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The Optimal Time Window for Complex Training in Order to Increase Repeated Sprint Ability in Professional Ice Hockey Players

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ABSTRACT

The goal of this study was to investigate the post-activation performance enhancement (PAPE) and optimal time window following complex training (CT) to increase ice-hockey player skating speed and endurance. Ten professional ice-hockey players (age= 19.8±1.23 years, height= 1.8± 0.06 m, weight= 83.37±4.79 Kg,) from the American Hockey League (AHL, n=7) and the National Hockey League (NHL, n=3) were assigned randomly into two groups. Both groups completed the same CT training protocol, designed to induce post-activation potentiation (PAP). One group completed the training 8 hours prior to testing (8HPT), and the other 4 hours (4HPT) before testing. The CT PAP training protocol consisted of 3 sets of 5 repetitions of trap high bar deadlifts superset with 6 box jumps on a 20-inch plyometric box. The effect of CT PAP training on performance was assessed using the following testing: the countermovement jump (CMJ), the static squat jump (SSJ), the stationary broad jump (BJ), reactive strength index (RSI), eccentric utilization ratio (EUR), the double leg incremental drop jump tests (DJ), and on ice 40 meter sprint time during the Peterson On-Ice repeated shift Test (POIT). Results showed significant improvements for both groups for the after CT PAP training for the SJ (4HPT: $p= 0.04$), BJ (8HPT: $p= 0.02$; 4HPT: $p=0.03$), POIT (8HPT: Sprint 4, 5, 6, 8: $p<0.05$; 4HPT: Sprint 2, 3: $p<0.05$), POIT total sprint time (8HPT: $p= 0.01$), mean 40-meter sprint time (8HPT: Sprint 1, 2, 3, 4, 5, 6 and 8: $p<0.05$; 4HPT: Sprint 2, 3, 4, 5, 6 and 7: $p<0.05$), and total 40 meter sprint time (8HPT and 4HPT: Sprint 2 $p= 0.03$). However, no significant difference ($p\geq0.05$) was found following CT PAP training for the CMJ, DJ, and RPE. Thus, the present study suggests that PAP has a greater effect on jumping and on ice-hockey repeated sprint performance when completed 8 hours before. Nonetheless, CT PAP training appears to be beneficial to improve the rate of force development and performance when performed more than 4 hours before the competition in professional North-American ice-hockey players. The present protocol and timing window can be utilized by strength and conditioning specialists to improve on-ice repeated sprint performance of professional ice-hockey players.

Keywords: Contrast Training; Pre-Game Training; Resistance Training; Skating Speed; Rate of Force Development (RFD), On-Ice Sprint, Acceleration, Repeated Sprint

INTRODUCTION

Post-activation potentiation (PAP) is defined as an acute increase in performance following a high load stimulus, often elicited through the use of heavy strength training exercises. The short-term improvement (5-30 mins) of PAP on jumping performance has been extensively studied over the past two decades (13, 27, 53,12, 21, 43, 46). Lately, it has been shown that a large proportion of the physiological and neuromuscular adaptations following a PAP strength training protocol could have a positive impact on athletic performance for several hours or even days following the PAP session (9, 16, 20, 51).

In contrast, PAPE (terminology use in the performance approach) was suggested to indicate the enhancement of maximal voluntary (dynamic or isometric) strength, power, or speed following a conditioning contraction (5). Recent research has linked these long-term neural adaptations to the post-activation performance enhancement (PAPE) (5). These studies have displayed that strength can be positively affected by transient changes induced by PAPE in the ability to produce force (24), as well as by long-lasting adaptations such as increase in voluntary activation (52), increased motor unit recruitment and an increase in rate of force development (RFD) (14, 34). Furthermore, complex training (CT), or the use of contrast loading (heavy loading /slow movement vs light loading /fast movement) to elicit acute enhancements in power output, force production (PAP response) and RFD is the most popular method used by strength and conditioning (S&C) coaches (13, 15, 49, 50).

Previous studies that have investigated the use of CT training protocols that included a strength movement followed immediately by a biomechanically similar power movement have demonstrated significant improvements in jumping performance and short sprint speed, whereas others found no such change in performance 3 to 12 mins after the training protocol (2, 8, 15, 25, 43).

To the authors knowledge, only two studies have used CT training in order to induce PAPE in ice-hockey players (29, 32). Matthews et al. reported a 2.6% (±0.04%) decrease in the 25-m ice sprint time 4 minutes after performing a heavy resisted sprint. (32)Lagrange et al. assessed repeated 40-meter on-ice sprints performed 6 hours after a CT training protocol. They reported a significant decrease in total sprint time (-4.1% ±0.6%), and an increase in both total mean sprint speed (4.3% ± 0.8%) and first 40-meter sprint speed (5.5% ± 0.8%) when compared to the control group (29).

In ice hockey, RFD is considered one of the most important factors to develop during strength training sessions in order to improve skating speed (29, 32). Previous research has shown that maximal strength and RFD can be improved through PAP methods (47). Thus, the annual periodization of a strength training program and the use of CT training protocols in order to increase ice-hockey game performance must be well embedded into the team annual and seasonal calendars in order to allow players to optimize their performance. Therefore, it is important to determine the optimal timing window of a CT training protocol to improve the ability to perform repeated sprints in ice-hockey players.

Thus, the purpose of this study was to compare two-time windows for the same CT protocol. The CT protocol was carried out either four or eight hours before on-ice repeated sprints and lower body power testing sessions in order to determine the PAP enhancement effect of both recovery time windows. The hypothesis being that the CT training protocol executed eight hours before would significantly improve on-ice repeated sprint ability and lower body power to a larger extent than the four-hour window. The present results will allow practitioners to determine the optimal window of time for CT (four or eight hours) before a competition with ice hockey players.

METHODS

Experimental Approach to the Problem

A quasi-experimental approach was adopted for this study, where a same-subject repeated measures design was used to determine the optimal time window by comparing the repeated on-ice sprints and lower body power testing after CT four (4HPT) or eight (8HPT) hours before. In addition, this sample size was enough to be able to obtain statistically significant results in terms of data saturation. A power calculation (G*Power, Ver.3.1.9.6) using the results of Lagrange et al. (2020) on the primary variable of total sprint time revealed that a total sample of n=8 was required. The power calculation was performed by retaining a size effect (d) of 1.0, an alpha value (α) of 0.05, and beta (β) of 0.80 on a two-factor repeated measures ANOVA model (group x time). The total recruitment was n=10, so 2 more than required by the power calculation and justified not using a control group with our specific cohort.

Prior to data collection, an ethical certificate (IRB No 3256) was obtained through the University of Quebec at Montreal's (UQÀM) institutional review board.

Subjects

Subjects (n=10) participating in this study were elite American Hockey League (n=7, AHL) or National Hockey League (n=3, NHL) hockey players, aged 18 to 22 years of age (19.8±1.23 yrs) with a minimum of 3 years of resistance training experience. The selection of our experimental model was justified by: (1) similar experimental models published on the improvement of jumps in athletes following PAP training (43, 44, 46), (2) the validation of our experimental model on elite hockey players (n=41) (29) and (3) that no learning and improvement effect could be observed between the groups by separating the data between pre-and post-test measurements of more than a week difference (18, 22).

Procedures

The data collection was conducted during the subject's off-season. Subjects were asked to refrain from training for 48 hours prior to each testing day. The total time to conduct the entire battery of testing was 3 hours. No instructions were given regarding nutrition and beverage intake. All testing was conducted in the evening (around 7:00 PM) to mimic evening hockey game conditions. At the start of the first testing session, the subject's height, weight, and body fat % were measured. Body fat % was estimated with 10 skinfolds (chin, cheek, pectoral, triceps, mid axillary, supra-iliac, umbilical, subscapular, knee, and calf) using the Zwiren Allen equation (1).

A mandatory standard dynamic warm-up was performed before each on or off-ice session to reduce the risk of injury. Briefly, the warm-up consisted of dynamic preparatory activities and functionally based movements that are specifically designed to prepare the body for the sport. Lower body power was assessed using the following: countermovement jump (CMJ), static squat jump (SSJ), stationary broad jump (SBJ), Reactive Strength Index, eccentric utilization ratio, and the double leg incremental drop jump tests (30, 45, 60 and 75cm) (DJ).

The CMJ required the subjects to squat down, then jump maximally for height without pausing. For the SJ, the instructions were the same as the CMJ except the subject was asked to wait at the 90° knee bent position for 2 seconds with their arms on their hips before jumping as high as they could. For both jumps, subjects were told to keep their knees straight during the flight phase. The Bosco mat was used to calculate jump height by measuring flight time (28). The BJ test was executed by having the subjects stand stationary behind a line drawn on the floor and then jump maximally for distance. Jump distance was measured from toes (line) to the closest heel. The best of 2 attempts was used for each jump test. In addition, for vertical jumps (CMJ and SJ), the GymAware (Mitchell, Australia) device (Fig. 1) was attached to each subject via a waist belt and the device was stabilized on the ground using a 10 lbs metal plate (36). This was used to assess total and peak power throughout the jumps.

The gFlight sensor (V.2.0, Exsurgo Technologies, Sterling, VA) was used to assess ground contact

Table 1. Physical characteristics.

Variables	All (n=10)	8HPT (n=5)	4HPT (n=5)
Age (years)	19.8 ± 1.2	19.8 ± 0.8	19.8 ± 1.6
Weight (lbs)	183.4 ± 10.2	187.0 ± 7.9	179.7 ± 12.5
Height (cm)	180.1 ± 6.8	182.1 ± 8.4	178.4 ± 5.1
BMI (kg/m2)	25.7 ± 1.8	25.7 ± 1.4	25.7 ± 2.1
Lean Mass (lbs)	165.9 ± 9	169.8 ± 6.6	161.9 ± 11.4
Body Fat Percentage (%)	9.6 ± 1.1	9.2 ± 0.6	9.9 ± 1.6

Note: There was no significant difference between groups, p≤0,05;* Mean ± (SD.).

time and jump height for the drop jump tests. The sensor was placed 45 cm from the box and subjects were instructed to step down from the box and jump as high as possible, and as quickly as possible, once they hit the ground. The test started with a box height of 15 cm and progressed to a 75 cm height using 15 cm increments. The test ended when the subject's ground contact time increased beyond 0.25 ms. Reactive strength index (RSI) was calculated by dividing the subject's jump height by the ground contact time during the rebound phase of a drop jump (19). These off-ice jump tests have direct applicability to lower body muscular power and rate of force development (RFD) that is associated with on-ice performance in skating speed and acceleration in elite hockey players (17, 23).

At the end of the off-ice testing session, subjects had 75 minutes to put on their gear (ex: Underwear, socks, shin guards, shoulder pads, elbow pads, skate, hockey pants, helmet, gloves, etc.) before the on-ice skating repeated sprint test.

The Peterson's on-ice repeated shift test (POIT) included 8 consecutive repeated shifts with 90 seconds of recovery between one. This validated test mimics a hockey player's typical shift which last approximately 30 seconds (30, 38, 39). Sprint performance was measured with photocell timing gates, as shown in Fig 2, placed at the start and at the end of the test and for a 40-meter sprint (between laser #2 and #3) to compare with our previous studies as shown in (29). The side start was the starting position for all the repeated sprints. After each sprint, the peak heart rate was recorded using a heart rate monitor (RS400, Polar, FI) to validate that during the sprint player heart rate should at a minimum reach 85% of their estimated maximum heart rate at each sprint (45). After completing the 8 repeated sprints, the players recorded their rate of perceived exertion (RPE) using a Borg scale (score of 1 to 10) (6). Total sprint time, fatigue index, and exertion perception are the most widely used measures to observe improvement in performance and the onset of fatigue (35). The use of RPE was to ensure that potential changes in performance were due to the CT protocol and not as a result of a change in perceived effort.

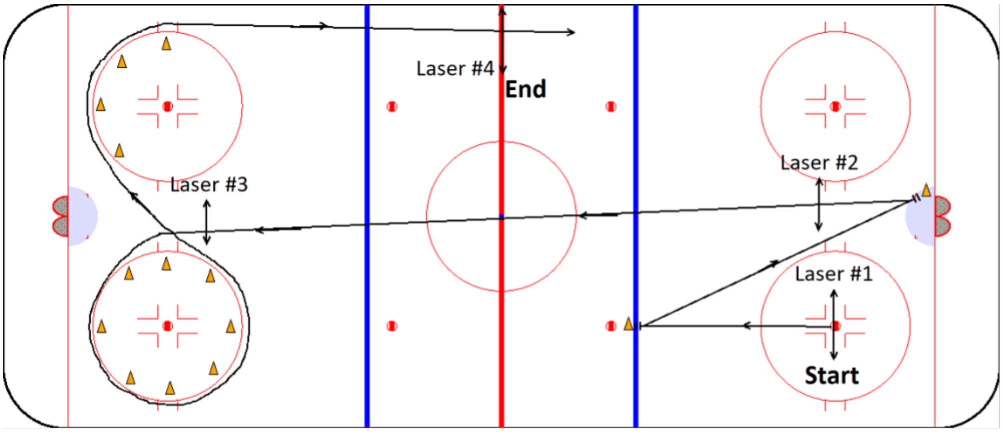

Figure 1. Peterson's repeated sprint test.

Table 2. Experimental procedures.

Order	Exercises	Sets	Repetitions	Tempo	Rest$_{(sec)}$	Load (%)
Warm-up	Trap bar Deadlift	4	6 ,4 ,2, 1	4-1-X-1	90-240	83%, 88%, 94%, 100%
A1	Trap bar Deadlift	3	5	4-1-X-1	15	85% 1 RM
A2	Box Jump (20 inches)	3	6		240	

Ten days following the first testing session subjects were randomly divided into two groups. The first group (8HPT) and the second group (4HPT) performed the same CT training protocol either eight or four hours before physical testing, respectively. No instructions were given regarding the 4-8 hours windows in terms of nutrition, recovery tools and beverage intake. The selection of our PAP exercise using the high trap bar (Rogue TB-2) deadlift has a smaller range of motion than the conventional squat or deadlift and is supported by previous research that has shown that the use of partial movements can enable the athlete to use supra-maximum loads and promote the increase in force production more quickly (48). The CT protocol is detailed in Table 2. At the appropriate time following the CT protocol, each group performed the same battery of tests as described above. Thus, the 8HPT group executed the CT training at11 AM,) eight hours before testing at 7:00 PM, while the 4HPT group executed the CT training at 3 PM, four hours before testing. No control group was used in this study since the latest research by Lagrange et al. showed with 41 elite hockey players that CT training improves the ability to repeat on-ice 40m sprint speed (29).

Statistical Analyses

All data are presented as mean and standard deviation (SD). The experimental plan consisted of two groups (8HPT and 4HPT), with pre- and post-CT training measures. Statistical analysis of anthropometric measurements for both groups (8HPT and 4HPT) was compared using the independent samples t-test. The differences in test performance between both groups were detected using a two-way repeated measure ANOVA (group X time). If a difference was detected, then a Post Hoc analysis was run using a paired comparison test (LSD). The effect size (ES) was calculated using Cohen's d where d ≥ 0.20 was considered a small ES; d ≥ 0.50 an average ES, and d ≥ 0.80 a large ES. A significant difference was retained when $p < 0.05$. Data were analyzed with SPSS software, version 21.

RESULTS

Lower-body Power

Results show that there was no significant difference between pre-and post CMJ test results for the 8HPT or 4HPT groups. Similarly, no significant difference was found in total DJ height for either group. There was a significant improvement between pre-and post-test scores for the 4HPT group in the SJ ($p=0.04$) and EUR ($p=0.04$). While both groups saw a significant improvement in BJ (8HPT: $p=0.02$; 4HPT: $p=0.03$). All data related to lower body power measures can be found in Table 3.

To see the effect of CT, regardless of the time interval since the CT session, on lower body power, we conducted paired-samples t-tests on the pre-and post-CT data (Table 4). This showed no significant difference CMJ or maximal height achieved during the DJ. However, CT prior to testing did result in an increase in SSJ ($p=0.01$), SBJ ($p=0.01$), and RSI ($p=0.05$). At the same time, EUR decreased following CT training ($p=0.02$).

Peterson On-Ice repeated shift Test (POIT)

Total time to complete all 8 sprints in the POIT decreased significantly more in the 8HPT group compared to the 4HPT group (Table 3). When assessing the sprints individually, the 8HPT group saw a decrease in the time to complete sprints 4,5,6, and 8 following the CT. Whereas the 4HPT group saw a decrease in the time to complete sprints 2 and 3 (Figure 2A). There were no significant differences seen in fatigue index or decrement of fatigue in either group, pre-and post-CT (Table3). To ensure each group's efforts were similar for pre-and post-testing, HR and RPE were recorded. There were no significant differences in HR or RPE for either group, pre-and post-CT, suggesting that any differences seen were not due to changes in effort intensity. (Table 3).

Again, we pooled the POIT data to see if CT training had a significant performance. These results show that prior CT PAP protocol significantly decreased the time taken to complete all 8 sprints in the POIT ($p=0.01$) (Table 4). No significant difference was seen in the fatigue decrement or the fatigue index. The decrease in total sprint time occurred without any change in HR or RPE, suggesting that the difference was related to the CT PAP and not a change in intensity of effort. When looking at the 8 individual sprints, we see that the CT PAP resulted in a significant decrease in the time it took to complete each sprint of the POIT in 6 of the 8 trials and decreased the time to cover 40m in all of the 8 trials (Figure 3).

Table 3. Physical and physiological responses between groups after CT training protocol

VARIABLE	8 Hours Before Group				4 Hours Before Group			
	Pre	Post	(Δ)	d_{cohen}	Pre	Post	(Δ)	d_{cohen}
CMJ (cm)	64.6 ± 3.4	65.3 ± 3.3	0.7 ± 3.8	0.2	68.6 ± 7	63 ± 9.6	5.5 ± 5.9	0.7
Gymaware (Power/Watt)	5261.2 ± 919.4	5424.4 ± 672.1	163.2 ± 855.4	0.2	5518 ± 1027.5	5684 ± 1425.5	166 ± 668.6	0.1
SSJ (cm)	55.5 ± 4.4	61 ± 8.7	5.5 ± 5.8	0.8	58.3 ± 4.4	65.9* ± 5.9	7.6 ± 5.5	1.5
PeakPower (watt)	4789.1 ± 364.4	4864.5 ± 352.1	75.4 ± 401.8	0.2	5214.5 ± 737.3	4627.5 ± 1019.5	586.9 ± 630.7	0.7
EUR (CMJ/SJ)	1.2 ± 0	1.1 ± 0.2	0.1 ± 0.2	0.7	1.2 ± 0	1* ± 0.2	0.2 ± 0.2	1.4
SBJ (cm)	248.2 ± 6.5	261.6* † ± 10.6	13.4 ± 8.2	1.5	253.2 ± 15.4	263.8* ± 15.3	10.6 ± 7	0.7
Drop Jump (avg)	36.3 ± 4.7	37.1 ± 4.1	0.8 ± 0.6	0.6	38.9 ± 4.5	37.1 ± 8.3	1.8 ± 3.8	0.3
RSI	1.7±0.2	1.8±0.4	0.1±0.3	0.2	1.7±0.5	2.0±0.8	0.3± 0.7	0.4

Note: † Significantly improved between groups, p≤0,05; significantly improved (pre to post) p≤0,05; Mean ± (SD.); SSJ: Static Squat jump, CMJ: Countermovement jump, SBJ: stationary broad jump, GCT: Ground contact time, RSI: reactive strength index, EUR: Eccentric utilization ratio.*

Table 4. Lower Body Power responses before and after CT training protocol. All subjects (n=10)

Tests	Pre	Post	(Δ)	p-value
CMJ (cm)	66.5 (5.5)	64.3 (6.8)	-2.2	0.22
SSJ (cm)	56.8 (4.3)	63.5* (7.6)	6.7	0.01
SBJ (cm)	250.7 (11.4)	262.7* (12.5)	12	0.01
Drop jump-avg. (cm)	38.7 (5)	39.2 (6.2)	0.5	0.81
EUR ratio	1.2 (0)	1* (0.2)	-0.2	0.02
RSI	1.8 (0.1)	2.2* (0.4)	0.4	0.05

*Note: * significantly different (pre to post) p≤0,05; Mean ± (SD.); SSJ: Static Squat jump, SBJ: Broad jump, CMJ: Countermovement jump, EUR: Eccentric utilization ratio, RSI, reactive strength index.*

Table 5. Physical and physiological responses between groups after CT training protocol

VARIABLE	8 Hours Before Group				4 Hours Before Group			
	Pre	Post	(Δ)	d_{cohen}	Pre	Post	(Δ)	d_{cohen}
8 Sprint Total	181.4 ± 8.6	174† ± 5.4	7.4 ± 6	1.03	175 ± 5.6	170.2 ± 4	4.8 ± 4.1	4.8
DF%	1.7 ± 3.8	1 ± 1.4	0.7 ± 3.2	0.2	0.3 ± 3.9	0.9 ± 2.1	0.6 ± 4.9	0.6
FI%	4 ± 4	2.3 ± 1.4	1.7 ± 4.2	1.5	-0.2 ± 11	4.8 ± 5.1	5 ± 14.5	3.3
HR_{avg}	164 ± 2.4	169.4 ± 3.5	5.4 ± 4.8	1.8	165.7 ± 3	163.6 †± 2.6	2.1 ± 3.3	2.1
RPE_{avg}	6.2 ± 0.5	6.6 ± 0.9	0.3 ± 1.1	0.6	6.6 ± 0.5	6.9 ± 0.7	0.3 ± 0.9	0.3

Note: † Significantly improved between groups, p≤0,05; significantly improved (pre to post) p≤0,05; Mean ± (SD.); HR avg: Heart rate average, RPE avg: Rate perceived effort average, FI: Fatigue index, DF: Decrement fatigue.*

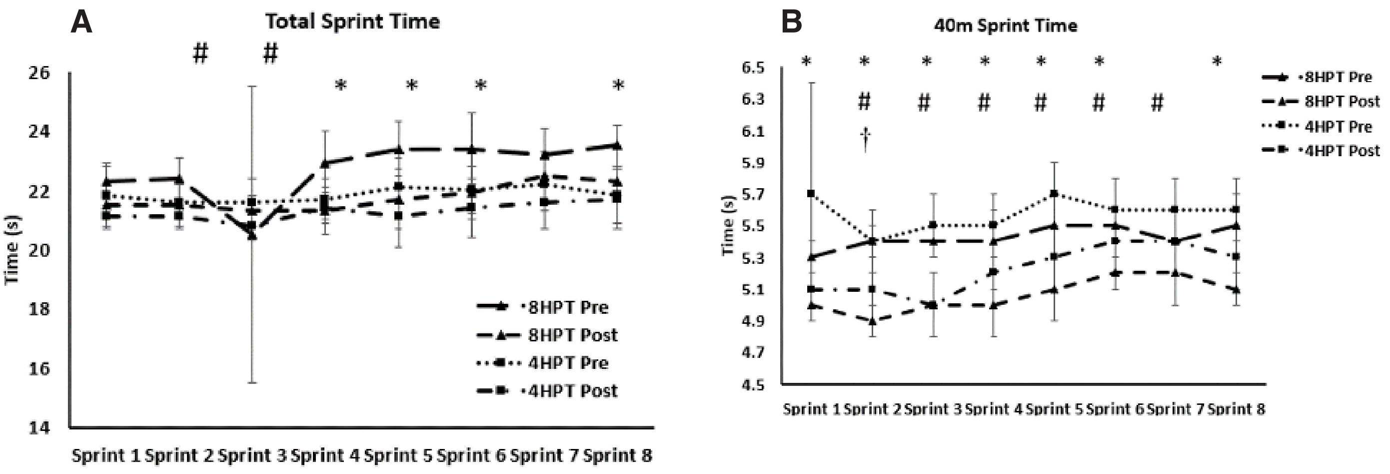

Figure 2. The effect of CT on repeated sprint time and speed. A) Total sprint time (sec) as a function of sprint number. B) 40-meter sprint time as a function of sprint number. Note: † Significantly improved between groups, p≤0,05; * significantly improved (pre to post) 8HPT p≤0,05;# significantly improved (pre to post) 4HPT p≤0.05.

Table 6. Physical and physiological responses before and after CT training protocol. All subjects (n=10)

Tests	Pre	Post	(Δ)	p-value
Total 8 sprints	178.2 (7.7)	172.1* (4.9)	6.1	0.01
HR $_{avg.}$	164.9 (2.7)	166.5 (4.2)	2.5	0.37
RPE $_{avg.}$	6.4 (0.5)	6.7 (0.8)	0.3	0.3
DF%	1 (3.7)	1 (1.7)	0	0.97
FI %	1.9 (8.1)	3.6 (3.8)	1.7	0.63

*Note: * significantly different improved (pre to post) p≤0,05; Mean ± (SD.); HR avg: Heart rate average, RPE avg: Rate perceived exertion average, FI: Fatigue index, DF: Decrement fatigue.*

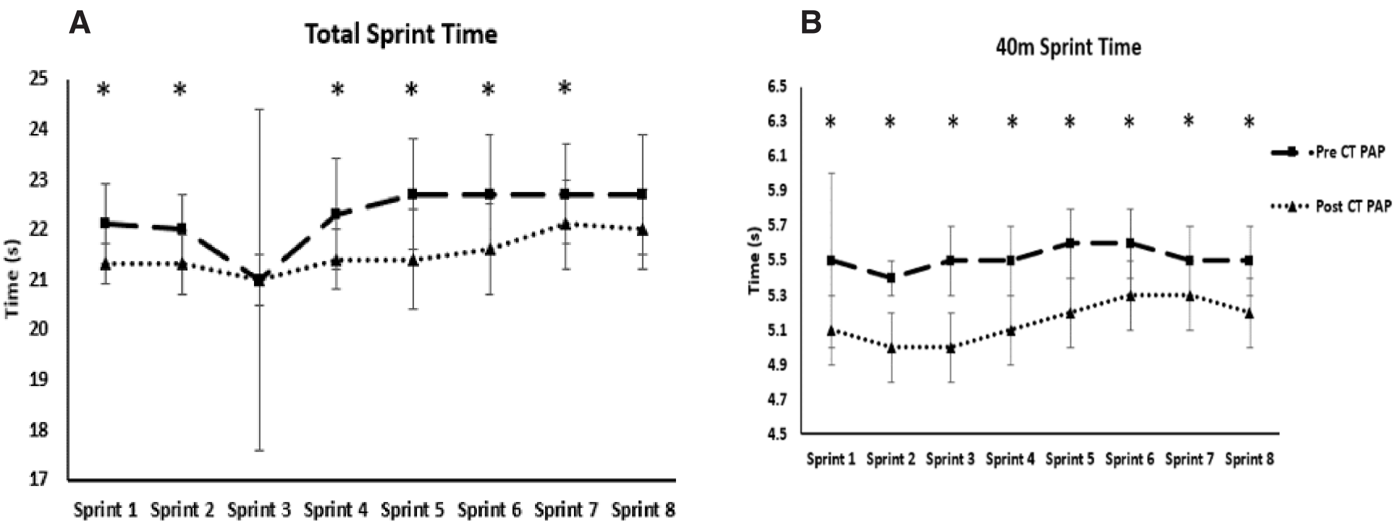

Figure 3. The effect of CT on repeated sprint time and speed (groups combined). A) Total sprint time (sec) as a function of sprint number. B) 40-meter sprint time as a function of sprint number. Note: * significantly improved (pre to post).

DISCUSSION

The purpose of this study was to investigate the effects of two-time windows (eight or four hours) following the same complex training protocol on lower body power and on-ice repeated sprint ability. The aim was to determine the post-activation performance enhancement effect (PAPE) of each protocol and investigate if one was superior to the other. However, this study also aimed to confirm that the CT protocol used did induce PAPE, regardless of the time between training and testing.

The results suggest that performing this complex training protocol eight hours prior to an on-ice repeated sprint test reduces professional ice hockey players' total sprint time and improves their average speed more so than four hours prior. This was confirmed by the fact that all subjects seemed to have provided the same effort (no significant difference between the two groups, pre-and post-intervention for RPE). Also, the result combined showed there was a significant reduction in almost all of the 40m sprint time for all of the subjects. Thus, the improvement observed in the repeated sprint seems to be generated by the induced CT training protocol coming from an acute response due to the PAPE and not by a variation in motivation, or intensity of execution during the pre-and post-intervention tests.

Results show that CT training improved performance in several physical aspects, regardless of when performed. The significant improvement in the SBJ observed in both groups following the CT training protocol may be advantageous for the performance of hockey players. The SBJ is not a common test in the literature as the majority of authors prioritize SSJ and CMJ during PAP protocols (13, 46). However, some studies have been able to show improvement in SBJ performance following exercise below 80% 1RM (3, 4, 44). Furthermore, in ice-hockey, the generation of vertical force is required to achieve maximum velocity during sprints while during acceleration the horizontal component of the reaction force on the ice is greater than the vertical force (31, 33). This suggests that SBJ improvements will translate to increased acceleration on the ice.

Our research found no significant difference in the CMJ in either the 8HPT or 4HPT groups. This is in line with our previous findings when the CMJ was performed 6 hours after CT training (29). This is despite the modification of the training parameters in terms of volume and rest time, and contrary to what the others have found (7, 53). Regarding the static squat jump (SSJ), a significant improvement was observed in the 4HPT group but not in the 8HPT group. The increase in SSJ in the 4HPT group could be explained by a better efficiency of the recruitment of muscle fibers from the group trained four hours before to produce the desired movement with greater force (52). Despite the insignificant increase in the 8HPT group for the CMJ and SSJ, this is the only group that did not achieve any decrease in performance. We presume that the improvement would be caused mainly by the excitation of the CNS which would increase the function of muscle contractility due to voluntary contraction of a heavy load eight hours prior (41, 50). This improvement in CNS can be seen by better muscle power and the RFD peak power (W) deployed +75.4 ±401.8 (W) in the 8HPT group, which explains the slight increase in CMJ performance while a decrease of -586.9 ±630.7 (W) in the 4HPT group that could explain the decrease in CMJ results. Thus, the difference between the two jumps is an indicator that can reveal an athlete's ability to effectively use the stretch-shortening cycle (SSC) and RFD which is a critical factor in hockey. Our research shows that the efficiency of the SSC may be more affected the closer the CT training protocol.

In this study, we were able to compare the benefits obtained from performing CT eight or four hours prior to on-ice repeated sprint tests. While both groups observed increases in performance in some of the sprints, i the 8HPT group experienced a greater number of performance benefits. Significant improvement in the 8HPT group was observed for the majority of the latter stage sprints (sprints 4, 5, 6, and 8). This suggests that performing CT eight hours before on-ice performance allows an athlete to maintain a high intensity in repeated efforts. Mean speed (m/s) over 40m decreased in all but one for the eight sprints for the 8HPT group. This resulted in a decreased total time of the 8 sprints by 7.4 ± 6 seconds. Meanwhile the players in the 4HPT group saw their performance improve significantly in only two of the sprints (sprints 2 and 3), despite an improvement in the mean speed in all but two of the 40m sprints(sprint 2, 3, 4, 5, 6 and 7). The improved power of muscle contractions from the CT training protocol seems to modify and improve the economy of hockey players by altering the use of the SSC and reducing the demand for ATP production by decreasing the heart rate during high-intensity exercise (37).

One could argue that the improvements in all testing result results obtain in this study (n=10; pre-and post-intervention) for all the professional ice-hockey players, could be due to the training effect even if the subjects executed the post-intervention testing sessions 10 days later. As previously mentioned in the methodology, the previous publication by Lagrange et al. demonstrated that when compared to a control group, researchers were able to show on 41 elite hockey players that the CT training protocol improves repeated on-ice 40m sprint speed six hours prior. Furthermore, the present show that the 8HPT group significantly improved more in total Sprint time and in the SBJ testing results compare to the 4HPT group.

In addition, it seems increasingly clear, with our latest research (Lagrange et al., 2020) and our present study that a minimum rest of six hours between CT training protocol and competition might be necessary to fully optimize the PAPE effects. Choosing the ideal time window between CT training protocol before the competition should not be overlooked (8, 12). However, during the season, Strength coaches, with the busy schedule of players on the day of a competition, may not always be able to meet the recovery time which appears to be at least six hours after CT training protocol. The significant improvements observed pre-and post-intervention for all subjects' post CT training protocol can allow us to justify the use of CT training protocol even if the athlete only has four hours of rest prior competition.

It is important for S&C coaches to understand that CT training protocols are more effective on athletes who have a higher relative strength ratio (minimum of 1.5 x bodyweight) compared to those with an inferior relative strength ratio (10, 27). Thus, since the relative strength ratio is a measure of PAP performance, each participant confirmed prior to the beginning of the study that they were able to lift at least 1.5 times their body weight. Therefore, it was necessary that our subjects have a minimum of 3 years' experience in resistance training and that they were engaged in a resistance training program at least three times per week continuously in the last year. This prerequisite could limit the choice of participants who can take part in the CT training protocol prior to competition (responder's vs non-responders).

PRACTICAL APPLICATIONS

The purpose of this study was to compare two-time windows for the same complex training protocol which was carried out either eight or four hours before repeated on-ice sprint ability and lower body power testing in order to determine the post-activation performance enhancement effect of each. According to our results, CT training protocol increasing the PAPE is one of the strategies that can be used to increase athletic performance and increase on-ice repeated sprints in hockey players on the day of competition (26). Several studies support our choice of the load used (85% 1RM) and participants were able to recover and return to their baseline muscle fatigue values to normal 3-6 hours after training (11, 20, 40). Another study by Chui et al. was able to demonstrate the restoration of the initial rate of force development (RFD) before the second session of high-intensity resistance exercise performed in the afternoon of the first session six hours later (9). In the literature, the majority of studies on this subject seemed to show that a 6-hour recovery between PAP training and competition was the optimal time window to optimize performance since fatigue dissipates at a rate faster than the potentiating effects of PAP. Thus, a minimum of six to eight hours is recommended for optimal recovery between resistance training and endurance training, common in team sports such as hockey (42). Therefore, the optimal time window with our obtained results seems to be eight hours before the competition.

So, while there were improvements in both groups in our study, it would seem interesting for strength coaches to take into account the differences made as a result of CT training protocol eight or four hours later. It would appear that eight hours prior CT training would be the best option to achieve the full potential in power and deployed force (RFD) of trained athletes. On the other hand, CT training protocol four hours before would be a possible option to increase the PAPE when the strength coaches have to plan two workouts in the same day, since it seems to promote and increase the local muscle strength of the muscle trained earlier. Finally, following this research, it is proposed to use this method with the athlete during a day of practice before performing it during a day of competition, since this study only represents about 30% of the number of total sprints an NHL player would make in a game (30, 38). It would be interesting for future researchers to study this PAPE phenomenon over the entire duration of a hockey game and to analyze its effect.

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