

The Effect of Selected Warm-Up Protocols on Forward Ice-Skating Performance in Elite
Ice-Hockey Players

by

Jeffrey Bruce Compton
B.Sc., University of Ottawa, 1993

A Thesis Submitted in Partial Fulfillment of the
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In the School of Physical Education

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Abstract

The purpose of this study was to investigate the effect of selected warm-up protocols (WUP) on forward ice-skating and perception of readiness to perform (RTP). Twenty male Jr. A hockey players (age = 18.7 ± 0.9 yrs; experience = 1.6 ± 1.0 seasons) participated in the study. Participants completed five different conditions: one with no warm-up (NO) performed on the first day and four WUP sessions administered in random order. WUP included: a) complete Hockey Canada WUP (HC), b) Hockey Canada off-ice only WUP (OFF), c) Hockey Canada on-ice only WUP (ON), d) on and off-ice explosive specific WUP (ES). Testing sessions consisted of the WUP followed by 15 minutes of rest after each on and/or off-ice portion. Skating performance (SP) was measured with infra-red timing gates (Brower Timing Systems, Utah, USA) at 4, 8, 12, 16 and 20 m. Three maximal trials with three minutes rest between trials were performed and averaged for statistical comparison. Significant SP differences occurred between ES vs. NO and OFF at all distances. Significant SP differences occurred between HC and ON vs. NO and OFF at 4 m and between HC and NO from 2 to 16 m. RTP was determined through a visual analogue scale question posed immediately pre and post-WUP and pre-SP. RTP increased significantly with each WUP while pre-WUP and pre-SP RTP scores were not significantly different across WUP. No correlation between RTP and SP was found.

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Dedication

This study is dedicated to all athletes, coaches, teachers and researchers on the journey towards excellence.

Introduction

Warm-up is defined as the activity that precedes participation of physical activity in order to reduce injury risk and increase physical performance and readiness to perform (Fox, Bowers, & Foss, 1993 and Bishop, 2003).

Researchers have attempted to provide recommendations for ideal warm-up protocols that maximize performance in measures such as running speed (Fletcher and Jones, 2004), explosive power (Young and Behm, 2003) and force (Burnley, Doust & Jones (2005), Church, Wiggins, Moode & Crist (2001) and Shilling and Stone (2000). Evidence supports a trend toward dynamic rather than static type warm up protocols.

Increased performance from the effects of warm-up on jumping (Young, Jenner & Griffiths, 1998), and running activities (Fletcher and Jones, 2004) has been reported. To date, no published research investigated the effect of warm-up common protocols on ice-skating in the sport of ice hockey.

Bishop (2003b) reviewed the literature pertaining to the performance changes following active warm-up. He indicated that warm-up protocols typically include general elements such as jogging or calisthenics, designed to increase muscle and core body temperature, flexibility elements such as stretching, which includes: passive/active and static/dynamic types and task specific elements that mimic the specific movement pattern, force, intensity and velocity of the intended physical activity.

Several variables in warm-up protocols have been manipulated to study their effect on performance. These include intensity and duration of general warm-up, type

and extent of stretching involved and the utilization of various loads and the inclusion of ballistic movements.

Bishop (2003b) indicated that short term performance could be increased at warm-up intensities equal to approximately 60% of VO_2 max and warned that warm-up at intensities greater than 60% can result in decreased performance due to depleted high energy phosphate concentrations and decreased pH leading to premature fatigue. He noted that four minutes of general warm-up can increase performance to the same extent as 20 minutes.

The use of static passive stretching has been shown to significantly reduce speed in 15m runs for gymnasts (Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003) and in 20 metre runs for rugby players (Fletcher & Jones, 2004). Although Siatris et al. (2003) found no benefits to dynamic or general warm ups, Fletcher and Jones reported significantly increased running performance using an active dynamic warm up. Their warm-up included up to 20 repetitions of running specific movements that matched the muscles being stretched in the static passive treatment. Passive stretching has also been shown to decrease performance in drop jumps (Young & Elliot, 2001), counter movement jumps using single joint movements [after 3 sets of stretches held for 20 seconds] (Cornwell, Nelson & Sidaway, 2002) as well as vertical jumps [using proprioceptive neuromuscular facilitation stretching] (Church et al., 2001). These results were similar to those of Fowles, Sale and MacDougal (2000) who also found that strength decreased after stretching.

Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, (2003) used loaded half squats in their warm-up, which resulted in improved rate of force development.

However, only subjects who demonstrated high maximum leg strength showed an improvement in vertical jumping performance (4%). Hrysomallis and Kidgell (2001) were also unable to improve performance in an explosive movement type using high loads for warm-up.

Explosive warm-up protocols have been shown to increase certain types of performance. Young and Behm (2003) reported that both drop jump and vertical jump performance increased ($p < 0.05$) as measured by concentric force as well as by rate of force development in a 'run plus stretch plus jump' group when compared to groups that performed static warm-up protocols.

Hockey Canada (1995) provides specific warm-up guidelines on their website (<http://www.hockeycanada.ca/multimedia/e/develop/safety/downloads/stretch.pdf>). This warm-up protocol consists of an off-ice portion which includes jogging, static and dynamic stretching and agility drills and an on-ice portion that includes dynamic and passive stretching activities performed while doing skating-specific skills. The effect of warm-up on ice-skating performance is a question that does not seem to have been investigated.

It might be possible that ice-skating performance can be enhanced by using new or unique warm-up protocols. For example, such protocols might include: a shorter time spent in general warm-up, elimination of static stretching, more time spent performing dynamic and sport specific movements; and/or the introduction of explosive movements while on the ice. Also, the benefit of off-ice warm-up compared to on-ice warm-up remains unknown.

Statement of the Problem

Research investigating the effects of warm-up on ice-skating performance is lacking. Studies have shown acute improvements in explosive movements after warm-up and reduced performance using static passive stretching; however, these investigations have not examined the effects on the ice-skating performance of elite ice-hockey players. Current ice-hockey warm-up protocols include an off-ice portion and an on-ice portion, each followed by 10 to 20 minutes of no activity. It remains unclear whether either is necessary to affect ice-skating performance. It is also not known how ice-hockey players' perception of their readiness relates to their ice-skating performance.

Statement of the Purpose

The purpose of this study was to investigate the acute effect of four WUP and no warm-up (NO), on ice-skating performance (SP) at 4, 8, 12, 16 and 20 m and the readiness to perform (RTP) following these conditions. Warm-up protocols included: a) complete Hockey Canada warm-up. (HC), b) Hockey Canada off-ice warm-up only (OFF), c) Hockey Canada on-ice warm-up only (ON) and d) Explosive specific warm-up (ES).

Research Questions

- 1) Are there differences in SP after various warm-up protocols (NO, HC, OFF, ON, ES)?
- 2) Are there differences in SP at different distances?
- 3) Which warm-up protocols elicit changes in RTP from pre-WUP to pre-SP?
- 4) Does the increase in RTP from pre-WUP to pre-SP differ across WUP?
- 5) Do SP scores match RTP perceptions?

Definitions:

Jogging: jogging at a moderate intensity as defined by the Borg Scale of perceived exertion.

Light skating: skating at a moderate intensity as defined by the Borg Scale of perceived exertion.

Static Stretching: two repetitions held for 15 seconds at the point of tension without pain in the following order: trunk/shoulder, quadriceps, thigh/hip flexor, groin hamstring/low back, low back/hip extensor, and gluteals/hip/low back muscles.

Off-Ice Explosive Specific Exercises: two sets of ten repetitions at maximal effort of: 2 leg jump downs and single leg jump-ups from/to dressing room bench (height = 51 cm), 2 leg lateral hops, single leg hops, and alternating lateral lunge hops.

On-Ice Specific Agility Exercises: two sets of ten repetitions at maximal effort of: 2 leg jump-ups, single leg jump-ups, 2 leg lateral hops and single leg lateral hops and alternating lateral lunge hops.

Ice-Skating Performance: maximal effort over 20 m sprint in a straight line measured at 4, 8, 12, 16, and 20 m distances.

Limitations

1. The results describe ice-skating performance as measured by velocity in a straight line over a 20 m distance.

2. Timing lights can detect changes in skating performance at all distances.

Delimitations

1. Participants were aged 16 to 20 year old males, playing on a Canadian Junior A hockey team.

Assumptions

1. Participants provided maximal effort
2. Friction remained constant throughout testing (ice and skate)
3. A moderate intensity on the Borg Scale represented approximately 60% of V_{O_2} max
4. Any changes in the dependent variables represents an effect of the warm-up protocol rather than an error in measurement or a change in the protocol.

Methodology

Participants

Twenty males with a mean age of 18.7 yrs (SD .9) volunteered to participate in the study. All participants were members of the same Junior A (BCHL) hockey team with 1.6 seasons (SD 1.0) experience at this level. All procedures were approved by the University of Victoria Human Research Ethics Committee and written informed consent was obtained from each participant. Individuals who had received proper instruction on testing protocols administered the warm-up protocols and tests.

Experimental Design

The dependent variables were mean time for three maximal 20 m skate performance as measured at 4, 8, 12, 16 and 20 m (SP). The warm-up protocol is the independent variable. Control variables included the time between on-ice and off-ice warm-up; the time from warm-up completion to SP testing; and the practice sprint trials completed immediately before testing SP. The participants were randomly assigned to four groups and performed WUP in random order. At least 24 hours separated each testing session.

Experimental Procedures

Practice Sessions

Each participant took part in one control session and four testing sessions. All participants arrived at the hockey arena for each session at the same time, which was

determined by the availability of ice-time. Participants were requested to refrain from any form of intense physical activity involving the leg musculature in the 48 hr prior to each testing session.

The purpose of the control session was to familiarize participants with all warm-up procedures, to understand the visual analogue scale used to determine perception of readiness and to measure SP without warm-up. Participants also agreed to maintain skate sharpness and to wear the same equipment for each testing session.

Testing Sessions

Participants performed four standardized warm-up protocols in random order: a) The Hockey Canada warm-up (HC) included on and off-ice portions with general warm-up, static stretching and skill movements; b) The Hockey Canada off-ice warm-up only (OFF); c) The Hockey Canada on-ice warm-up only (ON) and d) an explosive specific hockey warm-up (ES) that included on and off-ice portions with general warm-up and explosive specific exercises. (See Appendix F for details of all warm-up protocols.

Participants preceded SP with two practice trials at a self-estimated 50% and 75% of maximal effort followed by three minutes of rest. They then performed three maximal SP trials with three minutes rest between each trial.

All participants wore the same equipment for each session. The instructions for all warm-up protocols were read from a script by the same researcher each session. SP data was collected by a separate research assistant for all sessions. There was a minimum of 24h between testing sessions.

Participants provided their RTP before and after each warm-up portion and immediately before measuring SP.

Results

A total of 20 participants took part in up to five warm-up protocols; one practice session and four testing sessions were performed. The practice session measured skating performance with no warm-up (NO). The testing sessions measured SP at 4, 8, 12, 16 and 20 m. SP was taken as mean value for three trials. Skating performance trials included three minute rest intervals between trials.

RTP data was collected immediately before each WUP component and immediately before SP.

All 20 participants were present for HC and NO warm-up protocols. A total of 17 participants completed all measures for OFF warm-up protocol; however skating performance data for one participant was corrupted. A total of 17 participants completed skating performance in ON warm-up protocol, and 19 participants completed SP and RTP measures for ES warm-up protocol. Data from participants not completing all sessions was included in the analysis.

The effect sizes reduced as distances increased. Calculations, as suggested by Howell (1995), indicate effect sizes of 0.8 at 4 m and 0.4 at 20 m when comparing ES and OFF protocol data.

Significant main effects were observed for SP between the five warm-up protocols at all distances ($p < 0.05$). Repeated measures post hoc LSD analysis established significant differences between three WUP compared to NO (^a) and OFF (^b) ($p < 0.05$) (Table 1).

WUP	Time to Distance (s) (^{a, b} $p < .05$)				
	4 m	8 m	12 m	16 m	20 m
ON	0.90 (0.06) ^{a, b}	1.55 (0.08) ^a	2.14 (0.11) ^a	2.68 (0.14) ^a	3.18 (0.16)
HC	0.91(0.06) ^{a, b}	1.57 (0.10)	2.15 (0.10) ^a	2.69 (0.11)	3.20 (0.14)
ES	0.91 (0.07) ^{a, b}	1.56 (0.09) ^{a, b}	2.15 (0.11) ^{a, b}	2.69 (0.14) ^{a, b}	3.19 (0.16) ^{a, b}
NO	0.95 (0.05)	1.61 (0.07)	2.20 (0.10)	2.73 (0.12)	3.23 (0.15)
OFF	0.98 (0.10)	1.63 (0.12)	2.21 (0.15)	2.76 (0.17)	3.26 (0.18)

Table 1. Mean (SD) skating performance for five warm-up protocols: on-ice only (ON), Hockey Canada (HC), explosive specific (ES), no warm-up (NO) and off-ice only (OFF).

Split times were calculated and the results show that maximum SP was not reached at 16 m. (fig 2).

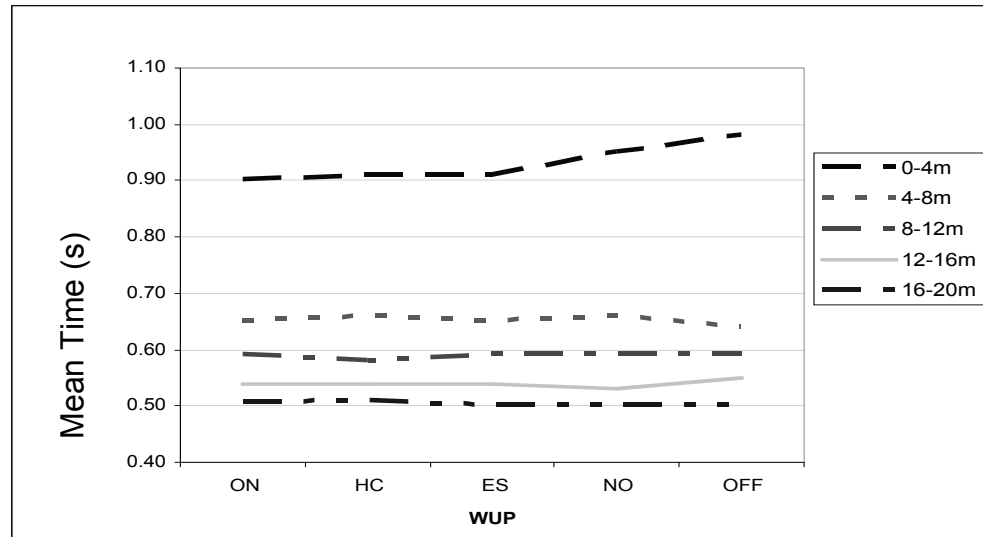


Figure 2. Mean (SD) skating performance split times (s) at 4, 8, 12, 16 and 20 m for five separate warm-up protocols: on-ice only (ON), Hockey Canada (HC), explosive specific (ES), no warm-up (NO) and off-ice only (OFF).

No significant main effects were observed for the four pre-warm-up protocols RTP. ($F = 1.375$; $p < 0.05$). (Fig. 3).

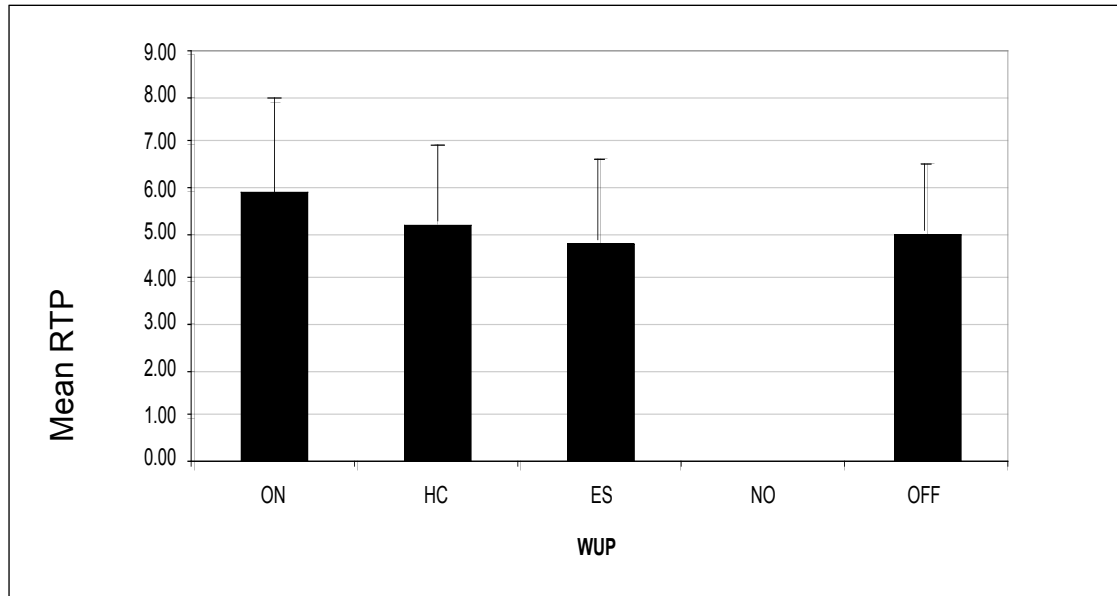


Figure 3. Mean (SD) readiness to perform taken immediately before four warm-up protocols: on-ice only (ON), Hockey Canada (HC), explosive specific (ES), no warm-up (NO) and off-ice only (OFF).

No significant main effects were observed for the pre-SP RTP between the five warm-up protocols ($F = 1.762$; $p < 0.05$). (Fig. 4).

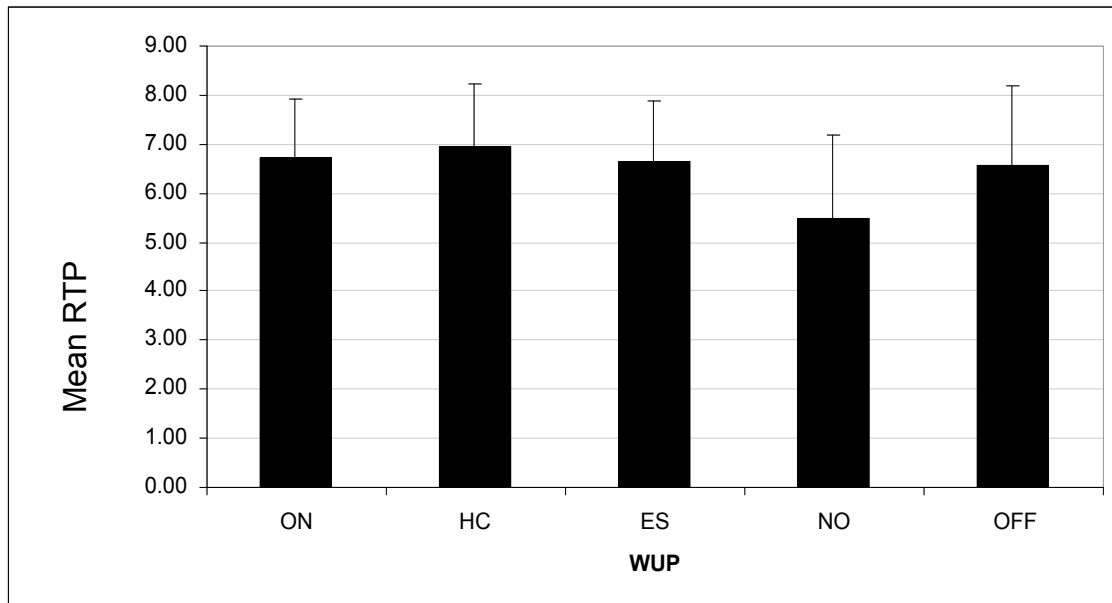


Figure 4. Mean (SD) readiness to perform taken immediately before skating performance measurement for five warm-up protocols: on-ice only (ON), Hockey Canada (HC), explosive specific (ES), no warm-up (NO) and off-ice only (OFF).

2 tailed t-tests established significant differences (*) in RTP from pre-warm-up protocols to pre-SP for HC ($t=3.599$), ES ($t=3.300$) and OFF ($t=3.765$) ($p < 0.05$). (Fig. 5).

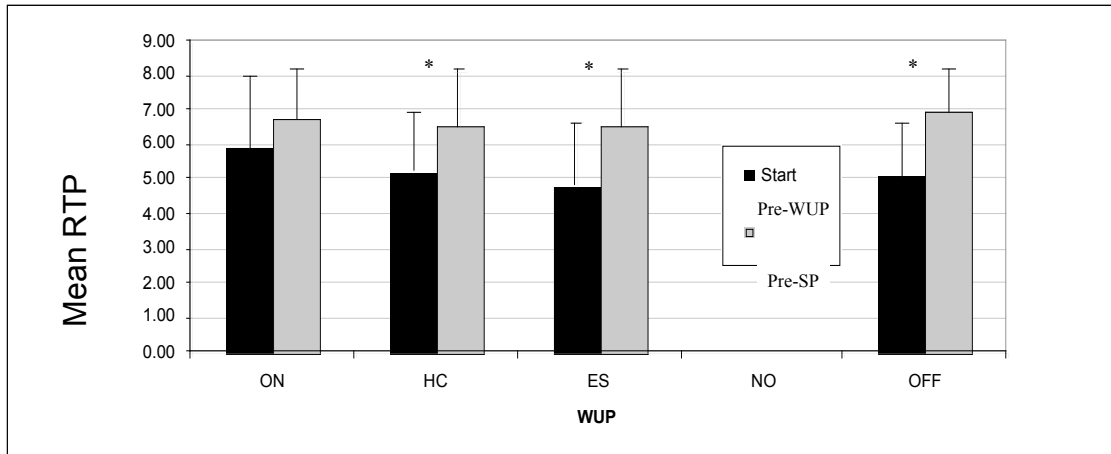


Figure 5. Mean (SD) readiness to perform for four warm-up protocols conditions prior to warm-up and prior to the sprint performance: on-ice only (ON), Hockey Canada (HC), explosive specific (ES) and off-ice only (OFF).

No significant main effects were observed for RTP change from pre- warm-up protocols to pre-SP ($F = 2.267$; $p < 0.05$). (Fig. 6).

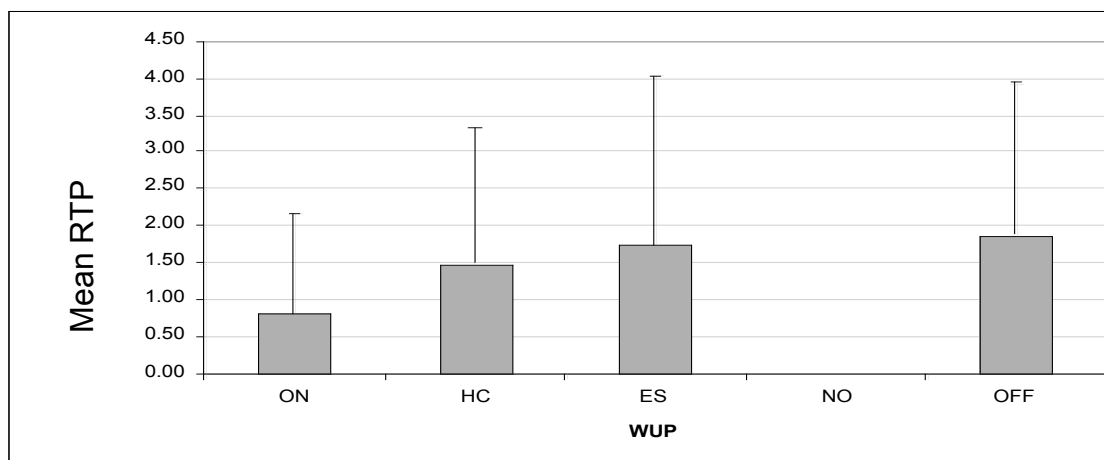


Figure 6. Mean (SD) readiness to perform change for the four warm-up protocols: on-ice only (ON), Hockey Canada (HC), explosive specific (ES) and off-ice only (OFF).

No significant main effects were observed for day of testing based on RTP at the start of each session. ($F = 0.474$; $p < 0.05$). (Fig. 7).

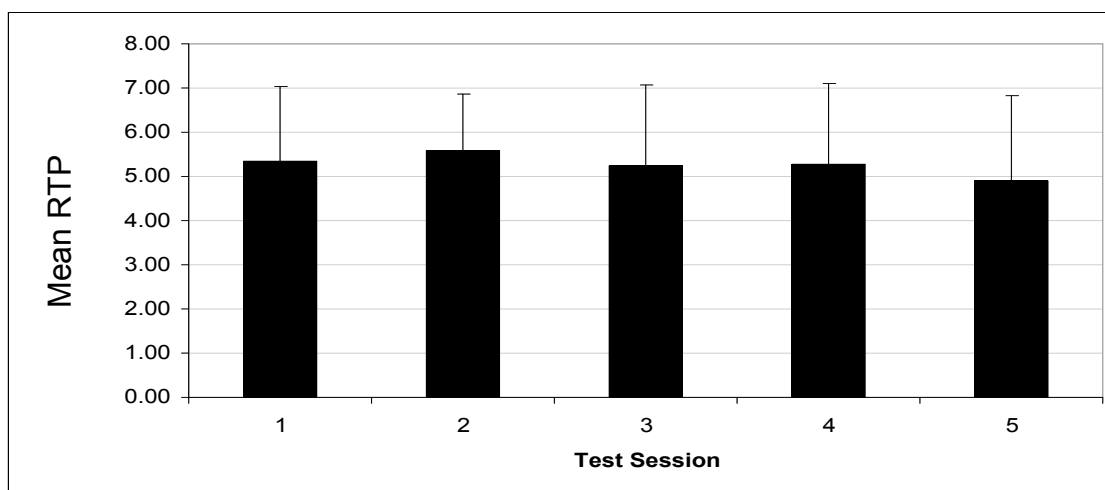


Figure 7. Mean (SD) session readiness to perform taken at the start of each testing session.

No significant correlations were found between pre-SP RTP and SP (any distance) in all WUP ($p < 0.05$) data for ES shown below (Table. 2).

		ES RTP- Pre-SP	ES RTP Change
ES4	Pearson Correlation	.020	.144
	Sig. (1-tailed)	.468	.278
	N	19	19
ES8	Pearson Correlation	.131	.039
	Sig. (1-tailed)	.297	.436
	N	19	19
ES12	Pearson Correlation	.222	.079
	Sig. (1-tailed)	.181	.373
	N	19	19
ES16	Pearson Correlation	.177	.021
	Sig. (1-tailed)	.234	.466
	N	19	19
ES20	Pearson Correlation	.123	-.013
	Sig. (1-tailed)	.307	.479
	N	19	19

Table 2. Correlations between skating performance in explosive specific warm-up protocol (ES) and readiness to perform (RTP).

Discussion

This study investigated the effect of five warm-up protocols (WUP) on linear ice-skating performance (SP) as measured by time at 4, 8, 12, 16, and 20 m and participants' perceived readiness to perform (RTP) as measured on a visual analogue scale (VAS) immediately before and after all WUP and immediately before SP. Skating performance included three trials separated by three minutes rest then averaged for each warm-up protocol. RTP scores were analyzed to determine if participants' SP was matched by their RTP scores.

Significant main effects of warm-up protocols on skating performance occurred at all distances (see table 1). The explosive-specific (ES) protocol was the only WUP that demonstrated significant differences in SP at all distances, although the effects of ES did not differ from the standard Hockey Canada (HC) warm-up protocol or the on-ice only portion of the Hockey Canada warm-up protocol (ON). The explosive-specific protocol data resulted in a significantly increased SP compared to both no warm-up (NO) and the off-ice only portion of the Hockey Canada protocol (OFF). No significant differences in SP were found between NO and OFF at any distances.

The increased skating performance resulting from the explosive-specific warm-up protocol is functionally relevant. At 4 m, skaters using this protocol would have been 0.29 m or 7.3% ahead of skaters using off-ice only protocol and at 20 m, this distance would have been 0.44 m or 2.2%. The game of ice-hockey requires players to race each other for the puck and for position. These distances are large considering a successful race can be determined by the diameter of a puck (0.075m).

The only warm-up protocols that elicited significant skating performance improvements utilized an on-ice component (ES, ON and HC). These warm-up protocols each demonstrated significant increases in SP compared to no warm-up and off-ice only warm-up protocols at 4 m. The only protocol to significantly affect SP at distances greater than 4 m was ON, where significant effects still existed at 16 m. The HC protocol elicited significant improvements in skating performance at both 4 m and 12 m compared to no warm-up.

The results indicate that all warm-up protocols except on-ice only protocol elicited significant change in readiness to perform (see figures 3 to 7); however, no WUP yielded significantly better results than another based on the amount of change elicited. No significant differences were found when comparing RTP scores taken before warm-up protocols started (pre-WUP) or RTP taken at the start of each testing session day. These results suggest that participants arrived to each warm-up protocol and/or testing session day with similar levels of perceived readiness. No significant correlations were found between RTP and skating performance which suggests that the participant's perceptions of readiness before testing SP did not predict their physiological readiness to perform. When participants' readiness to perform values were analyzed on an individual basis, some RTP values were related to their SP. However, some showed negative and some showed positive correlations, while others indicated similar readiness to perform despite large variations in skating performance.

Results from several studies have shown the performance benefits of dynamic, loaded or explosive WUP on speed and/or explosive movements (Young, Jenner and Griffiths, 1998; Duthie, Young & Aitken, 2002; Young and Behm, 2003; and Burkett,

Phillips and Ziuraitis, 2005). These results are supported in the present study where the warm-up protocol comprised of explosive rather than passive exercise resulted in consistent improvements to skating performance. Several factors may have played a role in the effects created by the ES protocol that could have optimized core/muscular temperature, elasticity/stiffness, activation, fatigue, and proprioception.

Bishop (2003b) indicated that optimal core and muscle temperature could be obtained in four minutes by exercising at 60% of $\text{VO}_{2\text{max}}$ and that these effects would increase muscular contraction speed and force and mechanical efficiency. All warm-up protocols in this study included either a jog component (off-ice) or a skating component (on-ice) for four minutes that was self directed at a moderate level based on the Borg scale [12-14].

No passive warm-up techniques were utilized in this study. Although core or muscular temperatures were not directly measured, it was likely that all warm-up protocols enabled all participants to attain ideal core and muscular temperature.

The timelines used in this research were designed to simulate the warm-up conditions associated with ice-hockey at the Junior level and higher. Typically, players perform a 15 minute off-ice warm-up and then spend 15 to 20 minutes getting dressed into playing gear. They then participate in a 15 minute on-ice warm-up, followed by another 15-20 minute delay while the ice is resurfaced. All warm-up protocols in this study contained 15 minute rest periods after both off and on-ice portions of the protocols. It has been shown that core temperature starts to cool-down after 20 minutes. Although increases in temperature are known to last for 15 to 20 minutes (Bishop 2003b), Mohr, Pink, Elsner & Kvitne (1998) found reduced sprint performance after 15 minutes of rest.

Based on both the design and the results of this study, it seems unlikely that temperature played a large role in any SP differences. If temperature had a large effect on skating performance, it could be expected that an effect from the off-ice only warm-up protocol compared to no warm-up where there was likely no significant increase in temperature; however, this was not the case. Since both off-ice only and on-ice only protocols were matched for intensity, volume and duration, one would expect each WUP to generate a similar amount of temperature affects; however, ON only demonstrated significant increases in SP from 4 to 16 m. If temperature was affected by the cumulative affect of an on-ice protocol preceded by an off-ice protocol, a similar effect from the explosive-specific and HC warm-up protocols could be expected, but this was not the case.

It is possible that the specific nature of the exercises used in the ES warm-up protocol followed recruitment patterns more similar to skating than the HC based WUP, leading to optimal muscle temperature in muscles used in skating performance.

Stretching has been shown to effect various characteristics of muscle physiology including increased elasticity (reduced stiffness) and decreased muscular-tendon unit viscosity (Kubo, Kanehisa, Kawakami, & Fukunaga, 2001). Three warm-up protocols in this study included static passive stretching exercises: HC, ON and OFF. All stretches were held for 15 seconds and repeated twice off-ice and twice on-ice. The ES protocol did not contain any stretching exercises.

Stretching has been shown to negatively affect explosive performance as measured by running speed (Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003), drop-jumps (Young and Elliot, 2001) and counter movement jumps (Cornwell,

Nelson & Sidaway, 2002). HC, ON and OFF all included elements of static stretching and resulted in poor SP compared to ES which did not include stretching. Although the off-ice only protocol was not statistically different from no warm-up at all, SP was still better by 3% when stretching was not performed.

Since various WUP showed effects at various distances, this may suggest an additive affect of stretching. For example, the on-ice only protocol data yielded significantly increased skating performance up to 16 m compared to HC which demonstrated significant changes in SP only at 4 m. The Hockey Canada warm-up protocol had a total of 3 sets of stretches compared to 1 set in the ON warm-up protocol. It is also possible that the addition of a sport specific movement (skating) after on and off-ice stretching mitigated a loss in stiffness since the HC warm-up protocol demonstrated significant improvements to SP compared to the on-ice only warm-up protocol at 4 m. The results suggest that off-ice WUP is not detrimental provided it is followed by on-ice warm-up.

The explosive-specific protocol included elements designed to increase stiffness such as drop-jumps and pylometrics. Fletcher and Jones (2004) found increased running speed after a dynamic warm-up that mimicked specific running patterns. They concluded that their protocol enhanced proprioception and enabled better switching from eccentric to concentric contractions while running utilizing the stretch shortening cycle (SSC).

The explosive-specific protocol data yielded increased skating performance results across all distances indicating that if stiffness is ergogenic to skating performance it may play a bigger role as the distance of SP increases. It is known that as distance increases, stride length increases (Marino & Drouin, 2002). Skating relies on SSC

movement; therefore, force production can be compromised by reduced stiffness. As stride length increases, joints and muscles approach their functional end ranges. If stiffness is reduced at these key positions, the SSC would have been impaired and skating performance negatively affected. Conversely, if stiffness was increased, the impact of SSC could have been enhanced. Since split times did not level off between 16 and 20 m distance, maximal skating performance may not have been reached. Therefore, it is possible that an even greater effect could be expected from the explosive-specific protocol over longer distances. Time motion analysis (TMA) of ice-hockey found that short distances of SP predominate in the game and average 2.6 seconds (Bracko, 1998), although SP at distances of 20 m and greater do occur. Distances of 20 m and greater have an impact in key situations such as break-aways, back-checking and fore-checking that can impact the players' overall game performance.

Explosive performance has been significantly improved by WUP that increase neuromuscular activation through various types of loading (Duthie et al. ,2002; Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; and Young & Behm 2003). Increased performance in these studies was credited to increased synchronization of motor neuron discharge which resulted in increased muscular recruitment and increased rate of force development (RFD). The ES warm-up protocol utilized explosive movements and drop-jumps from a height of 51 cm. Power generated during one drop-jump for a 90 kg participant would generate approximately 5100 Watts (Sayers, Harackiewicz, Harman, Frykman &Rosenstein, 1999). This is more than double the approximate 2400 watts generated by a 200 pound elite speed skaters after three seconds

during a 30 second maximal bicycle sprint (de Koning, de Groot & van Ingen Shenau, 1992).

The non-ES warm-up protocols did not utilize exercises that would require power development of this magnitude. These exercises included 2 sets of 10 repetitions of single and double limb activities, as well as linear and lateral movement directions. It is likely that any increase in stiffness created by performing the explosive-specific protocol lead to increased recruitment and RFD for SP compared to other warm-up protocols. The inclusion of the same exercises on-ice may have also contributed to the increased skating performance compared to no warm-up and off-ice only warm-up protocols throughout the 20 m distance.

There is an indication that the benefits to performance realized through increased loading are higher in trained subjects (Duthie et al., 2002; Chui, Fry, Weiss, Schilling, Brown & Smith, 2003). All participants in this study were playing at an elite level of hockey by virtue of being a member of a Junior A hockey team. Although this would imply a highly trained group their mean age was only 18.7 years. It is possible that older ice-hockey players with more training experience may find greater benefits in SP from explosive-specific warm-up protocol.

Participants' level of fatigue could affect SP. Fox, Bowers, & Foss (1993) stated that activities similar to a 3.2 second maximal sprint utilize ATP/CP as the predominant energy source for force production. The results from their study indicated that three minutes of rest is sufficient to enable sufficient repletion of these stores to repeat maximal sprint performance. Skating performance did not change significantly across trials suggesting that fatigue was not a factor during SP trials.

Excessive fatigue created within each warm-up protocol is also not likely. The overall intensity within each WUP was moderate since it included jogging and skill movements at moderate levels. The only maximal intensity activities occurred within the ES warm-up protocol. RTP scores increased after every warm-up protocol. If participants perceived to be fatigued after the warm-up protocol, RTP scores would be expected to drop. It is likely that if fatigue impaired SP, it would have occurred as a result of the ES WUP; however, this WUP elicited significant increases over more distance than all other warm-up protocols.

The explosive-specific warm-up protocol took 10 minutes to complete compared to 15 minutes for HC, ON and OFF. Although the latter protocols were longer, they included 5 minutes of stretching at an extremely low intensity. It is likely that any fatigue created during the warm-up protocols would have been eliminated as a result of the 15 minute rest breaks between protocols. Finally, if significant fatigue was created by any WUP it could be expected that NO would have a significant affect on skating performance, and this was not the case.

Results from a recent study by Behm, Wahl, Button, Power & Anderson (2005) indicated that ice-hockey players with high levels of balance demonstrated correspondingly high levels of skating performance. When ice-skating, greater balance of the support foot enables increased stride length which in turn can lead to increased force production and increased skating performance. The exercises utilized in the ES warm-up protocol required participants to land on one and two legs. These exercises may have caused acute overload to balance both on and off-ice WUP, and produced an acute increase in proprioception that lead to increased balance while measuring skating

performance. This could potentially explain why the explosive-specific protocol was the only protocol that significantly increased SP at 20 m.

The combined effect of increased balance and optimized SSC may explain why the explosive-specific protocol was the only protocol to yield significantly better results at 20 m. It is likely that the benefits of increased balance and SSC are more pronounced as the skating stride reaches full length. At this point in the stride, a support leg with better balance enables the propulsion leg to apply greater force, over a longer period of time. As well, since joints come closer to full range as strides reach full length, SSC optimization has greater impact on skating performance compared to strides of shorter length.

Finally, since no difference in skating performance was seen across the three SP trials for any of the warm-up conditions and in particular for the NO and OFF conditions, no specific warm-up was produced by one sprint trial on the next. This means that a specific warm-up of one or two 20 m sprints is not sufficient to enhance performance whereas extending or expanding warm-up to the intensity and/or duration of HC ON and ES protocols can provide sufficient stimulus to enhance the acceleration over 4 and up to 20 m.

In conclusion, increases in skating performance due to the explosive-specific warm-up protocol may be due to a combination of optimized muscle temperatures of the specific muscles used in skating performance, increased stiffness, increased activation, limited fatigue and increased proprioception. Although the only warm-up protocols to yield significant increases in skating performance data included an on-ice portion (ES, HC, ON), HC and ON only did so at 4 m compared to the no warm-up and off-ice only

protocol, and the on-ice only warm-up protocol was better than no warm-up at all from 4 to 16 m. The results from this research suggests that off-ice warm-up has the same effect as doing no warm-up at all as measured by linear skating over distances up to 20 m.

Based on the results of this research it appears that warm-up protocols that include explosive and specific on and off-ice elements are better for linear skating than standard on and/or off-ice WUP or no warm-up at all. The explosive-specific protocol used in this study is simple to perform, requires only a chair, takes less time to perform (10 minutes versus 15 minutes for other warm-up protocols) and demonstrates superior skating performance from 4 m to 20 m.

Further research is necessary to determine if these results are applicable to less trained, younger, or female ice-hockey players or speed skaters. Further study could also determine the separate effect on skating performance of ES off-ice compared to ES on-ice. Although increased SP was found, it was in a straight line. Skating performance in other non-linear directions was not measured. The minimum duration of the warm-up protocol and the duration of effect on sprint performance also remain to be determined.

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Appendix A: Review of the Literature

Introduction

Warm-up is a widely accepted activity that precedes amateur and elite level sport participation (Fox, Bowers, & Foss, 1993). The goal of warm-up is to decrease injury risk and increase performance. Warm-up technique is generally divided into two categories: passive and active. Bishop (2003a and 2003b) reviewed both categories of warm-up in two separate papers. He divided active warm-up into two parts: (a) general, which is comprised of cardiovascular activities such as jogging or calisthenics and (b) specific, which is comprised of stretching, force and velocity elevation as well as skill specific movements.

Researchers have attempted to provide recommendations for ideal warm-up protocols that maximize performance in measures such as running speed (Fletcher and Jones, 2004), power (Young and Behm, 2003) and force (Shilling and Stone, 2000; Church, Wiggins, Moode & Crist 2001 and Burnley, Doust & Jones, 2005). Over the last few decades there has been a trend towards using active and specific warm-up protocols instead of traditional passive and general protocols. Research that supports these trends has found increased performance from the effects of warm-up on jumping (Young, Jenner & Griffiths, 1998), and running activities (Fletcher and Jones, 2004). To date, no research has looked at the effect of warm-up protocols for ice-skating in the sport of ice hockey.

Hockey Canada (1995) provides hockey specific warm-up guidelines on their website (<http://www.hockeycanada.ca/e/develop/safety/downloads/stretch.pdf>). This warm-up protocol includes static and dynamic stretching, jogging and skating-specific skills. Based on recent studies dealing with warm-up, it appears that this protocol could be improved.

These improvements could establish a new warm-up protocol whose benefits may include: increased simplicity, reduced time to complete, increased perception of readiness to perform, minimized fatigue, maximized injury prevention and ergogenic effects.

The purpose of this review of literature is to examine the research on the performance enhancement effect of warm-up characteristics including: general warm up, stretching and specific movements that include resistance and ballistic actions. These protocols will be then be evaluated for potential inclusion in a warm-up protocol for elite ice hockey players.

General Warm-Up

General warm-up as described by Bishop (2003b) and Shellock and Prentice (1985) employs light aerobic activity such as jogging or calisthenics and has been shown to be more effective than simple passive warm-up. Passive warm-up is defined as the application of external heat to increase muscle temperature (T_m) and has been shown to be better than no warm-up at all (Bishop 2003a). The benefits of general warm-up generally attributed to increased muscular temperature include: increased oxygen kinetics to and from the blood stream, increased metabolic rate, increased mechanical efficiency through decreased muscle tendon unit viscosity and increased force characteristics such as increased contraction speed and force, increased sensitivity to nerve receptors, and increased transmission speed of nerve impulses (Bishop 2003b). Other physiological benefits of general warm-up are include: increased substrate availability, increased waste removal due to increased blood flow, increased oxygen delivery, and decreased muscular and blood lactic acid levels (Gray, Devito & Nimmo, 2002).

Bishop (2003b) summarized how the intensity of general warm-up effects performance. He suggested that short term performance could be increased at warm-up intensities equal to approximately 60% of the maximum VO_2 (MVO_2) and warned that warm ups at intensities greater than 60% decreased performance due to depleted high energy phosphate concentrations leading to premature fatigue.

Burnley et al. (2005), compared warm-ups classified as moderate, heavy and sprinting intensities and found increased performance of 2 to 3% improvement in cycling performance from the moderate or heavy intensities. Genovely and Stamford (1982) found no change in performance when warming up at anaerobic threshold (AT), but highlighted the fact that maximum performance declined with warm-up at intensities greater than AT.

The effect of duration on warm-up has also been summarized (Bishop, 2003b). He stated that muscular temperature rises rapidly within the first 3 to 5 minutes, but reaches a plateau after 10 to 20 minutes. Significant performance increases after a four minute warm-up were noted but benefits were no different than the same warm-up lasting 20 minutes.

Warm-up effect has also been shown to decay. Researchers studying soccer sprint performance showed a decline after 15 minute rest during half time, compared to after the pre-game warm-up (Mohr, Pink, Elsner & Kvitne, 1998). These researchers found a correlation of 0.6 for declining sprint performance and muscle temperature. Bishop, Bonetti & Spencer (2002) demonstrated the effects of an intermittent style warm-up and found increased 2 minute sprint performance using kayak paddling as a dependant measure. This warm-up protocol included 10 minutes general warm-up at 65 % of

MVO₂ as well as five 10 second sprints at 200 % of the VO₂ maximum separated by 50 seconds of recovery at 55 % of MVO₂.

These findings suggest that as little as four minutes of general warm-up may be sufficient to elevate muscular temperature and realize increased performance. Hockey Canada's guidelines suggest 10 to 15 minutes of general warm-up off-ice and another 10-15 minutes on-ice before games and practices. By reducing time of general warm-up to 4 to 10 minutes, participants could use 20 to 26 minutes for other activities that included: skill, tactical and/or mental preparation. These results indicated that warm-up intensity should not deplete energy stores which means minimizing the time spent above 60% MVO₂.

Stretching

Stretching protocols have been defined across two axes (Fletcher & Jones, 2004). The first axis describes the body's movement ranging from static (not moving) to dynamic (moving). The second axis describes stretching based on muscular recruitment ranging from active, where muscles are actively involved in creating the stretch, to passive, where there are no intended muscular recruitment patterns.

Static stretching typically involves maintaining a joint angle at a position just approaching pain sensation for greater than 10 seconds. Applied researchers typically have looked at stretches held for 20 to 30 seconds (Bandy & Irion, 1994; Rosenbaum & Hennig, 1995 and Bazaett-Jones, 2003). Use of static passive stretching has been shown to significantly reduce running speed (Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003) and in 20 metre runs for rugby players (Fletcher & Jones, 2004). Although Siatris et al., (2003) found no benefits to dynamic or general warm ups, Fletcher and

Jones indicated significantly increased running performance using an active dynamic warm up. Their warm-up included up to 20 repetitions of running specific movements that matched the muscles being stretched in the static passive treatment. Although temperature was not measured, they indicated that the likely cause for increased performance using dynamic stretch warm-up was increased core temperature. The authors also suggest that since the active dynamic warm-up mimicked specific running patterns, proprioception may have been enhanced enabling better switching from eccentric to concentric contraction while running.

Passive stretching has also been shown to decrease performance in drop jumps (Young & Elliot, 2001), counter movement jumps using single joint movements after three sets of stretched held for 20 seconds (Cornwell, Nelson & Sidaway, 2002) as well as vertical jumps (using proprioceptive neuromuscular facilitation stretching) (Curch et al., 2001). Fowles, Sale and MacDougal (2000) found decreased strength after stretching, although the stretching protocol was lengthy, 13 repetitions of 135 seconds in duration.

Other researchers found no difference in performance after a variety of stretch protocols. Koch, O'Bryant, Sanborn, Proulx, Hruby, Shannonhouse, Boros, & Stone (2003) did not find significant differences in broad jump performance when comparing static stretching high force warm up, high power warm-up and no activity. Knudson, Bennett, Corn, Leick, & Smith (2001) also found no differences in performance. They employed three repetitions of a 15 second hold for their stretch protocol. It is interesting to note that, although there was no significant difference in warm-up effect on performance, 35 % of their participants did shown an increase in vertical jump after

stretching. This supports findings on the highly individualized response to warm-up protocols.

Physiological effects of stretching include increased elasticity and decreased muscular-tendon unit viscosity, especially after 10 minute or longer holds (Kubo, Kanehisa, Kawakami, & Fukunaga, 2001). Six participants demonstrated a drop in maximum voluntary contraction (MVC) of 12 % following 20 minutes of stretching. The author suggests that this is due to inactivation rather than elastic component changes. Green, Grenier and McGill (2002) noted that the effect of warm-up as measured by decreased stiffness disappeared after 30 minutes of bench sitting. Results from EMG studies indicate reduced output after stretching (Rosenbaum & Hennig, 1995) while others noted that specific muscles respond to warm-up differently (Mohr, Krstrup, Nybo, Nielsen, & Bangsbo, 2004). Rosenbaum & Hennig also noted that the effect of reduced EMG output was eliminated after running.

It is a commonly held belief that stretching as part of a warm-up helps to reduce the occurrence of injuries. Although the purpose of this review is to study the effects of warm-up on performance, it should be noted that current research has been unable to definitively establish this correlation (Pope, Herbert, Kirwan, & Graham 2000; Weldon & Hill, 2003 and Witvrouw, Mahieu, Danneels, & McNair, 2004).

Although the Hockey Canada warm-up protocol utilizes active stretching, it contains limited dynamic and explosive movements. Further, it employs several static stretches on and off the ice. Since there appears to be no correlation between stretching and reduced injuries and its implications in reduced performance, it might be safe to

eliminate static stretching from the warm-up protocol and replace it with more dynamic and explosive movements.

Specific Warm-Up

Warm-up utilizing heavy loads has been studied. Some researchers have reported increased performance (Duthie, Young & Aitken, 2002 and Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003). Recent studies reported no significant increase in performance (Young et al., 1998; Hrysomallis & Kidgell, 2001 and Scott and Docherty, 2004). Researchers have also reported increased performance when ballistic or explosive movements preceded performance (Young & Behm, 2003). Several studies note that the benefit from these types of warm up protocol require that the users are trained and/or possess high levels of strength (Duthie et al., 2002; Chiu, Fry, Weiss, Schilling, Brown and Smith, 2003 and Gourgoulis et al., 2003).

Heavy Load Warm-Up

Gourgoulis et al. (2003) found that their warm up protocol, which consisted of five sets of half squats with two repetitions of each of the following intensities: 20, 40, 60, 80 and 90 % of their one repetition maximum (1 RM) lead to improvement in vertical jump performance ($p < 0.05$). Results indicated that the improvement in countermovement jumps (CMJ) represented an increase of 2.39 % in vertical jumping ability. Although a test for level of neuromuscular activation was not carried out, they credit the significant findings to high frequency stimulation of motor neurons (from the heavy squat sets) which may have increased individual motor unit activation. The authors also surmised a resultant increase in synchronized discharge of motor neurons so that increased activation enabled a greater number of muscle fibres to contract, resulting

in improved rate of force development. These researchers further clarified that their participants who demonstrated greater maximum strength, found a 4.01% improvement in vertical jumping performance.

Research by Young et al. (1998) demonstrated improved loaded countermovement jumps (LCMJ) after warm up consisting of 2 sets of 5 LCMJ, 1 set of 5 squat reps with 5RM load and 1 set of 5 LCMJ with 4 minute rests between sets. Jump height for the last set of LCMJ was significantly greater than the first (2.8 %). The authors attributed this change to the loaded squats.

Contrarily, in a similar study, Scott and Docherty (2004) were unable to elicit changes in either vertical or horizontal jump performance after one set of 5RM squat warm-up ($p < 0.05$). Although the authors found no improved performance in explosive movement (vertical or horizontal) from loading, they did find significantly increased squatting ability over four testing sessions. This may explain the difference in findings compared to Young et al. who inadvertently utilized a load less than 5RM.

Hrysomallis and Kidgell (2001) were also unable to improve performance explosive movement using increased loads for warm-ups. Participants performed 5 repetitions of a 5RM bench press and then performed explosive pushups on a force platform. No significant changes were found for power and maximal rate of force development ($p < 0.01$). They advised of the need to consider the volume of resistance, exercise intensity, type of resistance exercise as well as time between warm-up and performance measure period.

Explosive Warm-Up

Explosive warm up protocols have demonstrated increased explosive performance.

Young and Behm (2003) looked at the performance on a concentric jump test as well as drop jump test by comparing warm up protocols that consisted of: (a) running, (b) stretching, (c) running plus stretching, and (d) running plus stretching plus jumping, with a control warm-up protocol. These researchers discovered that both drop jump and vertical jump performance increased as measured by concentric force as well as rate of force development in the 'run plus stretch plus jump' group compared to all other groups ($p < 0.05$). It was also found that the stretch group had significantly reduced performance in the same explosive force and measures. Their stretching protocol included 2 sets of stretches held for 30 seconds each for plantar flexors, quadriceps.

Although there is potential to improve performance using heavy loads or explosive movement warm-up protocol, the performance increases seem to be limited by training status of an individual. Chiu et al. (2003) found that their loading protocol did not have an effect on the overall group, but when the group was separated into athlete and recreational trained groups, heavy loaded squats were found to improve performance of jump squat for the athlete group ($p < 0.05$). This effect was also observed by Duthie et al. (2002). They looked at jump squat performance before and after various squat protocols and found a significant improvement ($p < 0.05$) in performance for the higher strength group compared to the lower strength group.

Due to the conflicting results reported in the literature as well as practical issues pertaining to the possible cost and complexity of equipment, there does not appear to be any benefit to heavy loaded warm-up element for ice-hockey at this time; however, since

skating requires the same need for rapid switching from eccentric to concentric contraction for movement as does running, it is expected that a warm-up consisting of active dynamic movements could increase performance. These movements could consist of depth jumps utilizing the stretch shortening cycle and include skating specific movements such as lateral motion.

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Appendix B: Raw Data

Table 3

Skating performance raw data.

	N	Minimum	Maximum	Mean	Std. Deviation
HC4	20	.80	1.02	.90	.062
HC8	20	1.43	1.83	1.57	.10
HC12	20	1.99	2.41	2.15	.10
HC16	20	2.51	3.02	2.69	.12
HC20	20	2.99	3.61	3.204	.14
ON4	17	.82	1.02	.90	.06
ON8	17	1.45	1.72	1.55	.08
ON12	17	2.01	2.41	2.14	.11
ON16	17	2.51	3.07	2.68	.14
ON20	17	3.02	3.67	3.18	.16
NO4	20	.84	1.02	.95	.05
NO8	20	1.50	1.78	1.61	.07
NO12	20	2.06	2.45	2.20	.10
NO16	20	2.55	3.04	2.73	.12
NO20	20	3.03	3.64	3.23	.15
ES4	19	.84	1.06	.91	.07
ES8	19	1.41	1.78	1.56	.09
ES12	19	2.01	2.46	2.15	.11
ES16	19	2.51	3.09	2.69	.14
ES20	19	2.99	3.67	3.19	.16
OFF4	16	.76	1.13	.98	.10
OFF8	16	1.42	1.85	1.63	.12
OFF12	16	1.96	2.54	2.21	.15
OFF16	16	2.47	3.14	2.76	.17
OFF20	16	2.97	3.69	3.26	.18

Table 4

Readiness to perform raw data.

	N	Minimum	Maximum	Mean	Std. Deviation
HC-Pre-WUP	20	2.5	9.6	5.2	1.7
HC-Post-Off	20	3.4	8.9	6.7	1.3
HC-Pre-On	20	2.6	9.2	6.5	1.6
HC-Post-On	20	5.0	9.5	7.3	1.1
HC-Pre-SP	20	5.1	9.0	6.7	1.2
OFF-Pre-WUP	17	2.5	7.3	5.1	1.5
OFF-Post-Off	17	4.7	8.6	6.9	1.0
OFF-Pre-SP	17	4.6	10.0	6.9	1.3
ON-Pre-WUP	12	3.3	9.9	5.9	2.0
ON-Post-On	17	5.2	10.0	6.8	1.3
ON-Pre-SP	16	4.6	9.2	6.6	1.3
NO-Pre-SP	20	1.2	8.4	5.5	1.7
ES-Pre-WUP	19	1.6	8.0	4.8	1.8
ES-Post-Off	19	3.6	9.4	6.7	1.7
ES-Pre-On	15	2.6	9.5	7.0	1.7
ES-Post-On	14	2.2	8.1	5.6	1.4
ES-Pre-SP	19	2.5	8.8	6.6	1.6

Appendix C: Statistical Analysis

Table 5

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Skating Performance at 4 m for all Warm-up Protocols (n=20).

Effect		Value	F	Hypothesis df	Error df	Sig.
m4	Pillai's Trace	.718	6.988(a)	4.000	11.000	.005
	Wilks' Lambda	.282	6.988(a)	4.000	11.000	.005
	Hotelling's Trace	2.541	6.988(a)	4.000	11.000	.005
	Roy's Largest Root	2.541	6.988(a)	4.000	11.000	.005

Table 6

Pairwise Comparisons using Least Significant Differences Method for Mean Skating Performance at 4 m for all Warm-Up Protocols (n=20).

(I) m4	(J) m4	Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
					Lower Bound	Upper Bound
1 (HC)	2	-.063(*)	.026	.032	-.119	-.006
	3	.008	.016	.598	-.025	.042
	4	-.042(*)	.018	.036	-.081	-.003
	5	.003	.021	.900	-.042	.047
2 (OFF)	1	.063(*)	.026	.032	.006	.119
	3	.071(*)	.029	.027	.009	.133
	4	.020	.025	.426	-.033	.074
	5	.065(*)	.015	.001	.034	.096
3 (ON)	1	-.008	.016	.598	-.042	.025
	2	-.071(*)	.029	.027	-.133	-.009
	4	-.051(*)	.019	.017	-.091	-.011
	5	-.006	.021	.791	-.052	.040
4 (NO)	1	.042(*)	.018	.036	.003	.081
	2	-.020	.025	.426	-.074	.033
	3	.051(*)	.019	.017	.011	.091
	5	.045(*)	.018	.024	.007	.083
5 (ES)	1	-.003	.021	.900	-.047	.042
	2	-.065(*)	.015	.001	-.096	-.034
	3	.006	.021	.791	-.040	.052
	4	-.045(*)	.018	.024	-.083	-.007

Table 7

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Skating Performance at 8 m for all Warm-Up Protocols (n=20).

Effect		Value	F	Hypothesis df	Error df	Sig.
m8	Pillai's Trace	.708	6.660(a)	4.000	11.000	.006
	Wilks' Lambda	.292	6.660(a)	4.000	11.000	.006
	Hotelling's Trace	2.422	6.660(a)	4.000	11.000	.006
	Roy's Largest Root	2.422	6.660(a)	4.000	11.000	.006

Table 8

Pairwise Comparisons using Least Significant Differences Method for Mean Skating Performance at 8 m for all Warm-Up Protocols (n=20).

(I) m8	(J) m8	Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
					Lower Bound	Upper Bound
1 (HC)	2	-.034	.032	.309	-.103	.035
	3	.030	.024	.230	-.021	.081
	4	-.026	.026	.334	-.082	.030
	5	.026	.027	.348	-.032	.084
2 (OFF)	1	.034	.032	.309	-.035	.103
	3	.064	.033	.075	-.007	.135
	4	.008	.025	.762	-.046	.062
	5	.060(*)	.014	.001	.031	.089
3 (ON)	1	-.030	.024	.230	-.081	.021
	2	-.064	.033	.075	-.135	.007
	4	-.056(*)	.020	.015	-.100	-.013
	5	-.004	.025	.882	-.058	.050
4 (NO)	1	.026	.026	.334	-.030	.082
	2	-.008	.025	.762	-.062	.046
	3	.056(*)	.020	.015	.013	.100
	5	.052(*)	.019	.014	.012	.093
5 (ES)	1	-.026	.027	.348	-.084	.032
	2	-.060(*)	.014	.001	-.089	-.031
	3	.004	.025	.882	-.050	.058
	4	-.052(*)	.019	.014	-.093	-.012

Table 9

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Skating Performance at 12 m for all Warm-Up Protocols (n=20).

Effect		Value	F	Hypothesis df	Error df	Sig.
m12	Pillai's Trace	.687	6.036(a)	4.000	11.000	.008
	Wilks' Lambda	.313	6.036(a)	4.000	11.000	.008
	Hotelling's Trace	2.195	6.036(a)	4.000	11.000	.008
	Roy's Largest Root	2.195	6.036(a)	4.000	11.000	.008

Table 10

Pairwise Comparisons using Least Significant Differences Method for Mean Skating Performance at 12 m for all Warm-Up Protocols (n=20).

(I) m12	(J) m12	Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
					Lower Bound	Upper Bound
1 (HC)	2	-.049	.031	.133	-.114	.017
	3	.014	.016	.397	-.020	.048
	4	-.055(*)	.019	.012	-.095	-.014
	5	.013	.023	.571	-.035	.062
2 (OFF)	1	.049	.031	.133	-.017	.114
	3	.062	.033	.082	-.009	.134
	4	-.006	.028	.828	-.065	.053
	5	.062(*)	.018	.004	.023	.101
3 (ON)	1	-.014	.016	.397	-.048	.020
	2	-.062	.033	.082	-.134	.009
	4	-.069(*)	.019	.002	-.108	-.029
	5	-.001	.023	.977	-.050	.049
4 (NO)	1	.055(*)	.019	.012	.014	.095
	2	.006	.028	.828	-.053	.065
	3	.069(*)	.019	.002	.029	.108
	5	.068(*)	.019	.003	.027	.109
5 (ES)	1	-.013	.023	.571	-.062	.035
	2	-.062(*)	.018	.004	-.101	-.023
	3	.001	.023	.977	-.049	.050
	4	-.068(*)	.019	.003	-.109	-.027

Table 11

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Skating Performance at 16 m for all Warm-Up Protocols (n=20).

Effect		Value	F	Hypothesis df	Error df	Sig.
m16	Pillai's Trace	.648	5.054(a)	4.000	11.000	.015
	Wilks' Lambda	.352	5.054(a)	4.000	11.000	.015
	Hotelling's Trace	1.838	5.054(a)	4.000	11.000	.015
	Roy's Largest Root	1.838	5.054(a)	4.000	11.000	.015

Table 12

Pairwise Comparisons using Least Significant Differences Method for Mean Skating Performance at 12 m for all Warm-Up Protocols (n=20).

(I) m16	(J) m16	Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
					Lower Bound	Upper Bound
1 (HC)	2	-.053	.034	.147	-.127	.021
	3	.014	.020	.478	-.028	.056
	4	-.042	.022	.078	-.089	.005
	5	.010	.026	.690	-.045	.065
2 (OFF)	1	.053	.034	.147	-.021	.127
	3	.067	.037	.089	-.012	.146
	4	.011	.029	.702	-.050	.073
	5	.063(*)	.017	.002	.027	.100
3 (ON)	1	-.014	.020	.478	-.056	.028
	2	-.067	.037	.089	-.146	.012
	4	-.056(*)	.023	.029	-.105	-.006
	5	-.004	.025	.883	-.058	.050
4 (NO)	1	.042	.022	.078	-.005	.089
	2	-.011	.029	.702	-.073	.050
	3	.056(*)	.023	.029	.006	.105
	5	.052(*)	.020	.023	.008	.096
5 (ES)	1	-.010	.026	.690	-.065	.045
	2	-.063(*)	.017	.002	-.100	-.027
	3	.004	.025	.883	-.050	.058
	4	-.052(*)	.020	.023	-.096	-.008

Table 13

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Skating Performance at 20 m for all Warm-Up Protocols (n=20).

Effect		Value	F	Hypothesis df	Error df	Sig.
m20	Pillai's Trace	.602	4.154(a)	4.000	11.000	.027
	Wilks' Lambda	.398	4.154(a)	4.000	11.000	.027
	Hotelling's Trace	1.511	4.154(a)	4.000	11.000	.027
	Roy's Largest Root	1.511	4.154(a)	4.000	11.000	.027

Table 14

Pairwise Comparisons using Least Significant Differences Method for Mean Skating Performance at 12 m for all Warm-Up Protocols (n=20).

(I) m20	(J) m20	Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
					Lower Bound	Upper Bound
1 (HC)	2	-.042	.034	.238	-.116	.031
	3	.019	.019	.331	-.022	.060
	4	-.034	.024	.166	-.085	.016
	5	.017	.027	.544	-.041	.075
2 (OFF)	1	.042	.034	.238	-.031	.116
	3	.062	.036	.109	-.016	.139
	4	.008	.032	.806	-.060	.076
	5	.059(*)	.017	.004	.023	.096
3 (ON)	1	-.019	.019	.331	-.060	.022
	2	-.062	.036	.109	-.139	.016
	4	-.054	.027	.066	-.112	.004
	5	-.003	.027	.925	-.060	.055
4 (NO)	1	.034	.024	.166	-.016	.085
	2	-.008	.032	.806	-.076	.060
	3	.054	.027	.066	-.004	.112
	5	.051(*)	.024	.049	.000	.102
5 (ES)	1	-.017	.027	.544	-.075	.041
	2	-.059(*)	.017	.004	-.096	-.023
	3	.003	.027	.925	-.055	.060
	4	-.051(*)	.024	.049	-.102	.000

Table 15

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Change of Readiness To Perform.

Effect		Value	F	Hypothesis df	Error df	Sig.
rtp.chg	Pillai's Trace	.382	2.267(a)	3.000	11.000	.138
	Wilks' Lambda	.618	2.267(a)	3.000	11.000	.138
	Hotelling's Trace	.618	2.267(a)	3.000	11.000	.138
	Roy's Largest Root	.618	2.267(a)	3.000	11.000	.138

Table 16

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Readiness To Perform Pre-Skating Performance.

Effect		Value	F	Hypothesis df	Error df	Sig.
rtp.pre	Pillai's Trace	.413	1.762(a)	4.000	10.000	.213
	Wilks' Lambda	.587	1.762(a)	4.000	10.000	.213
	Hotelling's Trace	.705	1.762(a)	4.000	10.000	.213
	Roy's Largest Root	.705	1.762(a)	4.000	10.000	.213

Table 17

Repeated Measures (One-Way Within Subjects) Analysis of Variance for Mean Readiness To Perform Pre-Warm-up.

Effect		Value	F	Hypothesis df	Error df	Sig.
rtp.strt	Pillai's Trace	.371	1.375(a)	3.000	7.000	.327
	Wilks' Lambda	.629	1.375(a)	3.000	7.000	.327
	Hotelling's Trace	.589	1.375(a)	3.000	7.000	.327
	Roy's Largest Root	.589	1.375(a)	3.000	7.000	.327

Table 18

Repeated Measures (One-Way Within Subjects) Analysis of Variance for MeanReadiness To Perform Pre-Warm-up by testing session.

Effect		Value	F	Hypothesis df	Error df	Sig.
rtp.strt	Pillai's Trace	.371	1.375(a)	3.000	7.000	.327
	Wilks' Lambda	.629	1.375(a)	3.000	7.000	.327
	Hotelling's Trace	.589	1.375(a)	3.000	7.000	.327
	Roy's Largest Root	.589	1.375(a)	3.000	7.000	.327

Appendix D: Informed Consent

CONSENT FORM FOR PARTICIPATION IN THE STUDY ENTITLED,
**“The Effect of Various Warm-Up Protocols on Forward Ice-Skating Performance
in Elite Male Ice-Hockey Players”**

Description of the study:

You are being asked to voluntarily participate in a research project entitled “The Effect of Various Warm-Up Protocols on Forward Ice-Skating Performance in Elite Male Ice-Hockey Players” that is being conducted by a graduate student, Jeff Compton, as part of the requirements for the Masters in Sport and Exercise Science degree at the University of Victoria. If you have any questions or concerns about the project, you may contact either the student at 250.889.3343 or call his graduate supervisor, Dr. Howie Wenger, at 250.721.8386. You may verify the ethical approval of this study, or raise any questions you might have, by contacting the Associate Vice-President OF Research at the University of Victoria at 250.472.4545 or ovprhe@uvic.ca.

The purpose of this project is to examine the effects of various warm-up protocols on skating speed and readiness to perform.

The resources for conducting this study are being provided by the University of Victoria Ian Stewart Arena, Victoria.

The benefits of participating in this study include determining what warm-up protocol best improves your skating performance and mental readiness. The costs/inconvenience of participating is the likelihood of experiencing fatigue from skating at full speed over a short distance.

If you agree to participate you will be asked to take part in six testing sessions lasting approximately 1 hour each. You will be asked to provide your age and body weight. The first session will be an orientation session to familiarize yourself with the warm-up exercises and skating test. The skating test will be full sprint for 20 m, with three trials WITH THREE MINUTES REST BETWEEN EACH. Warm-up protocols include:

- 1) Practice sprints only;
- 2) Standardized on and off-ice warm-up;
- 3) Standardized off-ice warm-up only;
- 4) Standardized on -ice warm-up only;
- 5) Specific on and off-ice warm-up

You will be asked: “At this instant, how ready are you to skate your fastest?” immediately before and after each warm-up phase, including practice trials. You are permitted to decline any answer.

Your skating performance will be measured as speed and acceleration. It will be assessed through video taping and video analysis software.

Your participation in this project is entirely voluntary and you are free to refuse to participate, to withdraw from it, or to refuse to answer certain questions, and you will be given an opportunity to withdraw at each testing session without any negative

consequences. In the event that you withdraw from the study, you **WILL BE ASKED TO SIGN A RELEASE ALLOWING THE RESEARCHER TO USE YOUR DATA. IF YOU DO NOT WANT TO RELEASE YOUR DATA, IT will be destroyed.**

Your anonymity and confidentiality will be protected by not including your name on your data sheets; your data sheet will be assigned a code number for recording. Your name will not appear on any documentation. Consent forms will be stored separately from data sheets. Both forms and sheets will be stored in a locked filing cabinet to which only the primary investigator, Jeff Compton, will have access.

At the conclusion of the study, all of the raw data will be destroyed by shredding 6 months after the conclusion of the study.

The results of this study will be prepared for presentation as part of a thesis defense to a committee composed of three University of Victoria faculty members and one external examiner. **THE RESULTS OF THIS STUDY MAY BE DISCUSSED AT SCHOLARLY MEETINGS/PRESENTATIONS, PUBLISHED IN ARTICALS/BOOKS AND DESCRIBED IN MEDIA VENUES SUCH AS NEWSPAPERS OR TV NEWS ITEMS.** In addition, your testing results will be reviewed with you individually only after all research has been completed.

To ensure you are aware and fully understand the research procedures I will answer any questions you have regarding at any time.

I, the undersigned, having understood the above information and been given an opportunity to have my questions answered, agree to participate in this study:

Signature of Participant _____

Date: _____

PRINTED NAME OF PARTICIPANT _____

A COPY OF THIS CONSENT FORM WILL BE LEFT WITH YOU AND A COPY WILL BE TAKEN BY THE RESEARCHER.

Appendix E: Readiness to Perform Sheet

Event:

- Pre- Warm-Up 1
- Post Warm-Up 1
- Pre Warm-Up 2
- Post Warm-Up 2
- Pre Test

How ready are you to skate at your fastest speed?

Completely unready ----- Completely Ready

Subject Number: _____

Date:

Group:

Warm-Up:

- A
- E
- B
- C

Appendix F: Warm-Up Procedures

HOCKEY CANADA
HOCKEY CANADA SAFETY PROGRAM

**9.0 INJURY PREVENTION TECHNIQUES:
*PRINCIPLES OF CONDITIONING***

Motor Co-ordination Skill

This is the training of the athlete to perform new skills. It is important that the development of new skills follows an acceptable sequence, allowing the athlete enough time to practice these skills in a controlled situation prior to executing them in a game situation. During the growing years, motor co-ordination is influenced by periods of rapid growth causing the athlete to lose certain aspects of his/hers' motor co-ordination and skill. During these periods, it is important that time is allowed for the athletes' motor co-ordination and skill to catch up with their growth.

Muscular Endurance/Strength/Power

Muscular endurance is the ability of a muscle or group of muscles to work for an extended period of time.

Muscular strength is the ability of a muscle or group of muscles to produce a large amount of force a few times.

Muscular power is the ability of a muscle or group of muscles to produce force in a short period of time.

The training of these fitness components is complex and dependent on the athletes' age and experience. It is important to consult a professional in this field when introducing muscular endurance/strength/power training.

Joint Flexibility

Flexibility is defined as the range of motion (ROM) available at a joint or series of joints. The development of joint flexibility allows the body to move more freely with less energy costs. Joint flexibility is improved through stretching. There are generally two types of stretches; active and passive. An athlete can develop static flexibility however, it is more important to integrate this static flexibility into dynamic movements.

The development of these basic components of fitness is the goal of every coach. Their development should be aimed not only at improving the athletes' performance, but also for injury prevention. Through proper conditioning an athlete will better be able to handle the stresses of the game, putting them at a lower risk for injury.

Off-Ice Conditioning: Considerations and Guidelines

- The development of an appropriate off-ice training program should incorporate all the major components of fitness. It is necessary to consult with an appropriate fitness professional when starting an off-ice training program.

- For 9 to 12 year olds emphasis should be on motor coordination and skill development.
- For 13 to 16 year olds emphasis should be on development of aerobic conditioning and muscular endurance.
- For 17 to 20 year olds emphasis should be on development of aerobic conditioning, anaerobic conditioning and muscular strength and power.
- All players must stretch before and after all training sessions and players must drink sufficient amounts of cold water, before, during and after sessions. It is important that all players are properly supervised during off-ice conditioning and players should never participate in any form of conditioning that aggravates an injury.
- Training and exercise should not be used as a form of punishment.
- The exercises should be discussed with the player, with the player understanding both the purpose of the exercise and the expected stress and fatigue of the exercise.
- The player should be able to stop participating in any exercise if he/she chooses to do so.

WARM-UP AND COOL DOWN CONSIDERATIONS AND GUIDELINES

While the player may be in top form in terms of their physical conditioning, participation in vigorous sports like hockey requires a proper warm-up to help prepare the body for the increased demands and to help prevent injuries.

A proper warm-up provides a number of benefits to the body:

- Increased general body and tissue temperature.
- Increased blood flow throughout the cardio-respiratory system and ultimately to the working muscles.
- Increase in the body's metabolic processes.
- Decreased resistance of connective tissue thus allowing for greater movement in muscle and associated joint structures.
- Enhanced psychological preparedness of the athlete.
- Reduced chance of muscle/tendon pulls.

While the above is not an exhaustive list, the benefits are readily seen. But to be effective, a good warm-up should focus on the following:

1. To raise body temperature resulting in an increase in respiratory and heart rate.
2. It should affect as many of the large muscle groups as possible to effectively make tissues soft and flexible.
3. It should be made up of general body activities and some sport-related ones.

A warm-up activity should include, jogging or easy running. This should be of high enough intensity to produce a light sweat.

Off-Ice Warm-up

Players should arrive at the arena at least 30 minutes before a game or practice

to prepare themselves both mentally and physically.
Players should warm-up for approximately 10-15 minutes.

Range of Motion Exercises

Initially, the player should complete a series of warm-up exercises such as jogging on the spot, jumping jacks and any other type of calisthenic exercises. These exercises should start at low intensity and gradually get more demanding. During these calisthenic type exercises the players should complete the following range of motion exercises. During these range of motion exercises the player should control the amount of swing allowing for no bouncing (momentum). The range of motion exercises should be progressed from small ROM to larger ROM.

1. Neck Flexion/Extension
2. Neck Side Flexion
3. Neck Forward Rotation
4. Shoulder Circles
5. Trunk/Pelvic Circles
6. Ankle Rolls

After completing the ROM exercises the player should continue to do a variety of calisthenic exercises such as hopping, skipping and jumping. The athlete should then complete the 7 static stretching exercises.

9.2 STRETCHING

Players should perform the following seven (7) stretches to complete the off-ice warm-up. During the off-ice stretches, the stretch should be static with the athlete moving into and out of the stretch in a slow and smooth manner. Hold each stretch for 15 seconds and repeat 2-4 times. (see diagrams pages 68-71)

Stretching improves a player's flexibility. Flexibility is the ability to move freely, or more properly defined, is the range of motion (ROM) available at a joint or series of joints. Therefore, stretching is a fundamental component of any risk management and safety program. An appropriate stretching program can provide the following benefits:

- Increased Range of Motion
- Increased Strength
- Increased Movement Efficiency
- Increased Muscular Relaxation
- Improved Posture and Symmetry
- Improved Body Awareness
- Decreased Muscle Soreness

Stretching ultimately allows a player to increase their level of performance and decrease their risk of injury.

General Instructions:

1. Players should warm-up prior to stretching
2. Players should maintain the proper body position and alignment during each stretch.
3. Players should be alert to the feel of the stretch: the feeling should be one of gentle stretch not pain. **DO NOT OVER STRETCH.**
4. Players should maintain control of the movement during the stretch:
 - during the off-ice stretches the stretch should be static with the athlete moving into and out of the stretch in a slow and smooth manner.
 - during the on-ice stretch, the stretch should be dynamic but not “bouncy”.
 - during the range of motion exercises, control the swing: there should be little momentum with no bounce.
5. Stretches should be held for 15-20 seconds and repeated 2-4 times each.
6. Stretches should be completed before and after each practice and game.

Things to Remember

- The range of motion exercises and stretches should be considered the minimum requirements.
- For more stretches, consult an appropriate professional in your community.
- If a player complains of pain during any of the range of motion exercises or stretching exercises, the player should stop the exercises and seek medical advice.
- A player’s flexibility will decrease during their growth spurt. This occurs at approximately age 12 for girls and age 14 for boys.

1. Trunk/Shoulder

- Stand with feet shoulder width apart
- Bring left arm overhead reaching hand down spine
- Hold the left elbow behind the head with the right hand
- Bend the trunk straight sideways to the right
- Do not rotate the trunk
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite side

OFF-ICE STRETCHES

2. Thigh/Quadriceps

- Stand on your left foot holding wall with left hand for support
- Reach behind with the right hand holding the right foot
- Keep back straight and hips and shoulders square.
- Lift the right foot and ankle towards the right

buttocks

- Keep the right leg in good alignment: the right shoulder, hip, knee and ankle should be aligned
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite leg

3. Thigh/Hip Flexor

- Kneel on the right knee
- The left leg is forward with the knee bent
- Place hands on the floor at each side of the left foot
- Keep your back straight and hips and shoulders square
- Stretch forward feeling the stretch in the right thigh and hip flexor
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite leg

4. Groin

- Sit on the floor with your feet together as in the picture
- Keep your back straight
- Pull your feet in towards your groin until you cannot keep your back straight or keep your feet together
- Put your elbows on your knees and your hands on your ankles
- Press your knees towards the floor; to increase the stretch rotate forward at the hips while keeping your back straight
- Hold the stretch for 15 seconds and repeat 2-4 times

5. Hamstring/Lower Back

- Sit on the floor with the left leg extended and the right leg bent inward as in the picture
- Keep the back straight and hips and shoulders square
- Keep the left leg in neutral rotation and aligned with the left shoulder
- Reach forward with your hands keeping the back straight. Think of bringing your chest towards the thigh, not the head to the knee
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite leg

6. Low Back/Hip Extensor

- Lie on your back with the right knee bent up towards the chest as in the picture
- Hold the right knee with both hands. If a player complains of pain holding the knee as illustrated, instruct them to hold the leg/thigh under the knee
- Keep the right knee in alignment with the right shoulder
- Pull the right knee towards the chest
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite leg

7. Gluteal/Hip/Low Back

- Lie on your back with the right hip and knee bent and the foot over the left leg as in the picture
- Place the right hand flat on the floor with the shoulder at 90 degrees as in the picture
- Turn the head to the left
- Hold onto the right knee with the left hand and pull the knee towards the floor
- Allow the body to rotate until the shoulder is about to lift off the ground
- Keep the shoulders and right hand in contact with the ground
- Hold the stretch for 15 seconds and repeat 2-4 times
- Repeat the stretch for the opposite leg

After completing the stretching exercises the athlete should finish the off-ice warm-up with a series of motor coordination/skill callisthenic exercises such as agility, coordination and balance callisthenic exercises.

On-Ice Stretching: Guidelines and Considerations

Warm-up

Once players are on the ice, they should skate lightly, gradually increasing their speed. The player should get a feel for the ice by doing some basic skating skills:

1. forward/backward skating in a straight line as well as turning corners to the right and left.
2. skating in circles to the right and left
3. doing cross-overs to the right and left
4. doing some slow stops and starts to the right and left.

Range of Motion Exercises

During these basic skating exercises the player should complete a series of onice range of motion exercises:

1. Shoulder Flexion

- Holding the stick with both hands in front of their body, the player lifts their arms over the head as far as possible without arching their back.

2. Shoulder Extension

- Holding the stick with both hands behind the back, the player lifts

their arms behind the back as high as possible without arching the back.

3. Trunk Rotation

- Holding the stick at shoulder height with both hands, the player rotates the trunk to one side, returns to the middle and stops, then rotates to the opposite side. DO NOT rotate from side to side without stopping in the middle.

Stretching Exercises

As well the player should complete the following dynamic stretch while completing the basic skating exercises

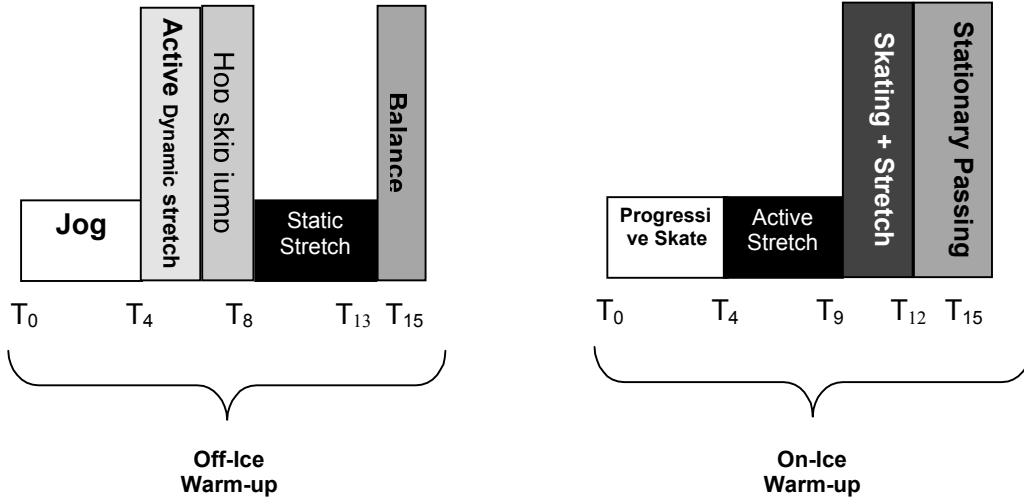
1. Adductor/Hip Flexor

- Following the completion of these basic skating exercises, ROM exercises and dynamic stretches, the player should do some acceleration, aggressive stops and starts and some technical skills.

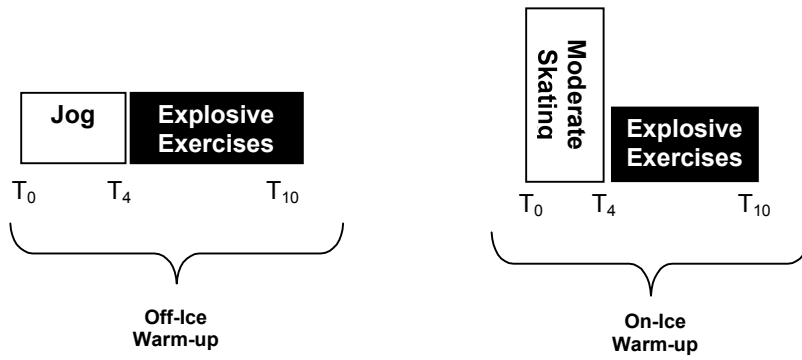
ON-ICE STRETCHING

1. Groin/Thigh

- While gliding, as in illustration, the left leg is forward with knee bent over the skate
- Keep back straight with hips and shoulders square
- Keep right leg straight with inside of skate gliding on the ice
- Press forward and down, bending the left knee, stretching the right groin and thigh
- Stretch should be dynamic but not “bouncy”
- Hold stretch for 10-15 seconds and repeat 2-4 times
- Repeat stretch for opposite leg



Hockey Canada warm-up timeline.



Explosive specific warm-up timeline.

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