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Neuromuscular adaptations to short-term high-intensity interval training in female ice hockey players

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ADAPTATIONS TO HIGH-INTENSITY INTERVAL TRAINING

ABSTRACT

High-intensity interval training (HIIT) related neuromuscular adaptations, changes in force production and on-ice performance were investigated in female ice-hockey players during pre-season. Fourteen Finnish championship level ice hockey players (average age 22 ± 3 years) participated in 2½-week HIIT. Both spinal (H-reflex) and supraspinal (V-wave) neuromuscular responses of the soleus muscle were recorded before and after the training period. Static jump (SJ) and countermovement jump (CMJ) heights, plantar flexor maximal voluntary contraction (MVC) and rate of force development (RFD) were measured. In addition, soleus and tibialis anterior muscles activations (electromyography; EMG) were measured during MVC and RFD tests. During on-ice training, skating speed and acceleration tests were performed.

Subjects significantly improved their plantarflexion MVC force ($11.6 \pm 11.2\%$, $p < 0.001$), RFD ($15.2 \pm 15.9\%$, $p < 0.01$) and SJ ($4.8 \pm 7.6\%$, $p < 0.05$). Voluntary motor drive to the soleus muscle (V-wave amplitude) increased by $16.0 \pm 15.4\%$ ($p < 0.01$) and co-activation of tibialis anterior muscle during the plantar flexion RFD test was reduced by $-18.9 \pm 22.2\%$ ($p < 0.05$). No change was observed in spinal α -motoneuron excitability (H-reflex) during MVC or in on-ice performance. These results indicate that HIIT can be used to improve athletes' capability to produce maximal and explosive forces, likely through enhanced voluntary activation of their muscles and reduced antagonist co-activation. Therefore, HIIT can be recommended in pre-season training to improve neuromuscular performance. However, a longer than 2½-week HIIT period is needed to improve on-ice performance in female ice-hockey players.

Key words: Intermittent training, electromyography, Hoffmann Reflex, co-activation, women

INTRODUCTION

High-intensity interval training (HIIT) can be used in various ways to design athletes training by modifying intensity, rest and recovery periods and, type of stimulus parameters (e.g. incline surface and degree of sport-specificity). HIIT is a good approach to improve athletes' anaerobic power (3,6,8,21) and maximal oxygen consumption (3,11,21,27). Functional performance improvements like improved repeated-sprint ability (11), sprint speed (27), skating speed (20) and vertical jump height (4, 14) have also been reported. Despite of the previous HIIT studies, underlying neuronal mechanisms during short term training periods and its effects in on-ice performance in females are not so clear at present.

Ice hockey is based on quick changes of direction and pace that rely on explosive production of muscle force, and thus one of the requirements for an elite ice hockey player is efficient acceleration ability. Explosive muscle contractions, e.g., quantified by rate of force development (RFD), and are primarily affected by changes in the amount and quality of the neural drive (6). Since HIIT causes dominantly supraspinal fatigue leading to less efficient neural drive (16), compensation through enhanced voluntary muscle activation is expected to match the desired motor-task demands. Transfer of improvements of HIIT to on-ice performance have been reported in men (20), which is logical as skating acceleration is mainly determined by one's ability of efficient RFD (5,29).

The most potential neuronal adaptation mechanisms related to HIIT are: optimization of motor unit recruitment strategies, increased spinal α -motoneuron excitability (25) and increased conduction velocity of peripheral nerves. Therefore, our aim was to investigate the aforementioned potential neuromuscular adaptations in female ice hockey players. More precisely, voluntary-motor drive (V-wave), muscle activation during maximal and explosive

force productions (EMG-RMS) and spinal α -motoneuron excitability (H-reflex) was measured to investigate the neuromuscular adaptations. Through better understanding the neuronal benefits of HIIT, one could better plan off-season conditioning to improve anaerobic and neuronal functions related to on-ice performance. Based on previous evidence, we hypothesized that HIIT improves motor control through more optimized descending voluntary-motor drive and spinal level sensorimotor integration, which is reflected as improvements in muscle force production capability and on-ice performance.

METHODS

Experimental Approach to the Problem

Purpose of this study was to clarify neuromuscular adaptations that relate to functional performance improvements achieved by HIIT and its connection to the on-ice performance. We studied the adaptations elicited by the HIIT intervention by measuring functional performance variables: maximum voluntary isometric plantarflexion (MVC) force, RFD, static jump (SJ) and countermovement jump (CMJ). Skating tests were added to test protocol to quantify sport-specific adaptations. We chose set of neuromuscular variables to clarify the mechanisms related to the sport-specific adaptations at different levels of the neuromuscular system. Therefore, volitional neural drive (V-wave), spinal α -motoneuron excitability (H-reflex) from the soleus muscle, and co-activation of the tibialis anterior muscle during plantar flexion (motor control) were measured. Analyzing neuromuscular variables, it can be determined whether HIIT elicits neuromuscular adaptations and what level of the neuromuscular system is affected. Functional performance measurements help to resolve possible connections between neuromuscular changes and on-ice performance. Clarifying, how conditioning professionals should utilize HIIT in female ice-hockey players' pre-season program.

Subjects

Eighteen Finnish championship level female ice hockey players volunteered to participate in this study. Four of them dropped out due to personal reasons or illness. The remaining fourteen subjects (height 165 ± 5 cm, weight 67 ± 13 kg, age 22 ± 3 , age range 16–28, 1 under aged) participated in all tests and training sessions. The subjects were informed about the risks, requirements and benefits of the study before signing written consent. In addition parental or guardian consent was obtained from under aged test subjects. The study was performed according to the Declaration of Helsinki and the Ethical Committee of the University has previously approved all measurements.

Procedures

Training Intervention

Players' off-season conditioning started in the third week of May and the workouts followed incremental increase in workout power. Training intervention was planned to begin in the latter part of the off-season (August), when exercise power was reaching its peak. In the beginning of the off-season, base conditioning and low power strength training were performed, lasting until the end of June. Base conditioning workouts were performed twice a week containing boxing (Sunday), stair and uphill running (Wednesday) with long intervals targeting adaptations in metabolic systems. Strength training workout sessions contained different program for upper body (Monday) and lower body (Thursday). In total 2–3 series of 7–9 weight exercises were performed in a session with 15–20RM intensity.

In July each subject had their own prescribed training program containing player specific strength and conditioning workouts. In August on-ice sessions started, and in the second week HIIT intervention was implemented as an extension to on-ice training. Training period

lasted until the beginning of September (pre-season). There were no other off-ice training sessions during the training intervention.

During the HIIT intervention subjects trained three times a week on-ice (Monday, Tuesday and Thursday). HIIT training sessions were added to their Tuesday and Thursday on-ice practices and were performed before the on-ice session. Each training session started with a 5–10 minute warm-up by running from the ice hockey arena to the training site followed by HIIT session. HIIT contained 30 s all-out sprints on a hill with a gradient of 9.5%. Six sprints in total were made in a session and 4-minute rest periods were held between the sprints. In total training session lasted approximately 45 minutes including warm-up and cooldown. All of the training sessions were supervised and verbal encouragement was given during the sprints to ensure all-out performance.

Testing Protocol

All measurements were made before and after a 2½-week HIIT intervention. Subjects' both measurements were done in a similar time of day (average difference: 1.5 ± 1.5 hours). Participants were familiarized with the testing protocol just before their first testing session. Subjects were instructed not to exercise 24 h before their test session. After surface electromyography (EMG) electrodes and transmitters were placed, each subject performed 8 minutes of step-ups for warm-up (25 cm step-up at 60 bpm). Measurements were made in an identical order for each subject: 1) H-reflex during standing at rest, 2) isometric plantarflexion (MVC), 3) V-wave during isometric plantarflexion (MVC), 4) MVC for ankle dorsiflexion, 5) H-reflex during isometric plantarflexion (MVC), 6) static jump and 7) countermovement jump. In addition, on-ice measurements were performed one day after neuromuscular tests.

All MVC, RFD, jump, force and EMG data were sampled with AD-converter (Power 1401, Cambridge Electronic Design, UK) at 1000 samples per second. Analyses were performed with Spike 2 v 5.21 software (Cambridge Electronic Design, UK).

MVC of the right plantarflexors were performed in a custom-made dynamometer (University of Jyväskylä, Finland). During the tests, subjects were fixated into seated position with 4-point seat belt. Their right knee was fully extended (to 180°) and the ankle was at a 90° angle with respect to tibia. The left leg was kept relaxed on the left side of the bench, so that it did not touch the dynamometer. Subjects were instructed to push against the fixed force plate of the dynamometer as hard and as fast as possible for 3 seconds whilst the instructor verbally encouraged them. A minimum of three attempts were made or until the improvement of the MVC was less than 5% from the previous best attempt with a 45-second-rest period between the trials. Maximum force was computed from the trial showing greatest peak-to-peak amplitude before the onset of the force production to the highest force level. RFD was computed from the trial showing the steepest initial force increase (averaged over 100 ms around the steepest point) during the early phase (0–500 ms) of the MVC.

CMJ and static jump SJ without arm swing were performed on a force plate (AMTI, Massachusetts, USA). Subjects were instructed to keep their arms on their hips while performing the vertical jumps. The lowest knee angle was instructed to be 90° on both jumps. For the SJ, subjects were instructed to stay at the correct knee angle for one second before jumping. For the CMJ, subjects started from a standing position and flexed to a 90° knee angle and then immediately jumped vertically as fast as possible. Each jump was performed three times with a 45-second rest interval. Flight time was determined from vertical force

data (i.e. take-off and landing) and was used to calculate maximum jump height (19). The test instructor supervised visually that all the CMJs reached the 90° knee angle.

Skating speed and acceleration were used to measure the sport-specific training adaptation. Measurements were made in standard international sized ice hockey rink (Figure 1) with full kit excluding the stick (to prevent false triggering of the photocells). Photocells (Newtest, Ele-Products Oy, Tyrnävä, Finland) were placed on the goal-line (start), defending faceoff spot's outer-line (acceleration) and on the attacking zone's blue line (speed). Three attempts were made for each subject and the best 11 m and 34 m skating times were recorded with a Powertimer (Newtest, Ele-Products Oy, Tyrnävä, Finland) measurement system.

FIGURE 1 about here

Surface EMG from gastrocnemius lateralis, soleus, tibialis anterior were recorded with bipolar electrodes (AMBU BlueSensor N, Copenhagen, Denmark) with a 2 cm inter-electrode distance. Electrodes were placed according to SENIAM recommendations (17). Before the placement, the skin was abraded with sand paper and cleaned with alcohol. If electrode impedance was higher than 8 k Ω the preparation was repeated. EMG (RMS) signals were acquired with a Telemyo 2400R (Noraxon, Scottsdale, AZ, USA) system. EMG-RMS values of 0–500 ms (RFD) and 500–1000 ms (MVC) from muscle contraction onset were computed for soleus, tibialis anterior and gastrocnemius lateralis muscles. To determine the level of coactivity, the ratio between tibialis anterior EMG-RMS amplitude during plantarflexion and dorsiflexion MVC tests was computed (26). Due to technical problems in EMG signal acquisition, the total number of subjects included in the analysis of the EMG-RMS amplitudes (RFD, MVC and co-activation) was reduced to 10.

H-reflex and M-wave during standing at rest were measured from the right soleus muscle to determine changes in synaptic transmission efficiency at spinal level. An oval 5.1×10 cm anode (V Trode, Mettler Electronics Corp., Anaheim, USA) was placed superior to the patella. A constant current stimulator (DS7A, Digitimer, UK) was used to stimulate the right tibial nerve in the popliteal fossa with a cathode using 200 μ s square pulse. Correct positioning of the cathode was confirmed by increasing the stimulation amplitude until both H-reflex and M-wave were visible. The optimal stimulation site was determined by moving a temporary cathode laterally to pinpoint position for the highest M-wave (peak-to-peak) amplitude. The temporary cathode was then replaced with a permanent 3×2 cm electrode (AMBU BlueSensor N, Copenhagen, Denmark) that was used during all the tests. The electrode was fixed using tape to ensure constant pressure throughout the session.

Next, the stimulation intensity was lowered until no visible response was elicited (typically around 10 mA). Stimulation was then increase in steps of 1 mA until the H-reflex was abolished and the maximal H-reflex (H_{rest}) was measured with the intensity that elicited highest peak-to-peak value. Stimulation intensity was further gradually increased in 5 mA steps until the maximal M-wave peak-to-peak value was achieved. Stimulation intensity was then increased by 50% to supramaximal level (M_{sup}) to ensure maximal M-wave (M_{max}). H_{rest} was normalized to M_{max} to enable comparison between test sessions (different days). At least 8-seconds inter-stimulus interval was used during H-reflex tests to avoid effects of post-activation depression (7).

H-reflex ($H_{20\%}$) responses were also measured during MVC. Stimulation intensity was adjusted to be $20 \pm 2.5\%$ of the supramaximal intensity used in M_{\max} -recording. This submaximal M-wave peak-to-peak amplitude was monitored online to constantly modify stimulation intensity to keep the M-wave amplitude stable. Ten attempts were made to obtain a minimum of two accepted samples that were within 17.5–22.5% of the supramaximal M_{\max} . Peak-to-peak values of H-reflexes and M-waves were then computed for the accepted samples (range: 2–5, average: 3), and were averaged prior to computing $H_{20\%}/M_{20\%}$ ratio.

V-waves were recorded to quantify changes in the level of descending motor drive. Subjects were instructed to perform similar efforts as in MVC measurements. When MVC force reached its plateau, stimulation with the supramaximal intensity used in M_{\max} -recording was given to the peripheral nerve to elicit M- and V-wave responses. Eight attempts were made and values from attempts that reached $\geq 90\%$ of measured MVC were analyzed. Peak-to-peak values from both responses were averaged and the V-wave value was then normalized to the M-wave from the accepted samples (range: 3–8, average: 6).

Statistical analyses

Statistical analysis was performed in SPSS 22 (IBM, New York, USA). After Shapiro-Wilk normality assurance, t-test for paired samples was used to compare pre- and post-training values. Variables not passing Shapiro-Wilk normality assurance, nonparametric Wilcoxon signed rank test for paired samples was used. Results were considered statistically significant for p-values below 0.05, and are reported as mean \pm standard deviation (SD).

RESULTS

Functional performance. The subjects showed significant increases in plantarflexor MVC ($11.6 \pm 11.2\%$, $p < 0.001$; Wilcoxon), RFD ($15.2 \pm 15.9\%$, $p < 0.01$) and SJ ($4.8 \pm 7.6\%$, $p < 0.05$; Wilcoxon) compared to pre-training values (see Table 1). However, no significant changes were observed in the CMJ ($0.2 \pm 6.0\%$), skating time ($-1.6 \pm 3.8\%$), or acceleration time ($-0.6 \pm 2.1\%$).

TABLE 1 about here

EMG-RMS amplitude. Normalized muscle activity of the tibialis anterior measured during plantarflexion RFD test decreased significantly ($p < 0.05$; Wilcoxon) from a pre-training value of 0.51 ± 0.23 to a post-training value 0.41 ± 0.18 ($n = 10$) indicating reduced co-activation (Figure 2B). No other significant differences were observed in the EMG-RMS amplitude, i.e. during RFD (gastrocnemius or soleus) or MVC (gastrocnemius, soleus, tibialis anterior (Figure 2A) tests.

H-reflex and V-wave. M_{\max} normalized V-wave values increased ($\Delta 16.0 \pm 15.4\%$, $p < 0.01$; Wilcoxon) significantly (Figure 2C). No training adaptations were observed in H_{rest} (Figure 2D) during standing rest ($\Delta -4.6 \pm 20.0\%$) or in $H_{20\%}$ (Figure 2E) during MVC ($\Delta 2.9 \pm 41.7\%$). $M_{20\%}$ during MVC did not change between the sessions (pre $19.61 \pm 1.69\%$, post $19.42 \pm 1.67\%$).

FIGURE 2 about here

DISCUSSION

Neuromuscular adaptations related to high-intensity interval training (HIIT) changes in force production and on-ice performance were investigated in female ice-hockey players during pre-season. First major finding of the study was that improved performance in isometric tests was caused by increased neural drive (soleus) and reduced co-activation of the antagonist (tibialis anterior) muscle. Because no changes were observed in spinal level, it seems that short term HIIT influences mainly supraspinal neural systems. Second major finding was that despite of the neuromuscular adaptations, no significant improvements were observed in on-ice performance. This indicates that, that training period should be longer, e.g. at least four weeks to cause improvements in one-ice performance.

Significant increase in V-wave amplitude after HIIT indicates increased or better coordinated cortical volitional motor drive to the muscles through the spinal α -motoneurons during the isometric MVC. Our results are in-line with previous studies indicating, that supraspinal adaptations, such as the increased volitional neural drive (the V-wave), are mainly detected during the first eight weeks of training (9,10,13). Similarly, improved RFD is accompanied with increase in V-wave amplitude, showing that increased corticospinal motor drive to the muscles has a significant role for the functional adaptations (1).

Reduced level of antagonist co-activation in the tibialis anterior muscle during plantarflexion suggested that, the functional improvements were partly due to motor learning. The level of co-activation is typically reduced at the early stages of strength training (18, 22). The HIIT may thus have improved selective motor control, but it should be noted that reduction in the co-activation can occur also due to increased reciprocal inhibition at the spinal level (15). However, since we did not observe any changes in the H-reflex responses, we argue that

possible adaptations in pre-synaptic inhibition (28) or other inhibition/facilitation of the spinal α -motoneuron pool (24) of the agonist muscle were negligible in the present HIIT. However, we did not measure H-reflex from the antagonist muscle, thus possible impact of reciprocal inhibition of the antagonist muscle (15) cannot be ruled out. Altogether, improved volitional motor drive (i.e. V-wave), reduced antagonist co-activation, and lack of spinal level adaptations (i.e. H-reflex) suggest a supraspinal origin for the neural adaptations induced by the present "all-out" HIIT.

Subjects' plantarflexion MVC force, RFD and SJ height increased significantly, which are typically improved by increased voluntary motor drive (2). Therefore, the subjects' maximal and explosive force production improved likely through enhanced muscle coordination and activation. We expected the improved SJ height to be transferred to the on-ice performance (12), however this was not the case. This is probably, because our subjects' were highly skilled skaters, and thus larger improvements in off-ice performance would have been required for significant transfer effects. Although, improvements were visible in most of the explosive force production variables, the CMJ height did not change, suggesting that improvements affected mainly the concentric force production.

The advantage of HIIT is that it improves performance diversely, combining several conditioning needs for ice hockey player, especially during pre-season training (e.g. maximal oxygen consumption (3,11,21,27) and anaerobic performance (3,6,8,21). Importantly, HIIT improves repeated sprint ability (11), benefitting the interval based sports like ice hockey. Based on our results, HIIT is an effective off-season workout to improve aforementioned parameters in female ice-hockey players.

The main limitations of the current study were 1) insufficient training period for significant sport-specific improvements and 2) lack of sedentary control group. Naimo et al. (20) observed significant on-ice performance improvement in ice-hockey players after a 4-week HIIT, as compared to their control group training at continuous intensity. Their HIIT program consisted of Wingate anaerobic test (WanT) that was performed twice a week, and also at all-out intensity. The control group performed 65% HR_{max} training on a bike ergometer. Our 2½-week HIIT indicated a good response to stimulus, but it was not transferred to the sport-specific performance, this could be due to small sample size or short training period. Therefore, despite positive neural and functional development, a longer training period should be used to improve on-ice performance. It is also worth mentioning, that quadriceps force correlates positively to on-ice performance (23), and thus future studies should examine the attributes of knee extensors, in addition to the plantar flexors.

In conclusion, a short term 2½-week training period is sufficient to induce significant beneficial adaptations in the neuromuscular system of female ice-hockey players. This suggests that HIIT can be used as an off-season workout to improve functional parameters related to on-ice performance (maximal and explosive muscle force production), although a longer period should be used to transfer the positive adaptations to the on-ice performance. The improvements in the functional performance were mainly explained by supraspinal factors related to cortical motor control, as no significant changes were observed in the spinal level excitability.

PRACTICAL APPLICATIONS

As time on-ice is valuable, coaches can use HIIT as an off-ice training method to improve their players' anaerobic power and neuromuscular functions simultaneously. Training can be done alone with a stopwatch and an uphill with a steep incline, as it is not needed to be supervised or controlled. This saves time for players and trainers to focus on game preparation and more sport-specific practice during the training schedule.

While no adaptations were observed in sport-specific tests, HIIT improved functional performance measurements related to explosive muscle force production, skating speed and acceleration (RFD and SJ). Thus, we expect that a longer training period would transfer the beneficial neuromuscular adaptations to the sport-specific performance as well adaptations. Therefore, it can be recommended that HIIT should be used in pre-season training to enhance neuromuscular performance. However, no shorter than four week period should be used to improve on-ice performance in female ice-hockey players.

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TABLE LEGENDS

TABLE 1: Pre- and post-training values for performance measurements (mean \pm standard deviation). MVC = maximum voluntary contraction; RFD = rate of force development; CMJ = counter movement jump; SJ = static jump; * = p value < 0.05, ** = p value < 0.01, *** p = value < 0.001 between pre- and post-training measurements (n = 14).

FIGURE LEGENDS

FIGURE 1. Skating tests. Acceleration time was measured with photocells (the yellow clock items) from the start to the defending faceoff spot's outer line (11 m from the start) and speed was measured from the start to the attacking zone's blue line (34 m from the start).

FIGURE 2. Mean co-activation of tibialis anterior and electrically elicited responses of soleus before and after HIIT. (A and B) Co-activation of tibialis anterior during plantarflexion MVC and RFD tests normalized to dorsiflexion MVC EMG-RMS, (C) V-wave amplitude normalized to maximal M-wave, (D) H-reflex amplitude normalized to maximal M-wave during standing at rest, and (E) H-reflex amplitude normalized to submaximal M-wave (20% of maximal M-wave) during plantar flexion MVC test. Error bars represent standard deviation. * = p value < 0.05; ** = p value < 0.01.

ACCEPTED

	Pre	Post	<i>p</i>
MVC (N)	1134 ± 254	1266 ± 203	.000***
RFD (N·s ⁻¹)	4488 ± 1746	5171 ± 1697	.001**
CMJ (cm)	21.75 ± 3.01	21.80 ± 3.18	.826
SJ (cm)	19.62 ± 2.55	20.56 ± 2.29	.019*
11 m skating time (ms)	2382 ± 154	2345 ± 117	.169
34 m skating time (ms)	5373 ± 355	5342 ± 118	.402

FIGURE 1.

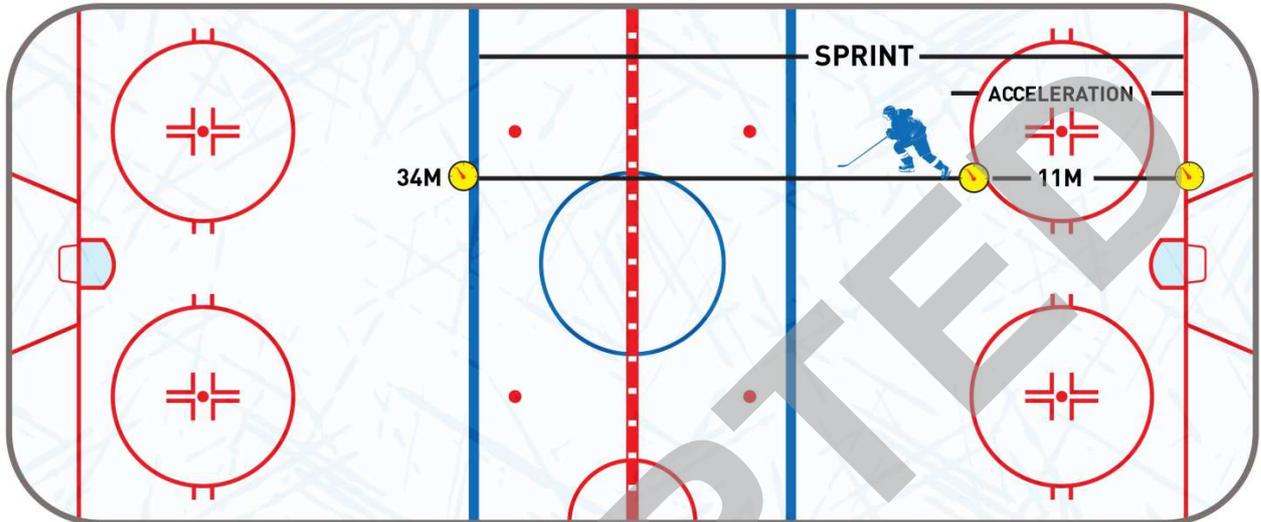


FIGURE 2.

