

Electromyographic Comparison of Flywheel Inertial Leg Curl and Nordic Hamstring Exercise Among Soccer Players

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1 **ELECTROMYOGRAPHIC COMPARISON OF FLYWHEEL INERTIAL**
2 **LEG CURL AND NORDIC HAMSTRING EXERCISE AMONG SOCCER**
3 **PLAYERS.**

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7 Running head: Flywheel vs Nordic hamstring exercise

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20 **Abstract**

21 **Purpose:** The Nordic hamstring exercise has been shown to considerably reduce hamstring
22 injuries among soccer players. However, as the load in the Nordic hamstring exercise is the
23 person`s own bodyweight, it is a very heavy exercise and difficult to individualize. The flywheel
24 inertial leg curl could be an alternative since the eccentric overload is based on the amount of
25 work produced in the concentric movement. Therefore, the primary aim of this study was to
26 compare the activation in the hamstrings at long muscle lengths in the Nordic hamstring
27 exercise and the flywheel inertial leg curl in amateur soccer players. **Methods:** Fifteen male
28 amateur soccer players performed five repetitions in each exercise in a randomized and
29 counterbalanced order. The concentric and eccentric movement were divided into lower and
30 upper phases. Surface EMG (sEMG) was measured distally, proximally and in the middle, at
31 both muscles. **Results:** In the lower phase in the eccentric movement there were no significant
32 differences between the two exercises ($p=0.101-0.826$). In the lower concentric movement,
33 flywheel inertial leg curl led to higher activation in all parts of both the biceps femoris (31-
34 52%, $p<0.001$) and the semitendinosus (20-35%, $p=0.001-0.023$). **Conclusion:** Both exercises
35 activated the hamstrings similarly at long muscle lengths during eccentric contractions (Nordic
36 hamstring, non-significantly higher). However, when performing concentric contractions the
37 flywheel inertial leg curl induced higher activations. Therefore, flywheel inertial leg curl could
38 be a useful alternative to the Nordic hamstring exercise, and particularly suitable for weaker
39 athletes before progressing to Nordic hamstring exercise.

40

41 **Key words:** Resistance training, biceps femoris, semitendinosus, eccentric, hamstring,
42 **EMG**

43

44 **Introduction**

45 Acute hamstring injury is one of the most common injuries in soccer^{1,2}. The Nordic hamstring
46 exercise (NHE) reduces the risk of acute hamstring injuries in soccer by more than 50% ¹. The
47 explanation of this dramatic effect is likely multifactorial ³, but strengthening the hamstring
48 muscles, especially at long muscle lengths where most strain injuries occur, seems highly
49 important ². In the NHE, the stress on the hamstring muscles is increased over the range of
50 motion due to the increasing lever arm, making the exercise especially heavy at long muscle
51 lengths. Further, it has been indicated that different exercises have different regional activating
52 patterns ⁴, with the NHE having a homogenous regional activating pattern with the
53 semitendinosus being more activated in the proximal region while the biceps femoris is more
54 activated in the distal region ⁵. This could be of importance since most hamstring injuries in
55 professional soccer occurs in the long head of the biceps femoris ⁶.

56 The NHE uses the bodyweight as the external load. It is therefore difficult to individualize the
57 load to soccer players with different strength levels, especially tall players, and those who are
58 weak in relation to their own bodyweight. This could reduce these players' ability to perform
59 the exercise in a controlled tempo and activate the hamstring muscles at long muscle lengths,
60 where the external torque is greatest ⁷. The use of bodyweight as loading causes another
61 problem when shifting from the eccentric to the concentric contractions. The player has to be
62 very strong in the hamstring muscles to be able to perform the ascending movement, hence in
63 most cases the Nordic hamstring is performed as a purely eccentric exercise ⁸. A possibility for
64 reducing the external load is to push with the arms in the concentric phase. This should be
65 considered since there have been promising results of combining eccentric overload with a
66 concentric contraction ⁹.

67 Despite the promising results of the NHE, the inclusion of the exercise into injury preventive
68 training programs has been poor ¹⁰. There are likely several reasons for this, but that the NHE
69 is a high intensity exercise ¹¹, with little room for individual adjustments, and a long recovery
70 period when the exercise is novel, which could interfere with soccer training, seem likely
71 candidates. Therefore, a gentler and more individualized exercise could be preferable for both
72 players and coaches. An alternative is to create an eccentric overload by using inertial resistance
73 via a flywheel device ¹². In this apparatus, the force created in the concentric movement is
74 transferred to a strap. When the strap unwinds, a shaft with the flywheels rotates and thereby
75 stores the energy ¹³. When the concentric movement is complete, the strap rewinds, and the
76 athlete must resist the rotation of the flywheel through the eccentric phase. To ensure high loads
77 towards the final parts of the eccentric movement, at long muscle lengths, it would be important
78 to not resist the movement immediately, but emphasize the latter half of the eccentric movement
79 ¹⁴. Previous research have indicated flywheel training to elicit higher neuromuscular activation,
80 especially in the eccentric movement, when compared to traditional resistance exercises ¹⁵.
81 Therefore, inertial exercises for the hamstring, such as the flywheel inertial leg curl (FLC),
82 could be a feasible alternative to the NHE. The FLC could offer a more individualized eccentric
83 overload compared to the NHE since its` magnitude depends on the concentric contraction and
84 has therefore been recommended for weaker athletes ¹⁶. Further, it would be easier to activate
85 the hamstring muscles in the concentric movement in the FLC.

86 To our knowledge, no study has compared muscle activation in the NHE to an inertial hamstring
87 exercise. Therefore, the primary aim of this study was to compare the muscle activations
88 generated by the NHE and the FLC, in the biceps femoris and the semitendinosus at long muscle
89 lengths in amateur soccer players.

91 **Methods**

92 **Experimental approach to the problem**

93 The study used a within-subject cross-over design where measurements were conducted in the
94 same session to assess the neuromuscular activation of the semitendinosus and biceps femoris
95 when performing the NHE and the FLC among amateur soccer players. Five repetitions were
96 performed in each exercise using either the body weight (NHE) or the load yielding maximal
97 power output (FLC). The order of the exercises was randomized and counterbalanced.

98

99 **Subjects**

100 Comparable to the number of participants in previous research^{15,17}, 15 active male amateur
101 soccer players (age 22.9 ± 1.8 years, body mass 75.9 ± 7.9 kg, height 179.2 ± 6.8 cm) were
102 recruited for the study. The players had 16.1 ± 1.6 years of experience playing soccer and were
103 at the time of the study playing at level 4-6 in the national series. The participants had to be at
104 least 18 years old and be able to perform the exercises without any pain or pain-related
105 discomfort limiting the effort. The participants had to refrain from resistance- and high intensity
106 training 48 hours before the test. Information about the study was provided orally and in writing
107 and a written consent had to be provided before the individual was enrolled in the study. The
108 study conformed to the Sogn og Fjordane University College and all appropriate consent
109 pursuant to law was obtained before the start of the study.

110

111 **Procedures**

112 Two familiarization sessions were performed before the experimental test. In the first, the
113 participants were familiarized with the execution of both exercises performing three to five sets

114 of five repetitions. The FLC was performed with increasing resistances to find the load where
115 the participants were able to produce the highest power output. The mean of the five repetitions
116 was used when calculating the power output. The testing started at inertial load $0.025 \text{ kg}\cdot\text{m}^2$
117 and was increased by $0.010 \text{ kg}\cdot\text{m}^2$ or $0.025 \text{ kg}\cdot\text{m}^2$ for each set until the power output decreased
118 compared to the previous set. The mean power output was measured by an application
119 (excentric kMeter) from the manufacturer of the flywheel device. In the second familiarization
120 session the protocol from session one was repeated in the NHE, while in the FLC the
121 participants performed all repetitions with the load producing maximal power output, found in
122 session one (ranging from 52 to 143 watts). A minimum of 48 hours separated the sessions.

123 Before each session, the participants completed the same warm-up consisting of five minutes
124 of cycling at an intensity defined as easy to moderate (10-12 on Borgs` RPE scale; range 6-20),
125 followed by two sets of eight repetitions in a leg curl machine (Technogym, Gambettola, Italy)
126 with moderate intensity (five on the Borg CR10 scale; range 0-10). The different scales were
127 thoroughly explained before the warm-up and a test leader was always present to control a
128 proper warm-up.

129 The NHE was performed on a gym mat with one person holding the ankles (below the calf
130 muscles) pinned to the floor (see figure 1A). The feet were held in a plantar flexion with the
131 toes pointing backwards. The eccentric part started in an upright position with a straight hip and
132 the arms held in front of the trunk (hand in front of the shoulders, see figure 1A). The
133 participants were instructed to lower them in a slow and controlled tempo, without flexing in
134 the hip. When the trunk touched the mat the participants were instructed to ascend as fast as
135 possible using their hamstrings, whilst maintaining a straight hip. They were allowed to use
136 their arms, but it was emphasized that they should contribute as little as possible. When they
137 were back at the starting position, the concentric part was complete and a new repetition began
138 without rest.

139 FIGURE 1 AROUND HERE

140 The FLC was performed standing and unilaterally in a flywheel apparatus (kBox4 active,
141 Exxentric, Bromma, Sweden) with only the dominant leg being tested. The participants were
142 positioned on a step higher than the apparatus to allow for full extension in the knee with the
143 hip straight above the flywheel (see figure 1B). They held onto a rack to keep their trunk and
144 hip in the same position during the exercise. The device/strap was adjusted to the desired
145 position (90 degree in the knee joint) using a goniometer. The participants were instructed to
146 contract with maximal effort (“as hard and fast as possible”) throughout the complete concentric
147 phase. After unwinding the strap from the shaft, stopping at a 90 degree angle in the knee joint,
148 the strap rewound due to the inertial forces, initiating the eccentric phase. In this phase, the
149 participants were instructed to resist the forces gently in the first third of the movement before
150 resisting the movement maximally until the knee was extended ¹⁴. Five repetitions with
151 maximal effort were completed in both exercises. The participants were given a minimum of
152 three minutes rest between each exercise¹⁸.

153

154 **Electromyography**

155 Before the experimental testing the skin on the dominant leg was prepared (shaved, abraded
156 and washed with alcohol) in accordance to the guidelines of SENIAM ¹⁹. Gel-coated self
157 adhesive electrodes (11 mm contact diameter and a 2 cm center-to-center distance, Dri-Stick
158 Silver circular surface EMG Electrodes AE-131, NeuroDyne Medical, USA) were placed in the
159 presumed direction of the underlying muscle fibers on three different parts (distal, middle and
160 proximal) of the semitendinosus and biceps femoris²⁰. For the middle part of the semitendinosus
161 the electrode was placed at 50% on the line between the ischial tuberosity and the medial
162 epicondyle of the tibia. The middle part of the biceps femoris was placed at 50% on the line

163 between the ischial tuberosity and the lateral epicondyle of the tibia (www.seniam.org). The
164 electrodes on the distal and proximal part of both muscles were placed the same line as the
165 middle electrode, however, the exact position was individually adjusted based on the palpation
166 of each individuals' hamstring²¹. In general, the proximal electrodes were placed as high as
167 possible without overlapping the glutei muscles and the distal parts as low as possible without
168 overlapping the tendons. The electrodes in each region were always placed parallel to each
169 other.

170 The raw EMG signal sampled at 1000 Hz, was amplified and filtered (8-600 Hz; fourth-order
171 Butterworth filter) using a preamplifier located close to the sampling point. The preamplifier
172 had a common mode rejection ratio of 106 dB. The EMG signals were root mean square (RMS)
173 converted using a hardware circuit network (frequency response 450 kHz, averaging constant
174 12 ms, total error $\pm 0.5\%$). Commercial software (MuscleLab 6000 system, Ergotest
175 Technology AS, Langesund, Norway) was used to analyze the stored EMG data. The mean
176 EMG amplitude obtained during repetition 1, 3 and 5 was used to calculate RMS EMG of the
177 upper and lower phases of the eccentric and concentric movement in addition to the whole
178 eccentric and concentric movement. The mean EMG amplitude of each phase was used to
179 calculate the RMS values. Finally, to normalize EMG activity, the participants performed two
180 maximal voluntary contractions (MVCs). The participants were placed on a mat lying in the
181 prone position, before instructed to perform an isometric knee flexion while the leg (knee angle
182 of approximately 45 degrees) and hip were manually held still. In both attempts (separated by
183 1-2 minutes), the participants were instructed to obtain maximal force and hold it for five
184 seconds. The attempt with the highest EMG amplitude was used to normalize the EMG signal
185 for each muscle. Commercial software (MuscleLab V10.4, Ergotest Technology AS,
186 Langesund, Norway) was used to analyze the stored EMG data.

187 To identify the beginning and the end of the eccentric and concentric movement, as well as the
188 different phases and the lifting time, a linear encoder (Ergotest Technology AS, Langesund
189 Norway, sampling frequency of 200 Hz) was attached to the trunk (NHE) or ankle (FLC). The
190 classification of the different phases (upper and lower) was made from the displacement of the
191 trunk (NHE) or ankle (leg curl), where the separation was done at 50% of the displacement.
192 The linear encoder was synchronized with the EMG recording system (MuscleLab 6000,
193 Ergotest Technology AS, Langesund, Norway).

194

195 **Statistical analyses**

196 The normality of the data was checked and confirmed with the Shapiro-Wilk test. Thus, paired
197 t-tests were used to compare the neuromuscular activation and the lifting time between the
198 different exercises. Statistical analyses were performed with SPSS version 17.0 (SPSS, Inc.,
199 Chicago, IL, USA).

200 Statistical significance was accepted at $p \leq 0.05$. All results are presented as mean \pm 95%
201 confidence interval (95%CI) and Cohen`s *d* effect size (ES) calculated by: mean FLC – mean
202 NHE divided by the pooled standard deviations of the two exercises. An ES of 0.2 was
203 considered small, 0.5 medium and 0.8 large ²².

204

205 **Results**

206 In the lower eccentric phase, both exercises showed similar activation in all parts of the two
207 muscles ($p = 0.101 - 0.826$, figure 2A). In the lower concentric movement the FLC lead to
208 higher activation in all parts of both the biceps femoris (31 - 52%, $p < 0.001$, ES = 0.98 – 1.31,
209 figure 2B) and the semitendinosus (20 - 35%, $p = < 0.001 - 0.023$, ES = 0.53 – 1.01).

210 FIGURE 2 AROUND HERE

211 In the upper phase of the eccentric movement the three parts of the biceps femoris were more
212 activated when performing FLC compared to the NHE (10 – 21%, $p = 0.005 – 0.049$, ES = 0.38
213 – 0.67, table 1), but no significant differences were observed in the semitendinosus ($p = 0.177$
214 – 0.284). In the upper concentric phase the FLC lead to higher activation in all parts of both
215 muscles when compared to the NHE (52 – 79%, $p < 0.001$, ES = 1.29 – 3.77).

216 TABLE 1 AROUND HERE

217 When analyzing the whole eccentric movement, the proximal part of semitendinosus
218 demonstrated higher activation during the NHE compared to the FLC (23%, $p = 0.016$, ES =
219 0.89). There were no significant differences for any of the other parts of the muscles in the
220 eccentric movement ($p = 0.237 – 0.807$). In the whole concentric movement, FLC lead to higher
221 activation for all parts of both semitendinosus (52 – 68%, $p < 0.001$, ES = 1.51 – 1.99) and
222 biceps femoris (64 – 78%, $p < 0.001$, ES = 2.22 – 2.79) when compared to NHE.

223 The mean time used in both the eccentric and concentric part of the movement was higher ($p <$
224 0.001) in the NHE (eccentric: 3.9 ± 0.7 sec. and concentric: 2.4 ± 0.5 sec.) compared to the FLC
225 (eccentric: 1.7 ± 0.2 sec. and concentric: 1.6 ± 0.2 sec.). The same differences were apparent in
226 the different phases with the exception of the lower eccentric phases where the times were not
227 statistical different ($p = 0.165$).

228

229 **Discussion**

230 The NHE and FLC induced similarly high activations in the semitendinosus and the biceps
231 femoris during the eccentric phase at long muscle length, while the FLC led to greater activation
232 in the concentric movement.

233 It should be noted that although there were no statistical differences between the exercises in
234 the lower phase of the eccentric movement, the EMG-activation was non-significantly higher
235 in all parts of the two muscles for the NHE (effect sizes ranging from 0.08 to 0.61). Although
236 the number of participants (i.e. 15) is similar to comparable studies ^{15,17}, it is possible that the
237 lack of statistical differences could be due to limited statistical power. Nevertheless, both
238 exercises induced quite high levels of neuromuscular activations at long muscle lengths during
239 the eccentric contraction. Since high levels of muscle activation is important for developing
240 muscle strength and muscle strength at long muscle lengths seems to be important for
241 preventing acute hamstring injuries, these results imply that the FLC could be a useful
242 alternative to the NHE as an injury preventing hamstring exercise. This implication is
243 strengthened by Askling et al. ²³ who reported an injury preventing effect of inertial flywheel
244 training on the occurrence of hamstring injury among professional soccer players

245 Although most of the focus has been on eccentric strength, previous research have shown that
246 imbalances in concentric and eccentric hamstring strength may increase the chance of hamstring
247 injury ²⁴. Exercises that activate the muscles optimally in both actions, could therefore be
248 preferable. To this end, the FLC could have some advantages. During the NHE, all subjects in
249 the present study had to use their arms to push off in the beginning of the concentric movement,
250 which indicates that they were not strong enough to activate the hamstring muscles optimally
251 in the concentric movement. Therefore, it could be argued that the NHE is better for stronger
252 athletes. This argument is supported by a previous study showing the glute-ham raise, a similar
253 exercise to the NHE, to be superior for concentric hamstring activation compared to the leg curl
254 when performed by resistance-trained subjects¹⁷.

255 Unlike the FLC, the NHE stresses the hamstring both as a knee flexor and as a hip extensor,
256 stabilizing the hip throughout the movement. The role as a hip stabilizer could explain the
257 increased activation in the proximal part of the semitendinosus during the NHE in the eccentric

258 movement. The semitendinosus is morphologically divided into two compartments by a
259 tendinous inscription which anchors the fascicles in the different compartments²⁵. Therefore,
260 it could be that the fibers in the upper compartment are more activated during hip movement
261 compared to the knee movement.

262 The increased activation in the upper phase of the eccentric movement during the FLC could
263 be explained by the function of the muscle. The biceps femoris is inserted at the head of the
264 fibula and therefore being active in the external rotation of the tibia¹⁷. It has been shown that
265 the tibia moves posteriorly as the knee is flexed²⁶ and performing an external rotation of the
266 foot during the knee flexion have led to higher activation of the lateral hamstring²⁷.
267 Furthermore, the FLC was performed unilaterally making it possible to externally rotate the leg
268 during the movement. However, in the NHE exercise, both ankles were pinned to the floor
269 counteracting such a rotation and hence reducing the neuromuscular stress on the biceps
270 femoris.

271 There are some limitations with the present study. Only male amateur soccer players were
272 recruited to the study. The results can therefore not necessarily be generalized to elite level
273 players. Moreover, EMG gives only an estimate of the neuromuscular activation of the muscles
274 and there will always be a possibility of crosstalk from neighboring muscles when using surface
275 EMG²⁸. There are also some additional methodological challenges when assessing EMG
276 during dynamic contractions such electrode shifting and changes in conductivity in the tissue²⁹.
277 However, to mitigate this all data were collected in the same session without having to replace
278 any of the electrodes²⁹.

279

280 **Practical applications**

281 Strengthening the hamstring muscles at long muscle lengths appear to be important to avoid
282 injuries in soccer players ². The results of the present study suggest that the NHE and the FLC
283 exercises induces relatively similar and high activities at longer muscle lengths in the eccentric
284 movement. However, if the practitioners also want to highlight the lower phase of the concentric
285 movement, the FLC is better. Furthermore, as the NHE uses body weight as loading, it could
286 be less suitable for weaker players, and in the beginning of a program, due to the need for a
287 long recovery period, which could impede soccer training. Conversely, the load in the FLC can
288 be individualized since the principle behind the flywheel equipment is that the energy produced
289 in the concentric movement will eventually be used in the eccentric movement ³⁰. Therefore, if
290 proper progression is followed, the FLC can be a “gentler” exercise that is suitable for weaker
291 athletes or in the beginning of a training program, or during rehabilitation after injury. Also,
292 performing unilateral exercises have the advantage of stressing each limb more optimally, thus
293 reducing potential differences in strength between the dominant and non-dominant side.
294 However, the time under tension was longer for the NHE which could be of importance for
295 muscular adaptations over time.

296 In addition, performing the concentric movement of the NHE would require very strong
297 hamstring muscles, and would therefore be reserved for stronger individuals ¹¹, while weaker
298 players use their arms to push past this phase, which could lead to strength imbalances.
299 However, an alternative could be to use elastic bands to assist during the movement, reducing
300 some of the bodyweight, but this would also reduce the load in the eccentric part of the
301 movement.

302

303 **Conclusion**

304 In conclusion, the NHE and the FLC showed similar activation of the hamstring muscles in the
305 lower phase of the eccentric movement, while the FLC induced higher activation in the
306 concentric phase. Nevertheless, the injury-reducing potential of the FLC should be investigated
307 in intervention studies.

308

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314

315

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398 **Figure Legends**

399 **Figure 1:** The Nordic hamstring exercise (A) and the flywheel inertial leg curl (B).

400

401 **Figure 2:** Normalized electromyographic (EMG) activation of the semitendinosus and the
402 biceps femoris during the Nordic hamstring exercise and the flywheel inertial leg curl in the
403 lower eccentric phase (A) and the lower concentric phase (B). Values are means and 95%CI. *
404 $p < 0.05$, ** $p < 0.01$, a = moderate effect size, b = large effect size. MVC = maximal voluntary
405 contraction

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