Electrostimulation Training Effects on the Physical Performance of Ice Hockey Players

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ABSTRACT

BROCHERIE, F., N. BABAULT, G. COMETTI, N. MAFFIULETTI, and J.-C. CHATARD. Electrostimulation Training Effects on the Physical Performance of Ice Hockey Players. *Med. Sci. Sports Exerc.*, Vol. 37, No. 3, pp. 455–460, 2005. **Purpose:** The aim of this study was to examine the influence of a short-term electromyostimulation (EMS) training program on the strength of knee extensors, skating, and vertical jump performance of a group of ice hockey players. **Methods:** Seventeen ice hockey players participated in this study, with nine in the electrostimulated group (ES) and the remaining height as controls (C). EMS sessions consisted of 30 contractions (4-s duration, 85 Hz) and were carried out $3\times$ wk^{-1} for 3 wk. Isokinetic strength of the knee extensor muscles was determined with a Biodex dynamometer at different eccentric and concentric angular velocities (angular velocities ranging from -120 to $300°\cdot s^{-1}$). Jumping ability was evaluated during squat jump (SJ), countermovement jump (CMJ), drop jump (DJ), and 15 consecutive CMJ (15J). Sprint times for 10- and 30-m skates in specific conditions were measured using an infrared photoelectric system. **Results:** After 3 wk of EMS training, isokinetic torque increased significantly ($P < 0.05$) for ES group in eccentric (-120 and $-60°\cdot s^{-1}$) and concentric conditions (60 and $300°\cdot s^{-1}$), whereas vertical jump height decreased significantly ($P < 0.05$) for SJ (-2.9 ± 2.4 cm), CMJ (-2.1 ± 2.0 cm), and DJ (-1.3 ± 1.1 cm). The 10-m skating performance was significantly improved (from 2.18 ± 0.20 to 2.07 ± 0.09 s, before and after the 3-wk EMS period, respectively; $P < 0.05$). **Conclusion:** It was demonstrated that an EMS program of the knee extensors significantly enhanced isokinetic strength (eccentric and for two concentric velocities) and short skating performance of a group of ice hockey players. **Key Words:** KNEE EXTENSORS, STRENGTH TRAINING, SPRINT, VERTICAL JUMP

Research on the use of electromyostimulation (EMS) as a method of training of healthy skeletal muscle has increased over the past decade (10,13,15,23). Several studies have indicated that this training modality enables the development of maximal force, albeit with a great diversity in reported strength gains, ranging from 0 to 44% (11,12,23). Differing stimulation modes (frequency, pulse duration), testing procedures, training protocols (number and duration of the sessions), pretraining status, and interindividual differences may account, at least partly, for the observed discrepancies (5,10).

Recently, some studies have attempted to investigate the effect of EMS training on the specific performance of athletes from various team sports. For instance, Maffiuletti et al. (13) and Malatesta et al. (15) demonstrated the positive effects of short-term EMS training on the vertical jump performance of basketball and volleyball players. These changes were also associated with isokinetic and isometric strength gains (13). However, to the best of our knowledge, no study has been published regarding EMS training effects on the specific performance of ice hockey players.

Analysis of physiological profile of elite ice hockey teams reveals the importance of aerobic endurance, anaerobic power and endurance, muscular strength, and skating speed (9,18). It was also pointed out that the strength decrement observed during the hockey season can be attributed to the lack of specific strength programs (18). Our study used EMS training as a complement to standard training practices with the goal of improving both the muscular strength and physical performance of ice hockey athletes. Therefore, the purpose of the present study was to determine the influence of a 3-wk EMS training program on the quadriceps femoris muscle strength and on specific physical abilities of ice hockey players, such as vertical jump and speed skating performance. The quadriceps muscle group was firstly chosen because it develops the largest contractile strength during the push-off of the skating thrust, whereas the hamstrings and gastrocnemius muscles primarily act to stabilize the knee joint (18). This muscle group was secondly chosen because three of its four component muscles are superficial and can be easily stimulated.

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MATERIALS AND METHODS

Subjects

A group of 17 ice hockey players competing in the French Ice Hockey Federation League, division II (age = 22.6 ± 4.5 yr; height = 178.3 ± 4.8 cm; mass = 73.8 ± 7.6 kg) participated in the study. They were randomly divided into two groups with nine assigned to the electrostimulated (ES) and eight to the control players (C). None of them had previously engaged in systematic EMS experience. All the subjects agreed to participate in the study on a voluntary basis and signed an informed consent form. The study was conducted according to the declaration of Helsinki and approval for the project was obtained from the University of Burgundy committee on human research. During the experiment, the ice hockey training was the same for all players and was performed with the same coach with all athletes practicing three times a week in 1.5-h sessions and playing one game per week. No subjects had to stop the experiment due to injuries resulting from EMS training and/or ice hockey practicing.

Training

EMS training. A total of nine EMS sessions were spread over a 3-wk period, with 12 min per session and three sessions per week, as recommended by Sale and MacDougall (22). EMS sessions, separated from the specific ice hockey training, were always performed at the same time of day and the same days of a week. During EMS, athletes were seated in a leg extension machine with the knee flexed at a 60° angle (0° corresponding to complete leg extension). EMS was delivered to both quadriceps simultaneously with a Compex-2 stimulator (MediCompex SA, Ecublens, Switzerland). Two pairs of self-adhesive positive electrodes (each measuring 25 cm^2; 5 × 5 cm), which have the property of depolarizing the membrane, were placed on the vastus medialis and vastus lateralis muscle bellies. Two rectangular negative electrodes, each measuring 50 cm^2 (10 × 5 cm) were placed over the femoral triangle of each leg, 1–3 cm below the inguinal ligament. Pulse currents of 85-Hz frequency lasting 250 μs were used. The contraction time was 4 s, and the rest time was 20 s. During each training session, 30 EMS contractions were completed. To ensure identical contraction intensity throughout the training session, electrically evoked (isometric) force was consistently measured with a myostatic type dynamometer (Allegro, Sallanches, France). At the beginning of each training session, the subject's maximal voluntary isometric force was measured at 60° (i.e., the angle of stimulation). Then stimulation intensity was individually increased to the maximal tolerated intensity, and to attain at least 60% of each individual pretest maximal voluntary contraction score. This contraction level was reached at the beginning of the stimulation and maintained for 4 s.

Testing

Isokinetic test. Maximal voluntary torque of the right knee extensor muscles (N·m) was measured before and after the 3-wk period, using a Biodex isokinetic dynamometer (Biodex Corporation, Shirley, NY) validated by Taylor et al. (26). A 7-min period of standardized warm-up and familiarization with the measurement apparatus was conducted with submaximal repetitions at each experimental angular velocity. Then subjects performed three maximal voluntary knee extensions at five concentric angular velocities (60, 120, 180, 240, and $300°\cdot s^{-1}$) and at two eccentric velocities (-60 and $-120°\cdot s^{-1}$) with a 90° range of motion (starting position = 10° knee flexion). In each case, only the best performance was retained. A 4-min rest period was allowed between each trial. To minimize hip and thigh motion during all contractions, a series of straps were applied across the chest, pelvis, mid-thigh, and lower leg. The latter strap secured the leg to the dynamometer lever arm. The alignment between the center of rotation of the dynamometer shaft and the axis of the knee joint (lateral femoral condyle) was checked at the beginning of each trial. The subject's arms were positioned across the chest with each hand clasping the opposite shoulder. Torques were gravity corrected at each joint angle, using the torque produced by the weight of the limb at a joint angle corresponding to the maximal gravity effect (26). For each angular velocity, the 60° knee flexion maximal voluntary torque (constant angular torque technique) was directly computed by the Biodex software and included in the analyses.

Vertical jump test. Jumping ability was evaluated with a contact mat (Globus, Codogne, Italy). The squat jump (SJ), countermovement jump (CMJ), and drop jump (DJ) from a height of 30 cm were randomly performed according to Asmussen and Bonde-Petersen's recommendations (1). Three tests were carried out for each type of jump, and the best result was retained. Fifteen consecutive CMJ (15J) were also performed to evaluate the resistive capacities of the knee extensors. During this 15J test, jump height and power were measured for each jump and then averaged together.

Sprint test. Times, determined at the hip level for 10- and 30-m sprints on ice, were measured with infrared photoelectric cells (TEL.SI s.r.l., Vignola, Italy) positioned 10 and 30 m from the start line and controlled by commercially available software. The players set off upon a visual signal and skated as fast as possible the 30-m distance. This sprint allowed us to directly measure both times with the 10-m time as intermediate. Only the best performance of three trials was retained.

Statistical Analysis

Mean values and standard deviations (SD) were calculated for all variables. A repeated measures analysis of variances (ANOVA) followed by a Newman–Keuls *post hoc* procedure was used to test differences between both groups and the effects of the EMS program on dependent variables (strength, jump, and sprint performances) in each group before and after the 3-wk period. Relationships between isokinetic strength, vertical jump, and skating performance were also examined using Pearson product correla-

TABLE 1. Vertical jump performances on electrostimulated (ES) and control (C) groups before and after a 3-wk period. Values are means (± SD).

	ES Group		C Group	
	Before	After	Before	After
SJ (cm)	34.9 ± 6.0	32.0 ± 3.1†*	35.8 ± 4.3	35.5 ± 4.3
CMJ (cm)	38.1 ± 5.0	36.0 ± 4.5†*	40.8 ± 3.5	40.6 ± 3.6
DJ (cm)	31.6 ± 1.9	30.3 ± 2.4*	32.2 ± 0.3	29.9 ± 7.1
15J height (cm)	26.3 ± 2.7†	26.9 ± 3.1†	29.5 ± 1.1	29.3 ± 2.9
15J power (W)	24.1 ± 4.0†	26.4 ± 5.4*	27.7 ± 2.3	26.9 ± 5.5

SJ, squat jump; CMJ, countermovement jump; DJ, drop jump; 15J, 15 repetitive CMJ.
* Significantly different than before the 3-wk period ($P < 0.05$); † Significantly different than the C group for a similar period ($P < 0.05$).

tions. In all statistical procedures, a 0.05 level of significance was adopted.

RESULTS

Before training, no significant difference was observed between ES and C groups in physical characteristics, knee extensor strength, and skating performance. C group had, however, significantly higher values for 15J height ($P < 0.01$) and power ($P < 0.05$) compared with ES group (Table 1). When considering both groups ($N = 17$) before the 3-wk period, a significant negative relationship was observed between the 10- and 30-m skating performance and the $240°\cdot s^{-1}$ concentric torque ($r = -0.61$, $P < 0.01$ and $r = -0.76$, $P < 0.01$, respectively, for 10 and 30 m; Fig. 1).

Muscular strength. After 3 wk of EMS training, the isokinetic torque increased significantly (Fig. 2) for ES in eccentric (37.1 ± 21.9% at $-120°\cdot s^{-1}$ and 24.2 ± 17.9% at $-60°\cdot s^{-1}$; $P < 0.01$), and concentric conditions (41.3 ± 37.6% at $60°\cdot s^{-1}$ and 49.2 ± 48.9% at $300°\cdot s^{-1}$; $P < 0.05$). Except for the $-60°\cdot s^{-1}$ eccentric condition, the C group did not exhibit any significant torque increase. When comparing torque changes after the 3-wk period, it appears that the ES group had significantly higher torque increases than the C group. The $-60°\cdot s^{-1}$ eccentric torque increase was, however, not significantly different between the ES and C groups.

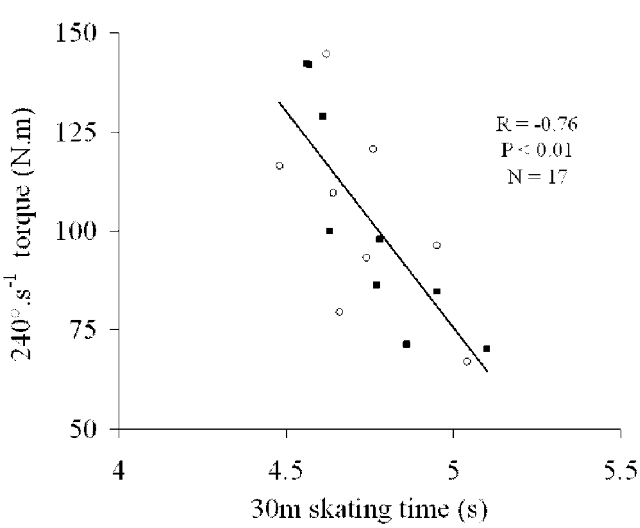

FIGURE 1—Relationship between the $240°\cdot s^{-1}$ concentric torque and the 30-m skating time obtained before the 3-wk period. ES (*filled square*) and C groups (*open circle*) have been grouped together to fit the linear relation.

Vertical jump performance. Vertical jump results, obtained before and after the 3-wk period, are shown on Table 1 for both ES and C groups. After EMS training, the ES group vertical jump height decreased significantly ($P < 0.05$) for the SJ (−8.4 ± 6.9%), CMJ (−6.1 ± 6.0%), and DJ (−5.2 ± 4.6%). No significant difference was found before and after the 3-wk period for members of the C group. For the ES group, the 15J power increased after training (14.3 ± 17.2%; $P < 0.05$), whereas gain in 15J height was not significant. No significant difference was obtained for the C group.

Skating performances. For the ES group, the 10-m skating time significantly declined (−4.8 ± 5.8%, $P < 0.05$), whereas no change was observed for 30-m sprints (Fig. 3). C-group skating performances were comparable before and after the 3-wk period.

DISCUSSION

The present study demonstrated that a 3-wk EMS training program enhanced isokinetic eccentric and concentric strength of the knee extensor muscles as well as skating performance of a group of competitive ice hockey players compared with a control group. This suggests that EMS may be a useful mean for developing muscular strength and skating speed in ice hockey players. These findings are consistent with previous reports confirming that brief periods of EMS have beneficial effects on muscle strength (13,16,21) and specific abilities of highly skilled athletes (14,15,20).

It is generally accepted that neural adaptations predominate in short-term voluntary strength training and EMS training (5,16). For instance, Maffiuletti et al. (14) recently suggested that EMS training would increase the neural drive from supraspinal centers, resulting in a greater number of recruited motor units. Therefore, strength gains observed after the present EMS training during concentric (60 and $300°\cdot s^{-1}$) but more likely during eccentric (−120 and $-60°\cdot s^{-1}$) maximal voluntary isokinetic contractions could be partly attributed to neural adaptations. Surprisingly, the $-60°\cdot s^{-1}$ eccentric strength was also improved for the C group, the improvement being similar to the ES group. This result suggests that strength gains, observed in the present study, could be partly explained by the fact that after the 3-wk period subjects were more accustomed to perform isokinetic contractions. Nevertheless, such a conclusion is only valid for a given angular velocity, and strength gains obtained for our ES group would be primarily attributed to

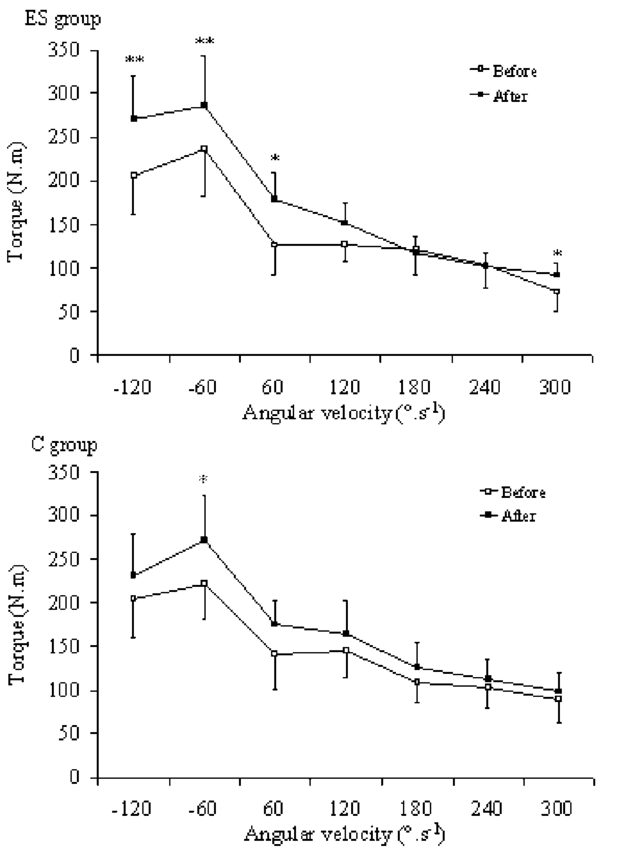

FIGURE 2—Torque–angular velocity relationship of the knee extensors using a constant angular torque (60°) for electrostimulated (ES group; upper graph) and control group (C group; lower graph). Values are means (± SD); * and ** indicate values significantly higher than before the 3-wk period at $P < 0.05$ and $P < 0.01$, respectively.

neural adaptations preferentially affecting fast-twitch fibers. Indeed, fast-twitch fibers have been suggested to be preferentially recruited during eccentric contractions ((7,19); for a contrary view, see (25)) and increasingly recruited at high concentric velocities (2,4,8). Moreover, the effectiveness of supplementing training with electrical stimulation is based on the concept that fast-twitch fibers are activated first and to a greater extent than that predicted by Henneman's size principle (3,5,6,24). Whatever the underlying mechanisms related to strength gains, the present study supports Kots and Chwilon's previous hypothesis (11). Indeed, as originally obtained (11), EMS-induced contraction increases strength and would correct the maximal voluntary contraction force deficit by achieving maximal motor unit recruitment, thereby allowing greater force production. The fact that EMS corrected the force deficit by possibly resulting in a greater proportion of fast motor units being recruited beyond those of voluntary contraction could be the basis for greater strength gains.

Research concerning the effect of EMS training on vertical jump performance is very limited. In the present study, SJ, CMJ, and DJ height significantly decreased after 3 wk of EMS. Such findings are somewhat surprising but are in general accordance with previous experiments. Indeed, several studies dealing with the effects of EMS on vertical jump found no significant change in single jump height (27,29). Other authors observed improvements of the jumping ability only 10 d (15) or 4 wk (13) after the end of the EMS training period, whereas no or few gains were registered immediately after the training program. Compared with these two last-cited studies (13,15), which use quite similar stimulation procedures to our experiment, our observed impairment in vertical jump ability could be attributed to the population tested. Indeed, these two studies (13,15) considered subjects that were specifically trained for vertical jumps, also in addition to their EMS program, because they were volleyball (15) or basketball (13) players. Contrarily, in our study, subjects were not specifically trained for vertical jumps but for speed skating. Therefore, training alone does not appear efficient enough to improve the neuromuscular performance during complex and specific abilities such as vertical jumps but seems sufficient to improve the monoarticular performance by a neural drive enhancement. Thus, specific and longer training sessions are required to observe beneficial effects in vertical jump performances by allowing a more complete control of the neuromuscular properties and/or to develop the elastic behavior of skeletal muscle. In the present study, such more complete control of the neuromuscular properties during complex tasks has been demonstrated when considering the skating performance (see below).

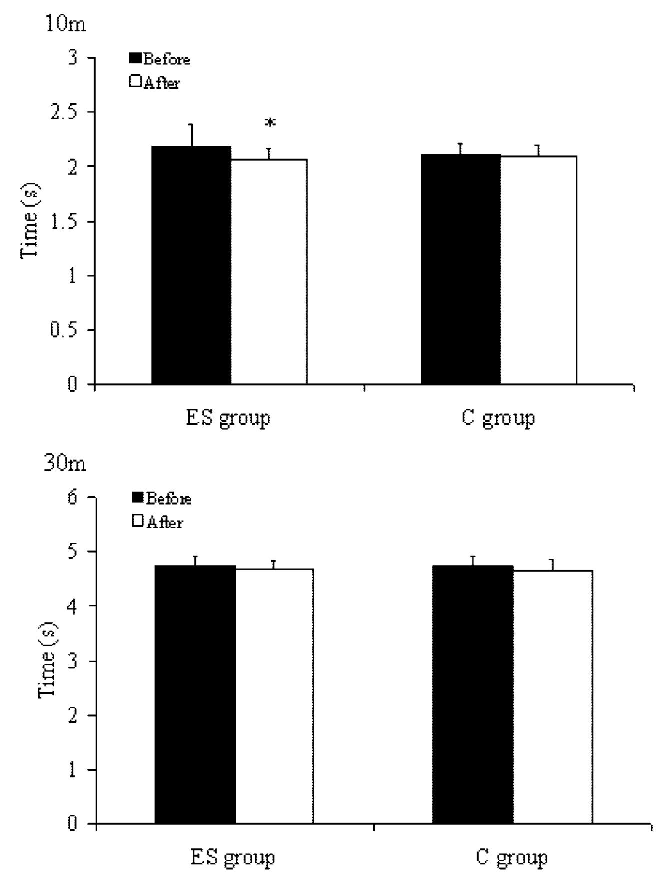

FIGURE 3—Skating times for electrostimulated (ES) and control groups (C) over 10 m (upper graph) and 30 m (lower graph). Values are means (± SD); * indicates values significantly lower than before the 3-wk period at $P < 0.05$.

Nevertheless, EMS training also has positive effects on vertical jump ability and, more particularly, on the 15J mean power. This significant power increase in the 15J procedure, already registered (15), would reveal better resistive capacities of the knee extensor muscles. Translated in practical terms, this finding suggests higher performances toward the end of specific ice hockey sequences. Moreover, it may be speculated that this 3-wk EMS training program may have a specific effect during match situations. Indeed, these improved resistive and neuromuscular capacities of the knee extensors could be beneficial, since skating requires repetitive and rapid movement direction changes.

Skating performance was significantly correlated to the $240°\cdot s^{-1}$ concentric muscular strength ($r = -0.61$ and $r = -0.76$, respectively, for 10 and 30 m). Thus, the practical applications of EMS training cannot solely amount to strength gains and better resistive capacities, but also to an improvement of the skating performance, with a significant decrease in 10-m (but not in 30-m) skating time. The 30-m results are much more representative of the maximum sprinting speed but are less important in ice hockey situations. Indeed, during match-winning situations, players are able to exceed an $8\text{-m}\cdot s^{-1}$ velocity just after four strides (18). The quick dash at the beginning of the sprint, concomitant with the increased knee extensor strength, could be a result of the EMS training and could suggest a possible translation effect on short-sprinting performance. However, no correlation was found between gains in muscular strength and in 10-m skating performances. Therefore, as suggested by others (15), this specific EMS training-induced adaptation could result from the concomitant ice-hockey workouts during the EMS training program that would enable the central nervous system to optimize the neuromuscular properties control. Thus, sport-specific trainings should be performed during EMS to obtain specific adaptations.

The EMS training used in the present study was basically a form of isometric strength training. Like in the present study, strength increases are often observed after EMS (12,17,21,23), but, interestingly, these are not superior to those obtained during voluntary training performed with similar intensities and durations (12,17,23). Thus, when used in conjunction with periodized exercise programs, EMS appears more effective to increase the knee extensor strength (11,13,28) through its translation effect on dynamic performance like the 10-m speed skating. Another advantage with EMS would be that training sessions have more often than not shorter duration (12 min) compared with voluntary strength trainings. However, the effects of EMS training on the physical performance of healthy individuals is still unclear, and more research is needed to investigate the use of EMS in conjunction with isometric contraction (either voluntary or EMS-induced) and in conjunction with other types of training, thereby increasing the specificity of training (e.g., plyometrics).

To summarize, the present study demonstrated that an increase in the eccentric and concentric strength of the knee extensors and skating performance can be achieved in a relatively short period (3 wk) by using EMS training. As a practical recommendation for ice hockey players, it is suggested that EMS training could be used over the season to enhance strength and skating performance without interfering with ice hockey training. Nevertheless, further experiments are needed to determine long-term benefits of the EMS training during ice hockey.

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