdot s^{-1}$).
309 Furthermore, the significant increase in PT found at $30^{\circ} \cdot s^{-1}$ in eccentric mode was likely due
310 to the development of injury prevention routines during this period. Indeed, the mechanical
311 needs of this muscle group, regularly constrained by the stretching phase during sports
312 practice, constitute one of the justifications for the observed improvements in eccentric mode.

313 The constant need to optimize performance necessarily requires consideration of
314 individual muscular characteristics and the assessment of how training influences muscle
315 balance in the knee (1,4,13,34,37). For DNDR, our results showed no significant changes. In
316 the early phase of Pc2P, the ratio was already good, as demonstrated by a value close to 1.0. It
317 is therefore normal that the ratio would not change in eight weeks. These results also indicate
318 that handball does not significantly affect major imbalances between the dominant and non-
319 dominant legs, even though handball players preferentially use the same leg when throwing.
320 For the notion of agonist/antagonist balance, represented by the AAR, at $60^{\circ} \cdot s^{-1}$ for dominant
321 leg ($p < 0.003$), non-dominant leg ($p < 0.01$) and at $240^{\circ} \cdot s^{-1}$ for both side ($p < 0.02$), the Pc2P
322 favors a significant increase. Nevertheless, the little changes near the reference values, from
323 0.6 at low velocity to 0.7 at high velocity, limits the interpretation of the data (14,20).
324 Duration of Pc2p appears too short to expect changes in muscle balance or lead to
325 physiological adaptations.

326 Regarding these two ratios, some authors (14,16,36) have critiqued their use due to
327 their distance from functional reality, and propose the use of CR. This last ratio measures the
328 maximum strength of Q at high angular velocity ($240^{\circ} \cdot s^{-1}$ in concentric mode) in relation to
329 that of H at low angular velocity ($30^{\circ} \cdot s^{-1}$ in eccentric mode), which could be more useful to

330 prevent damage of H. Analysis reveals absence of significant changes and maintenance at a
331 value slightly greater than 1.0 (Table 2). However, the results were satisfactory and suggest
332 that Pc2P is not necessarily suitable for rebalancing ratios in order to prevent injury for
333 several reasons. Physical training in Pc2P is mainly focused on developing strength and
334 endurance. Given the high proportion of training time assigned to technical and tactical
335 components (51.1%), which are essential factors of handball performance, it would be
336 difficult to further increase the overall training load without the risk of overreaching or
337 overtraining. This finding makes it problematic for an individualized treatment goal of
338 achieving a balanced muscle mass. In addition, the Pc2P period is perhaps not long enough to
339 efficiently impact muscle imbalances, even though the program regularly includes prevention
340 exercises.

341 Our results show that eight weeks of Pc2P significantly increased isokinetic PT,
342 except for PT at $60^{\circ} \cdot s^{-1}$ and MP for the dominant and the non-dominant sides for the two
343 velocities of $60^{\circ} \cdot s^{-1}$ and $240^{\circ} \cdot s^{-1}$ in world-class handball players. The ratios did not change
344 during this period, except for some AAR ratio, thus the study shows that eight weeks of Pc2P
345 does not lead to a major imbalance of the knee joint muscles in world-class handball players.

346 *Limitation of study*

347 One limitation of this study is that muscle groups were tested using an isokinetic
348 dynamometer with a monoarticular approach, while sports are played in a closed system,
349 suggesting that several muscle groups contribute to athletic performance. Moreover, it was
350 impossible to establish a control group with regard to the elite level of the team (6).

351

352 **PRACTICAL APPLICATIONS**

353 To increase the efficiency of the training program and optimize performance in the
354 season, the head coach of strength and conditioning will have to multiply the sessions

355 dedicated to the development of the strength and muscular power during this Pc2P. The study
356 by Silva et al. (49) show, in professional soccer players, with an important initial level of
357 strength and muscular power, leads to a less-marked decrease of performance in the game.
358 Given these observations it would be necessary that players start the season with their
359 maximum capacity developed in order to tolerate the stress of a competitive season that
360 usually runs for 9-10 months, with official matches played every week. Thereafter, the
361 increasingly busy schedules do not allow for the maintenance of strength and muscular
362 power. This has long been understood in rugby, which limits almost exclusively the first three
363 weeks of Pc2P to physical work. In handball, there are several possibilities to consider in
364 order to counteract this. In the absence of being able to lengthen the duration of Pc2P, it
365 would be advantageous to modify the training program in volume and/or intensity. In order to
366 optimize the Pc2P, it would be interesting to increase the number of practice sessions that are
367 focused on maximal strength. For this reason, the organization of practice sessions initially
368 planned (Table 2) for the first week of training to be dedicated to strength endurance,
369 followed by a week of hypertrophy, followed directly by three weeks of maximal strength.
370 These final three weeks could be followed by two weeks of power development by the
371 method of contrasting loads (light-heavy) to maintain the strength levels for a longer period of
372 time. Finally, the last week would focus exclusively on the development of explosivity. This
373 new programming strategy would allow for five weeks of maximum strength training instead
374 of the previously stated three weeks.

375 This study, which reveals Pc2P as an appropriate and measurable period, could guide the
376 head coach of strength and conditioning, coaches of professional sports teams, and
377 researchers to optimize the performance of professional players and consequently to better
378 protect them from injuries acquired during the length of the sport's seasons, including the
379 increase in quantity of competitions.

380

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386

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525 **Figure titles**

526 **Figure 1:** Evolution of the volume training in Pc2P

527

528 **Figure 2:** Evolution of the peak torque in concentric and eccentric mode

529 Q : Quadriceps ; H : Hamstrings ; 60QdomC : 60°.s⁻¹ on Q concentric dominant side ; 60QndomC :
 530 60°.s⁻¹ on Q concentric non-dominant side ; 60HdomC : 60°.s⁻¹ on H concentric dominant side ;
 531 60HndomC : 60°.s⁻¹ on H concentric non-dominant side ; 240QdomC : 240°.s⁻¹ on Q concentric
 532 dominant side ; 240QndomC : 240°.s⁻¹ on Q concentric non-dominant side ; 240HdomC : 240°.s⁻¹ on
 533 H concentric dominant side ; 240HndomC : 240°.s⁻¹ on H concentric non-dominant side ; 30HdomE :
 534 30°.s⁻¹ on H eccentric dominant side ; 30HndomE : 30°.s⁻¹ on H eccentric non-dominant side ;
 535 NS : No significant ; ** : p<0.01, *** : p<0.001.

536

537 **Figure 3:** Evolution of the mean power in concentric and eccentric mode

538 Q : Quadriceps ; H : Hamstrings ; 60QdomC: 60°.s⁻¹ on Q concentric dominant side ; 60QndomC :
 539 60°.s⁻¹ on Q concentric non-dominant side ; 60HdomC : 60°.s⁻¹ on H concentric dominant side ;
 540 60HndomC : 60°.s⁻¹ on H concentric non-dominant side ; 240QdomC : 240°.s⁻¹ on Q concentric
 541 dominant side ; 240QndomC : 240°.s⁻¹ on Q concentric non-dominant side ; 240HdomC : 240°.s⁻¹ on
 542 H concentric dominant side ; 240HndomC : 240°.s⁻¹ on H concentric non-dominant side ; 30HdomE :
 543 30°.s⁻¹ on H eccentric dominant side ; 30HndomE : 30°.s⁻¹ on H eccentric non-dominant side
 544 ** : p<0.01 ; *** : p<0.001.

545

546 **Table titles**

547 **Table 1:** Organization of the endurance training program over the Pc2P

548 Pc2P : pre-competitive preparation period ; AC : aerobic capacity ; MAP : maximum aerobic power ;
 549 AP : anaerobic power ; r = recovery between repetitions ; R = recovery between series.
 550 Example : (3 x (8 x 30 sec), r = 30 sec, R = 4 min). It means that the subject had to run 3 series of 8
 551 times 30 sec composed of 30 sec running at 90-100 % of HRmax and 30 sec passive recovery. The
 552 subject recovers passively 4 min between each series. Each session is repeated 2 times a week.

553

554 **Table 2:** Organization of the lower body strength training program over the Pc2P

555 Pc2P : pre-competitive preparation period ; 1-RM : one-repetition maximum ; rep : repetitions ; R :
 556 recovery.
 557 Example : (3 x (12 rep x 60% 1-RM), R = 1 min 30). It means that the subject had to realize 3 series of
 558 12 repetitions at 60% 1-RM. The subject recovers passively 1 min 30 between each series. Each
 559 session is repeated 3 times a week.

560

561 **Table 3:** Ratios analyses

562 Pc2P : Pre-competitive preparation period ; m : mean ; SD : Standard deviation ; DNDR :
 563 Dominant/non-dominant ratio ; AAR : Agonist/antagonist ratio ; CR : Combined ratio (eccentric at
 564 30°.s⁻¹ of H and concentric at 240°.s⁻¹ of Q) ; RQ : Quadriceps ratio ; RH : Hamstrings ratio ; Dom :
 565 Dominant ; Ndom : Non-dominant ; P : significativity ; NS : No significant.

566

1 Table 1: Organization of the endurance training program over the Pc2P

Pc2P								
Weeks	1	2	3	4	5	6	7	8
Objectives	AC		MAP				MAP-AP	
Modality	Continuous training 40-50 min	Fartlek training 30-40 min (10 sec acceleration every min)	8 x 3 min R = 3 min	(10-12) x 1 min R = 1 min	3 x (8 x 30 sec) r = 30 sec R = 4 min	3 x (14 x 15 sec) r = 15 sec R = 4 min	2 x (5 x 30 sec) R = 4 min	2 x (6 x 5 sec) r = 15 sec R = 8 min
Intensity	65-70 % HRmax	75-80% HRmax	85-90% HRmax	90-95% HRmax	90-100% HRmax	90-100% HRmax	90-100% HRmax	HR not used
Sessions	Tuesday Thursday Saturday	Tuesday Thursday Saturday	Monday Friday	Monday Friday	Monday Friday	Monday Friday	Tuesday	Tuesday

2 Pc2P : pre-competitive preparation period ; AC : aerobic capacity ; MAP : maximum aerobic power ; AP : anaerobic power ; r = recovery between
3 repetitions ; R = recovery between series

4 Example : (3 x (8 x 30 sec), r = 30 sec, R = 4 min). It means that the subject had to run 3 series of 8 times 30 sec composed of 30 sec running at 90-100 % of
5 HRmax and 30 sec passive recovery. The subject recovers passively 4 min between each series. Each session is repeated 2 times a week.

1 Table 2: Organization of the lower body strength training program over the Pc2P

Pc2P								
Weeks	1	2	3	4	5	6	7	8
Objectives	Endurance of strength		Hypertrophy and maximal strength				Power	
Modality	Circuit Training 30 s / exercise 4 rounds R = 5 min	3 x 12 rep R = 1 min 30	3 x 10 rep R = 2 min	4 x (6 to 7) rep R = 3 min	3 x 4 rep R = 4 min	3 x (2 rep + 6 rep) R = 4 min	3 x 6 rep R = 2 min 30	3 x 6 rep R = 2 min 30
Training Session	- Squat - Core stability - Leg Curl - Core stability - Deadlift - Core stability - Leg Extension - Core stability - Swing Kettle - Core stability	- Squat - Deadlift - Step-up - Lunge - Swing Kettle	- Hack squat - R. Deadlift - Step-up - Lunge	- Squat - Deadlift - Power clean	- Squat - Deadlift - Step-up	- Squat + Pliometry body weight - Deadlift + Clean and Jerk - Step-up + Split Squat	- Step-up - Squat - Clean and Jerk - Snatch - Plyometry body weight	- Step-up - Squat - Clean and Jerk - Snatch - Plyometry body weight
Intensity	40% 1-RM	60% 1-RM	70% 1-RM	80% 1-RM	90% 1-RM	90% 1-RM	60% 1-RM	50% 1-RM
Sessions	Monday Wednesday Friday	Monday Wednesday Friday	Monday Thursday	Monday Thursday	Monday Thursday	Monday Thursday	Monday Thursday	Monday Thursday

2 Pc2P : pre-competitive preparation period ; 1-RM : one-repetition maximum ; rep : repetitions ; R : recovery
 3 Example : (3 x (12 rep x 60% 1-RM), R = 1 min 30). It means that the subject had to realize 3 series of 12 repetitions at 60% 1-RM. The subject recovers
 4 passively 1 min 30 between each series. Each session is repeated 3 times a week.
 5

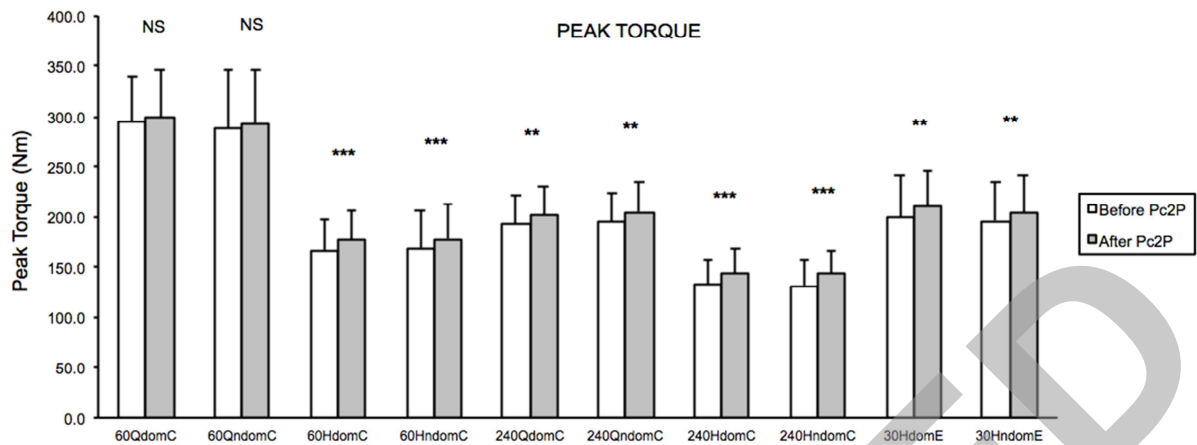
1 Table 3 : Ratios analysis

		Concentric (60°.s ⁻¹)				Concentric (240°.s ⁻¹)				CR	
		DNDR		AAR		DNDR		AAR			
		RQ	RH	Dom	Ndom	RQ	RH	Dom	Ndom		
Before Pc2P	m (±)	1.04	1.01	0.57	0.6	1	1.01	0.68	0.68	1.05	1.02
	SD	0.15	0.19	0.09	0.13	0.15	0.1	0.1	0.12	0.24	0.23
After Pc2P	m (±)	1.03	1.01	0.6	0.61	0.99	1.01	0.72	0.7	1.06	1.02
	SD	0.11	0.16	0.09	0.11	0.14	0.1	0.07	0.12	0.21	0.23
	<i>P</i>	NS	NS	0.003	0.01	NS	NS	0.02	0.02	NS	NS

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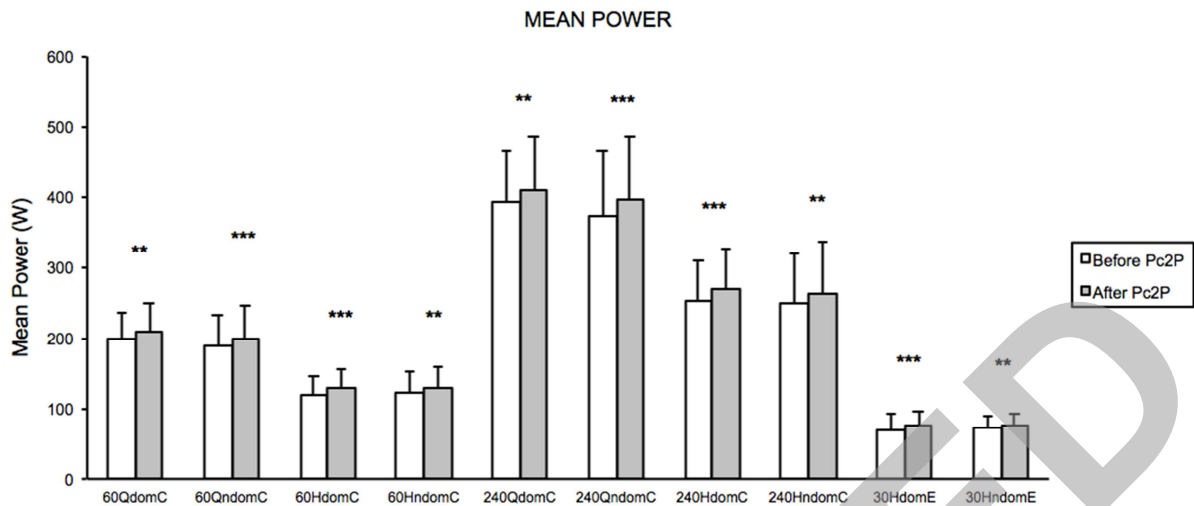
Pc2P : Pre-competitive preparation period ; *m* : mean ; *SD* : Standard deviation ; *DNDR* : Dominant/non-dominant ratio ; *AAR* : Agonist/antagonist ratio ; *CR* : Combined ratio (eccentric at 30°.s⁻¹ of H and concentric at 240°.s⁻¹ of Q) ; *RQ* : Quadriceps ratio ; *RH* : Hamstring ratio ; *Dom* : Dominant ; *Ndom* : Non-dominant ; *P* : significativity ; *NS* : No significant

1 Figure 2. Evolution of the peak torque in concentric and eccentric mode



2
3 *Q* : Quadriceps ; *H* : Hamstrings ; 60QdomC : 60°.s⁻¹ on *Q* concentric dominant side ;
4 60QndomC : 60°.s⁻¹ on *Q* concentric non-dominant side ; 60HdomC : 60°.s⁻¹ on *H* concentric
5 dominant side ; 60HndomC : 60°.s⁻¹ on *H* concentric non-dominant side ; 240QdomC :
6 240°.s⁻¹ on *Q* concentric dominant side ; 240QndomC : 240°.s⁻¹ on *Q* concentric non-
7 dominant side ; 240HdomC : 240°.s⁻¹ on *H* concentric dominant side ; 240HndomC : 240°.s⁻¹
8 on *H* concentric non-dominant side ; 30HdomE : 30°.s⁻¹ on *H* eccentric dominant side ;
9 30HndomE : 30°.s⁻¹ on *H* eccentric non-dominant side ; NS : No significant ; ** : p<0.01 ;
10 *** : p<0.001.

1 Figure 3. Evolution of the mean power in concentric and eccentric mode



2
 3 *Q* : *Quadriceps* ; *H* : *Hamstrings* ; 60QdomC: $60^{\circ}.s^{-1}$ on *Q* concentric dominant side ;
 4 60QndomC : $60^{\circ}.s^{-1}$ on *Q* concentric non-dominant side ; 60HdomC : $60^{\circ}.s^{-1}$ on *H* concentric
 5 dominant side ; 60HndomC : $60^{\circ}.s^{-1}$ on *H* concentric non-dominant side ; 240QdomC :
 6 $240^{\circ}.s^{-1}$ on *Q* concentric dominant side ; 240QndomC : $240^{\circ}.s^{-1}$ on *Q* concentric non-
 7 dominant side ; 240HdomC : $240^{\circ}.s^{-1}$ on *H* concentric dominant side ; 240HndomC : $240^{\circ}.s^{-1}$
 8 on *H* concentric non-dominant side ; 30HdomE : $30^{\circ}.s^{-1}$ on *H* eccentric dominant side ;
 9 30HndomE : $30^{\circ}.s^{-1}$ on *H* eccentric non-dominant side ; ** : $p < 0.01$; *** : $p < 0.001$.
 10

