RELATIONSHIPS BETWEEN GENERAL AND SPECIFIC PHYSICAL CHARACTERISTICS AND MATCH-RELATED INDICATORS IN ELITE FINNISH ICE HOCKEY PLAYERS AT DIFFERENT PLAYING POSITIONS

Ville Korte

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Supervisors: Dr. Juha Ahtiainen & PhD student Marko Haverinen

ABSTRACT

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One of the challenges in ice hockey is understanding the differences in physical characteristics between players of different rink playing positions. In game situations, differences are obvious mainly because of tactical elements of game activities. Differences have occurred by various on-ice and off-ice tests of which many have correlated with each other. For example, general and specific speed and power tests have showed significant relationships whereas only low correlations between endurance tests. Only a few authors have investigated association between strength and on-ice performance showing contradictory results. Regardless of the lack of research in this area, authors have observed high-intensity performance during game correlating with cardiovascular loading in submaximal Yo-Yo intermittent recovery ice hockey tests, level 1 (Yo IR1-IH_{SUB}). The aim of this study was to examine the relationships between on- and off-ice tests and match-related indicators. The second aim was to investigate differences between forwards and defensemen in general and specific physical qualities and match-related activities.

The male subjects were recruited from five different teams and played elite level ice hockey in Finland (n = 140). Four of teams represented Finnish Elite Ice Hockey League and one of the teams was Finnish U20 Ice Hockey League team. The measurements were executed in fall 2019. General tests included anthropometric measurements, 30-metre running speed test with 5- and 10-metre splits, countermovement jump (CMJ) and CMJ with extra loads (20, 40 and 60 kg), pro agility (5-10-5-m) off-ice test (COD_{RUN}), Wingate test and incremental cycle ergometer test. Specific tests consisted of 30-metre skating speed test with 5- and 10-metre splits, pro agility (5-10-5-m) on-ice test (COD_{ICE}) and maximal Yo-Yo intermittent recovery ice hockey tests, level 1 (Yo IR1-IH). Bitwise corporation provided match-related data including playing time, covered distance, number of shifts, playing time per shift, average speed and maximal speed.

No differences were found between forwards and defensemen in any off-ice and on-ice variables ($p > 0.05$). However, differences were obvious in match-related indicators. Defenders spent more time on ice (16:35 vs. 14:39 min) and still, had higher playing time per shift (0:47 vs. 0:44 min) even though no significant differences in number of shifts. The forward players' maximal speed and average speed were significantly higher than that of defensemen ($p > 0.001$, both). Especially, speed-power tests showed significant correlations with on-ice tests. CMJ without load and with extra loads had highest association with on-ice performance, showing correlations with all on-ice power tests ($r = -0.380$ - -0.686, $p < 0.01$). VO_2max correlated with distance in Yo IR1-IH ($r = 0.514$, $p < 0.01$). Only some, but mainly low correlations occurred between tests and match-related indicators.

The nature of the sports of ice hockey, such as tactical aspects and roles of players may affect significantly to relationships between physical qualities and match activities. Consequently, it cannot be argued that physical characteristics would not play a decisive role in the game of ice hockey. However, coaches and trainers should be aware of what tests to use to assess players' performance on-ice. Especially speed-power tests are usable tools to assess on-ice performance. However, it seems that body composition of players does not affect significantly to on-ice performance. According to this study, positional differences do not occur in physical qualities but do appear in game activities. Due to these findings, coaches should focus more to develop physical performance corresponding with positional demands in match activities.

Key words: forwards, defensemen, physical qualities, match activities

ABBREVIATIONS

ATP	Adenosine triphosphate
CMJ	Countermovement jump
COD_{ICE}	Pro agility (5-10-5-m) on-ice test
COD_{RUN}	Pro agility (5-10-5-m) off-ice test
ErMaxP	Maximal power in incremental cycle ergometer test
F_{MAX}	Maximal force in isometric leg press
LPS	Local positioning system
MP_{ABS}	Absolute mean power in Wingate anaerobic test
MP_{REL}	Relative mean power in Wingate anaerobic test
NHL	National Hockey League
PCr	Phosphocreatine
PP_{ABS}	Absolute peak power in Wingate anaerobic test
PP_{REL}	Relative peak power in Wingate anaerobic test
RFD	Rate of force development
TMM	Total muscle mass measured by Tanita bioimpedance
VO_2max	Maximal oxygen consumption
Yo IR1-IH	Maximal Yo-Yo intermittent recovery ice hockey test, level 1
Yo IR1-IH_{SUB}	Submaximal Yo-Yo intermittent recovery ice hockey test, level 1

CONTENT

1 INTRODUCTION

Ice hockey is metabolically diverse team sport demanding high-level physical capabilities and technical skills (Cox et al. 1995). A game consists of high-intensity intermittent skating bouts, quick change of directions and frequent body contacts and collisions (Montgomery 1988). Professional elite player skates approximately 4600 metres in a game of which most of distance is covered with high intensity skating (Lignell et al. 2018). Typically, playing time is 10-25 minutes per player consisting of 20-35 shifts of 30-90 seconds each (Green et al. 1976; Cox et al. 1995; Lignell et al. 2018).

Testing of physical performance of ice hockey players provides essential information for trainers and coaches about qualities to consider in physical conditioning. In addition, testing allows observing positional differences between forwards and defensemen that have been shown contradictory results in earlier studies (Burr et al. 2008; Quinney et al. 2008 Vigh-Larsen et al. 2019). According to Quinney et al. (2008) defenders are heavier, taller and have better overall musculoskeletal fitness whereas forwards have higher relative aerobic capacity. Instead, some authors have noted no differences in physical qualities between positions (Vigh-Larsen et al. 2019). Lignell et al. (2018) observed that defensemen spend almost 50 % longer on ice and cover 30 % greater distances during a game. However, they noted that forwards cover greater distances in high-intensity skating zones than defenders.

For coaches, it is crucial to gain information of players' physical capabilities. In addition, it is important to know what tests are reliable and necessary to use in field of ice hockey. Many authors have investigated the relationship between general and specific tests (Comtois et al. 1998; Bracko & George 2001; Behm et al. 2005; Burr et al. 2008; Krause et al. 2012; Potteiger et al. 2010; Janot et al. 2015; Boucher et al. 2017). Although, conflicting results have been observed, most of authors have suggested many speed and power tests, such as sprints and CMJ being valid methods when assessing on-ice skating speed and abilities (Mascaro et al. 1992; Farlinger et al. 2007; Janot et al. 2015). Instead lower correlations have been found between aerobic capacity and on-ice performance (Durocher et al. 2010). Lignell et al. (2018) have suggested that Yo IR1-IH_{SUB} is useful tool to assess high-intensity skating performance during a game. However, no other studies have investigated the relationship of physical characteristics and high-intensity activities during a game.

Thus, the purpose of the study was to investigate the relationships between general and specific physical characteristics as well as associations between physical qualities and match-related indicators. Additionally, the aim was to examine the positional differences between forwards and defensemen in general and specific physical variables and in match-related indicators.

This study was part of a larger research, the doctoral thesis project of Marko Haverinen in University of Jyväskylä (*Interactions between physical qualities, training, match loads and health profiles in ice hockey players during one-year follow-up*). The study was executed in co-operation with University of Jyväskylä, Varala Sports Institute, Bitwise Corporation, Finnish Elite Ice Hockey League, Finnish Ice Hockey Players´ Association and Finnish Ice Hockey Association.

2 CHARACTERISTICS OF ICE HOCKEY

International Ice Hockey Federation (IIHF) has 76 member countries with a total of over 1.8 million registered players. Ice hockey is a popular winter sport, especially in North America and Scandinavia. In Finland, there is over 70 000 registered players which is about 1.3 % of the total population of the country. (International Ice Hockey Federation 2019.) (Table 1.)

TABLE 1. Ice hockey popularity in top-5 ranked countries (International Ice Hockey Federation 2019.)

Country	Players	% of total population	Indoor rinks	Men's World ranking	Women's World ranking
Finland	73 374	1.32	268	5	3
Sweden	62 701	0.62	362	2	6
USA	562 145	0.17	1535	4	1
Canada	637 000	1.78	3300	1	2
Russia	110 624	0.07	584	3	4

According to Cox et al. (1995) ice hockey is the fastest game played on two feet. Ice hockey is a game consisting of high intensity intermittent skating, rapid accelerations and change of movements including frequent body contacts (Montgomery 1988). Aerobic endurance, strength, power, speed, agility and balance have all crucial role for successful playing performance (Bracko & George 2001; Behm et al. 2005; Burr et al. 2008).

In a ice hockey game, normal playing time lasts 60 minutes that consists of three 20-minute long periods and there are typically 15-minute breaks between periods (Cox et al. 1995). Total playing time of a single player is typically 10-25 minutes but with some players the time on-ice may be even 35 minutes. The playing time consists approximately of 20-25 shifts each lasting about 30-90 seconds. (Cox et al. 1995; Roczniok et al. 2016; Lignell et al. 2018.) The recovery time between the shifts range generally between 2 to 5 minutes (Montgomery 1988; Lignell et al. 2018). According to Lignell et al. (2018) National Hockey League (NHL) players skate on average 4606 ± 219 m during a match.

3 PHYSIOLOGICAL DEMANDS OF ICE HOCKEY

Ice hockey is a game that sets diverse demands on players' performance and physiology. When looking at energy production requirements in ice hockey, it has been found that players require not only extremely strong anaerobic characteristics, but also highly trained aerobic pathways: aerobic power and capacity (Cox et al. 1988). It has been suggested that anaerobic energy system would take about 69 % of the energy needed to play and aerobic endurance approximately 31% of the energy metabolism (Leger et al. 1979).

In ice hockey, versatile physiological demands are similar to other team sports such as in soccer, basketball and rugby. In addition to high-level anaerobic and aerobic capacity, players need great muscle strength, speed and a huge amount of specific skills to succeed. (Lignell 2018.) Ice hockey is a one-on-one sport requiring puck and stick handling, hitting, shooting and passing as well as interaction with other players (Twist & Rhodes 1993a).

3.1 Aerobic performance

Although the contribution of anaerobic energy production is high during ice hockey match, aerobic power and capacity plays a crucial role in players' performance. In order to tolerate high intensity work continuously during the game, players must have strong aerobic qualities. Consequently, good aerobic base helps to delay fatigue and allows player to work longer with high-intensity. (Rhodes & Twist 1990.) Higher aerobic power has been related to better performance on-ice. It has been observed that playing time is in association with maximal oxygen uptake. Players with better aerobic endurance are able to maintain higher performance during game resisting fatigue that means also longer playing times. In addition, maximal oxygen uptake has been connected with opportunity to score more frequently which might be explained by longer playing times. (Green et al. 2006.)

Authors have observed that there is strong relationship between recovery from high-intensity intermittent exercise and aerobic fitness (Rhodes & Twist 1990; Tomlin & Wenger 2001). According to Karlsson et al. (1972) high VO_2max reduces lactate formation and saves glycogen stores during exercise. Tomlin & Wenger (2001) have suggested that the main factors for faster recovery due to aerobic fitness are enhanced lactate removal and improved phosphocreatine (PCr) regeneration. In addition, the previous argument supports that better aerobic fitness allows for a greater amount of training and therefore greater development (Twist & Rhodes 1993a).

According to Montgomery (1988) peak heart rate during the game rises typically over 90 % of maximum and the mean on-ice values are approximately 85 % of maximum. Snyder et al. (2008) have observed that mean heart rate during the game is approximately 77-80 % with young elite ice hockey players. They also showed that players reached higher mean heart rate values in game than on-ice practices that is in line with other studies (Spiering et al. 2003). However, Snyder et al. (2008) used the age predicted maximal heart rate which might restrict the findings. Paterson (1979) have evaluated that the mean oxygen uptake would be approximately 70-80 % of VO_2max during the match. Because of linear relationship between heart rate and oxygen uptake, the assessment is somewhat in line with other authors who observed mean heart rate being about 80 % of maximum.

A comprehensive longitudinal study by Quinney et al. (2008) have revealed that many physiological characteristics have improved during 26 years among NHL-players (n = 703). Relative VO_2max values have increased significantly even though increase have been more great in the absolute VO_2peak values. One explanation for huge development in absolute values might be the increased size of average player. In the same study they observed that there was no differences between oxygen uptake values or any other physical characteristics in succesful and non-succesful years with same players. According to Montgomery (1988), relative VO_2max values among ice hockey players are typically between 55 and 60 ml/kg/min. Relative VO_2max values in different level ice hockey players are presented in table 2.

TABLE 2. VO_2max values in different age and level ice hockey players.

Age (mean)	Level	Weight (kg)	VO_2max (ml/kg/min)	Method	Reference
11	Minor hockey	63.9	56.6	cycle	Cunningham et al. 1976
21	University	70.5	58.1	treadmill	Montpetit et al. 1979
22	Finnish National team	81.4	61.5	treadmill	Rusko et al. 1978
	Finnish National team	81.1	52.0	cycle	Vainikka et al. 1982
	NHL players	88.4	60.2	cycle	Cox et al. 1993
	Team Canada	89.3	62.4	cycle	Cox et al. 1993
	NHL team	92.0	59.0	cycle	Montgomery 2006
18	Elite junior players	87.3	57.4	cycle	Burr et al. 2008
28	NHL-players	79.0	58.8	cycle	Lignell et al. 2018

Cycle = cycle ergometer test for prediction of VO_2max. Treadmill = Treadmill test for prediction of VO_2max.

3.2 Anaerobic performance

As mentioned, anaerobic energy production plays a major role in high-intensity intermittent games, such as in ice hockey (Leger et al. 1979). Phosphagen system (ATP-PCr system) is the main energy source when maximal-effort activity takes 3 to 15 seconds (Wilmore & Costill 2004, 55-56). All the fast, explosive movements such as accelerations, stops, tackles and shots are made mainly by using direct energy sources (Twist & Rhodes 1993a).

Anaerobic glycolysis is crucial when exercise with exhaustive effort takes about 60 seconds (McArdle 2014, 160-175). Due to the length of the shifts, lactic energy production is a significant factor of the performance. Consequently, in order to maintain optimum performance, shifts should not be too long. Short shifts reduce the accumulation of lactate in the muscles, allowing faster recovery of ATP-PCr storages. If the accumulation of lactate is high, it will decrease the performance significantly. (Montgomery 1988.)

Even though the anaerobic glycolysis is main energy source on ice hockey, the lactate measured from venous blood samples have been relatively low during the game. In the studies, lactate have changed between 4.4 mmol/l and 13.7 mmol/l during the game or after the final shift (Green et al. 1976; Wilson & Hedberg 1976; Noonan 2010). One explanation is that during the shifts there are typically 2-3 stoppages and the continous playing time is only approximately 30 seconds while the whole shift on-ice takes on average 132 seconds. In addition, typical shift includes long periods of coasting after high intensity skating. Consequenlty, the pauses during shift allow time for 60-65 % resynthesized the PCr-storages that can be used in the next phase of the shift. (Green 1979.)

Since glycogen plays a significant role in energy production on ice hockey, researchers have investigated the adequacy of glycogen stores and the effect of carbohydrate supplement in on-ice performance. According to Palmer et al. (2017), ingesting a carbohydrate-electrolyte during game simulated on-ice exercise would improve voluntary performance. In addition, there is evidence that carbohydrate loading before ice hockey game would enhance performance during the game. Åkermark et al. (1996) found that players who had carbohydrate based diet before games improved skating speed and skating distance, increased the skating time during shifts and number of shifts. Therefore, it can be suggested that glycogen plays prominent role in ice hockey energy production.

Some authors have suggested that in ice hockey game all glycogen will be depleted by the end of the match (Green et al. 1978; Montpetit et al. 1979). However, most of the time on-ice in match, players work under lactate threshold and as mentioned total playing time per player is 10-25 minutes. Consequently, it is unlikely or even impossible to deplete all glycogen storages during the ice hockey match meaning that the sufficiency of glycogen is not a limiting factor of performance. (Cox 1995.)

3.3 Speed, power and strength

As a contact game, it is beneficial to have great lower and upper body power and strength qualities (Montgomery 1988). Absolute strength and body size are factors that are crucial for bodychecking and defensive play (Twist & Rhodes 1993a). It has been noted that muscle strength and power are some of the key factors that separates amateur and professional players (Reed et al. 1979, 127-131 according to Montgomery 1988; Vigh-Larsen et al. 2019). High-level upper body strength is important especially in puck controlling, shooting and body checking. Conversely, lower body strength characteristics are necessary in accelerations, skating, agility and body checking. Specific strength particularly in leg muscles and its training are important factors to enhance inertia and yield lower center of gravity. The development of strength is crucial not only for physical performance but also in preventing injuries. (Twist & Rhodes 1993.)

Strength is also the base factor for speed and power production. Power is product of force and velocity, and it is described as equivalent to energy output per unit of time (Laird & Rozier 1979). Ice hockey game includes a lot of fast reactions, accelerations, stops, change of directions, shots and hits. The base for effective action in all those situations is power. It has also been argued that power is the most important physical factor in ice hockey. (Twist & Rhodes 1993a.) In addition, authors have suggested that first skating strides or acceleration are vitally important for the game performance. Ability to accelerate in two or three skating strides have noted to be highly in association with forward skating performance. (Marino 1983.) Speed of the game is emphasized by the low coefficient of friction between skate and ice (Pearsall et al. 2000, 675-692).

De Boer et al. (1987) have investigated force and power production in speed skating. They suggested that gluteus muscles, especially gluteus maximus have a major role in power generation in skating. In addition, concentric power of quadriceps muscles has crucial role in power production when extending knee joint. Soleus muscles affect to force production in late phase of push-off. Instead, the eccentric control of hamstring muscles affects to skating glides but do not participate in power generation. However, knee flexors and extensors are both active and optimizing leg position during the gliding phase. (de Boer et al. 1987.) Buckeridge et al. (2015) have supported those findings in ice hockey skating. However, they concluded that gluteus and gastrocnemius muscles activities are emphasized during acceleration strides while knee extensors (vastus medialis, gluteus medius and vastus lateralis) show higher activities in steady state skating strides.

4 POSITIONAL DIFFERENCES

The longitudinal studies have shown that there are differences between players and the position of players in anthropometric, neuromuscular and physiological parameters (Montgomery 2006; Vescovi et al. 2006; Quinney et al. 2008). In comprehensive study (n = 703) Quinney et al. (2008) have observed NHL defensemen being heavier and taller and having higher absolute VO_2peak values and better grip strength than forwards and goaltenders. In addition, the overall musculoskeletal fitness is better with defenders. Instead, forwards have better relative VO_2peak values than defensemen. In the same study, they observed that goaltenders are smaller and more flexible than defensemen and forwards, but their overall physical fitness is reduced compared to other positions. Burr et al. (2008) mostly support the claims above when investigated with young elite ice hockey players (n = 853) who were ranked to top 120 players of their respective year by NHL scouting. (Table 3.) However, they did not observed differences in muscular development between forwards and defensemen. They suggested that even though goalies have lower leg-power values, VO_2max values, muscle force and less muscular development, they are not poorer athletes. They also noted that goaltenders have different kind of physical demands, and the testing of goalies should focus more on flexibility, skill, hand-eye coordination and reaction time.

TABLE 3. Characteristics of ice hockey players.

Subjects	n	age (mean)	Position	Height (cm)	Body mass (kg)	Relative VO_2max (ml/kg/min)	Wingate PP (W/kg)	Sit and reach (cm)	Reference
NHL drafted players	277	18	D	188.0	90.3	56.7	11.1	38.1	Burr et al. 2008
	493	18	F	184.9	86.2	58.1	11.3	38.4	
	83	18	G	185.9	84.6	55.9	10.6	44.7	
NHL players	180	25	D	187.6	93.8	52.5	13.0	41.9	Quinney et al. 2008
	372	24	F	184.1	89.8	54.0	13.0	40.6	
	45	25	G	180.1	84.0	49.8	12.8	46.2	

Relative VO_2max = VO_2max in relation to body weight. Wingate PP = Peak power in Wingate anaerobic test.

However, contradicting findings have also been observed (Agre et al. 1988; Vigh-Larsen et al. 2019). Vigh-Larsen et al. (2019) investigated positional differences with elite Danish ice hockey players (n = 145). They did not find any differences in body composition between forwards and defensemen when weight, height, body fat-% and muscle mass were considered. Additionally, no differences occurred in CMJ and on-ice tests including submaximal and maximal Yo IR1-IH, COD_{ICE} and sprint performance on ice.

When compared the on-ice performance, authors have found significant differences between positions. Boucher et al. (2017) found that forwards were superior in Modified Repeated Skate Sprint Test that simulates game situations and assess anaerobic capacity. Lignell et al. (2018) investigated the high-intensity activity and fatigue patterns during NHL-game, and the effect of training status on match performance and game related muscle damage. They also examined the differences between positions in the game and found that defensemen’s time on-ice were almost 50 % longer than the same of forwards. In addition, the distance covered on-ice were approximately 30 % greater than forwards which, however, would be explained by the longer time on-ice. They also observed that forwards covered greater distances on-ice in high-intensity skating zones. Paterson (1979) have made similar findings, however the author suggests that many defensemen spend almost 50 % on-ice in a game while forwards are on-ice only 35 % of playing time. According to Green et al. (1978) defenders have shorter recovery times between shifts and they play more frequently per game than forwards. Lignell et al. (2018) have suggested that because of remarkable differences between forward and defense in the match, coaches must consider special positional requirements also in physical conditioning.

However, Stanula & Roczniok (2014) have made dissimilar observation when investigated with young elite ice hockey players. They found that defensemen spent slightly more time in high-intensity zone than forwards even though the difference was small. They also found that both, forwards and defensemen spent most of the time in low-intensity zone on-ice. However, the level and age of players were substantially lower than in the study of Lignell et al. (2018) and that is why findings are not directly comparable.

According to Twist & Rhodes (1993b) lactate accumulation is higher in defensive zone than attacking zone regardless position of the player. In addition, no differences occur between forwards and defensemen in lactate measures even though forwards work more with anaerobic energy systems. However, also opposite results have been reported, some of those showing that forwards reach higher lactate values than defensemen. (Green et al. 1976; Green et al. 1978). Even though forwards skate in markedly higher intensities, the non-existed positional difference in lactate values has been explained by the fact that defensemen have significantly lower recovery times. Consequently, that account for the similar lactate values. (Green et al. 1976.) The rate of energy expenditure is higher for forwards because they cover greater distances with higher intensity. (Twist & Rhodes 1993b.)

5 ASSOCIATIONS BETWEEN GENERAL AND SPECIFIC PHYSICAL QUALITIES AND MATCH ACTIVITIES

When the physical characteristics of players are compared to the match-related indicators there have been found some associations (Peterson et al. 2015; Lignell et al. 2018). However, not many studies have investigated the relationship between physical variables and match-related indicators. According to Lignell et al. (2018) higher maximal aerobic capacity has been correlated to greater amount of high-intensity skating during match. Even though there is lack of studies analysing the relationship of physical variables and match activities in ice hockey, many researchers have studied the associations in other team sports (Rampinini et al. 2007; Krustrup & Mohr 2015; Black et al. 2018). In those studies, there have been shown to be positive correlations between many physical and game-related variables. For example, the tolerance of fatigue and recovery ability have been observed to be higher in rugby players with better neuromuscular and cardiovascular characteristics (Gabbett et al. 2013; Johnston et al. 2015). However, authors have focused to examine the associations between general and specific physical qualities in ice hockey (Farlinger et al. 2007; Burr et al. 2008; Boucher et al. 2017). Only few studies have implemented with NHL-players as subjects and most of the scientists have been focused to analyse slightly lower level athletes.

5.1 Associations between general and specific physical qualities

It has been shown that many anaerobic and neuromuscular off-ice tests predict better on-ice performance (Bracko & George 2001; Burr et al. 2008; Potteiger et al. 2010; Krause et al. 2012; Janot et al. 2015; Boucher et al. 2017). For example, vertical jump, 40-yard dash and 1.5-mile run time have been related to better on-ice skating speed performance. Peak power and fatiguing in Wingate test have also been shown to correlate with the performance on-ice (Janot et al. 2015). Potteiger et al. (2010) has observed that body composition, leg strength and power production predict on-ice performance as well with 21 I-division male ice hockey players. However, many conflicting findings have been reported. According to Behm et al. (2005) off-ice power and strength tests would not predict on-ice performance. In addition, Comtois et al. (1998) did not find significant correlation between vertical jump and on-ice sprint performance.

Most of the studies have compared off-ice indicators to skating performance such as speed and skating ability.

5.1.1 Aerobic endurance

When considering aerobic performance, contradictory observations have been reported. Durocher et al. (2010) analysed if lactate thresholds (LT) and VO_2max would correlate between cycle ergometer and specific skating test. The skating test was developed to assess players aerobic capacity. All variables measured (VO_2max, LT and heart rate) were significantly higher on-ice than off-ice and no correlations were found between cycle ergometry test and skating endurance test. Previous studies of Durocher et al. (2008) also support the claim of non-significant correlation of VO_2max between on-ice and off-ice tests.

However, according to Lignell et al. (2018) higher maximal aerobic capacity have been correlated inversely to Yo $IR1\text{-}IH_{SUB}$. Vigh-Larsen et al. (2019) observed Yo IR1-IH being highly correlated with on-ice sprint and agility performance and moderately correlated with CMJ. Roczniok et al. (2013) have observed that players with higher power values in the Wingate test and higher VO_2max in incremental cycle ergometer test have better sprint performance (30 m), repeated sprint ability (6 × 9 m) and endurance (6 × 30 m) on-ice. According to Peterson et al. (2015) on-ice repeated sprint ability is correlated with aerobic capacity. As a difference to previous studies, they used a skating treadmill to determine VO_2max.

5.1.2 Anaerobic endurance

Wingate test is one of the most widely used anaerobic testing method (Bar-Or 1987). Even though, many authors have suggested to use Wingate test to evaluate on-ice performance, there are also many conflicting observations. Watson & Sargeant (1986) compared the relationship of Wingate test (40-seconds) and the two popular on-ice shuttle tests: the Sargeant Anaerobic Skate test and Reed Repeat Sprint Skate test. Twenty-four young university ice hockey players participated in the study and performed all three tests in a randomized order. In the study they did not find significant relationship between Wingate test anaerobic power and anaerobic capacity and on-ice tests even though they found a good correlation ($r = 0.73$). Peterson et al. (2015) made similar findings suggesting that Wingate test indicators are not correlated with repeated shift ability. However, they found that Wingate relative peak power (PP_{REL}) and relative mean power (MP_{REL}) predict on-ice acceleration and speed. Some other authors have also found high relationship between Wingate test and skating speed and acceleration (Farlinger et al. 2007; Janot et al. 2015; Delisde-Houde et al. 2019).

Interestingly, a large study ($n = 853$) by Burr et al. (2008) demonstrated that absolute peak power (PP_{ABS}) and fatigue rate of Wingate test is correlated with draft entry position and may predict playing success. They found that those indicators are more significant for defensemen than forwards. Smaller study by Roczniok et al. (2013) investigated whether off-ice indicators were correlated with players who were chosen to the Polish junior National team and who were not. They found that PP_{REL} was in connection with selection to the team. Players who were selected had significantly higher power output. Relative peak power and time to peak power have also noted to be in relationship with selection to team with older Polish ice hockey players (Roczniok et al. 2016). Peterson et al. (2015) have shown that Wingate peak power and fatigue index are significantly higher with higher level (division I) than lower level (division III) National Collegiate Athletic Association (NCAA) players. However, they did not find difference in Wingate mean power between the levels.

5.1.3 Speed

Many authors have observed off-ice sprint performance being correlated with on-ice sprint performance (Behm et al. 2005; Farlinger et al. 2007; Krause et al. 2012; Haukali & Tjelta 2015; Janot et al. 2015). Farlinger et al. (2007) studied the relationship between off-ice tests and on-ice performance with 36 young male ice hockey players. They found that off-ice 30-metre sprint had strongest correlation with on-ice 35-metre sprint time ($r = 0.78$, $p < 0.001$). They also found that 30-metre sprint time was correlated with on-ice Cornering S test that assess skating agility. Krause et al. (2012) made similar findings suggesting that off-ice sprint time would be the best indicator of on-ice skating performance.

Nevertheless, some authors have not found any relationship between off-ice sprint and on-ice skating performance (Mascaro et al. 1992; Runner et al. 2015). Mascaro et al. (1992) suggested vertical jump to be best indicator of skating speed with eight NHL-players. However, they did not observe correlation between off-ice 40-yard sprint time and on-ice skating speed.

5.1.4 Power

Vertical jump is a popular method to estimate maximal power of lower limbs. Countermovement jump is a relevant test and used in many different sports to assess athletes' performance, such as in rugby, volleyball and basketball (Ziv & Lidor 2010; Gabbett et al. 2011). In ice hockey, many authors support of using CMJ in assessing on-ice performance and the studies are mainly concentrated to skating performance (Mascaro et al. 1992; Farlinger et al. 2007; Janot et al 2015; Peterson et al. 2015; Runner et al. 2015; Boucher et al. 2017; Delisle-Houde et al. 2019). However, authors have found dissimilar results of comparing CMJ to on-ice performance.

According to Mascaro et al. (1992) CMJ is the best test to predict skating speed. Boucher et al. (2017) have found that CMJ is valid method to provide information about defensemen skating ability but not forwards when compared CMJ to the Sargeant Anaerobic Skate test in which player must skate 40 seconds maximally. Instead, they found that broad jump would be better method to assess forwards skating ability suggesting that positional differences should be considered when implementing off-ice tests. There is also evidence that CMJ is in association with on-ice acceleration and top speed but not repeated shift performance (Peterson et al. 2015). In addition, Runner et al. (2015) found that vertical jump is correlated not only to forward acceleration but also backward acceleration. However, several authors have not observed correlations between CMJ and skating performance (Comtois et al. 1998; Krause et al. 2012; Boland et al. 2017).

5.1.5 Strength

There is lack of studies investigating relationship between strength and on-ice performance. In addition, no research has been done to compare isometric force production to physical characteristics on-ice. It also seems that only isokinetic force production has been correlated with on-ice speed (Mascaro et al. 1992; Potteiger et al. 2010).

According to Potteiger et al. (2010) isokinetic force production can be used to evaluate on-ice skating power and skating speed with 21 division-I men's intercollegiate players. Mascaro et al. (1992) supports the claim when investigated the relationship of 54.9-metre skating speed test and isokinetic force production in lower limbs. Instead, one-repetition maximum in back squat has not been found to correlate with skating speed. Runner et al. (2015) investigated the relationship between back squat and different skating speed tests: 90-feet forward and backward acceleration tests and 50-feet flying maximal speed test. None of the skating tests correlated with maximal back squat. Additionally, one-repetition maximum in leg press has not been correlated with skating speed with 30 competitive junior ice hockey players (Behm et al. 2005).

5.2 Associations between body composition and specific physical qualities

Anthropometric variables have shown diverse relationships with on-ice performance. Vigh-Larsen et al. (2019) observed low to moderate correlation between fat percentage and Yo IR1-IH test with elite Danish ice hockey players. In addition, they found that body fat percentage was in connection with sprint time and COD_{ICE}. Muscle mass had also low correlation with sprint time, Yo IR1-IH test and COD_{ICE}. Potteiger et al. (2010) support finding that body fat percentage would correlate with on-ice skating times.

However, many authors have also observed with sub-elite athletes that anthropometric measurements do not predict on-ice performance. Gilenstam et al. (2011) investigated body composition associations with on-ice performance with 11 female and 10 male Swedish ice hockey players who played in women's and men's 2-divisions. They found that in female ice hockey players' skating time was positively correlated to body weight and negatively correlated to lean body mass percentage in speed test. Furthermore, acceleration test correlated with body weight with female players. Instead in male ice hockey players, no correlations were found between any anthropometric variables and on-ice tests. Authors considered that small sample size and more homogenous background might have affected to non-existent associations in group of male ice hockey players.

In large study (n = 853), Burr et al. (2008) observed that body composition variables are useful parameters in assessing ice hockey playing potential with young elite players who were invited to NHL draft testing combine. However, Roczniok et al. (2013) suggested that body fat percentage is not appropriate indicator to use when selecting players to junior national team of Poland with 60 elite adolescent Polish players. In addition, some other studies have proposed that body fat percentage would not predict success on-ice (Peyer et al. 2010; Kniffin et al. 2017).

5.3 Associations between physical qualities and match activities

As mentioned, not many authors have investigated the relationship between physical variables and match-related indicators. Lignell et al. (2018) studied high-intensity activities during an official NHL-game and the effect of training status with 35 top elite male ice hockey players of whom 24 were forwards and 11 defensemen. Submaximal Yo-Yo intermittent recovery test, level 1 with heart rate collection was used to assess on-ice aerobic performance. VO_2max was determined by maximal incremental cycle ergometer test. In addition, subjects performed repeated CMJ test including five maximal jumps with five seconds recovery between each. Creatine kinase, white blood cells, testosterone, cortisol and C-reactive protein were analysed by blood samples. Player's skating profiles of one game were obtained by using a multiple-camera computerised tracking system. The profile included speeds, distances and durations of the match. In addition, different skating zones were analysed.

They found that cardiovascular loading in Yo IR1-IH_{SUB}, was correlated inversely to VO_2max and to the frequency of high-intensity skating sprints. Heart rate of the test also correlated with skating distance in high-intensity skating zone and very fast speed skating zone but not with the total skating distance during the match. In addition, neither any other physical variables correlated with total distance in match. However, VO_2max was in association with total high-intensity skating distance. They observed positive relationship between the cardiovascular loading of Yo IR1-IH_{SUB} and creatine kinase but not any correlations between the blood variables and match-related indicators. Authors suggested that the amount of high-intensity skating was lower in the latter periods than in first period due to accumulated fatigue.

Peterson et al. (2015) compared general physical characteristics to simulated game-situation. As on-ice test, they used repeated-sprint skate test including eight maximal skating bouts with 90 seconds recovery. Each bout took about 20 to 25 seconds. They found that power tests; vertical jump and MP_{REL} and PP_{REL} in Wingate test correlated with fastest course time, velocity and acceleration in the on-ice test. However, tests did not correlate with repeated sprint performance. In addition, no significant relationship occurred between VO_2peak determined with skate treadmill test and repeated sprint performance. When comparing the repeated-sprint skate test to normal game situation, it should be noted that the test does not correspond exactly to a normal shift in match. As mentioned, each shift takes about 30-90 seconds and the recovery time between shifts are 2-5 minutes (Cox et al. 1995). Shift includes about 5-7 burst each lasting 2-3.5 seconds (Montgomery 1988). According to Lignell et al. (2018) almost half of the distance on-ice is covered in high-intensity skating zones and only one fourth of that is sprint skating. Consequently, validity of using repeated-sprint skate test as a simulated game-situation must be considered.

Green et al. (2006) investigated whether total playing time and scoring during a season are in association with aerobic capacity, body fat percentage and blood lactate in 29 NCAA, Division I ice hockey players. They found that blood lactate in fourth stage of incremental treadmill test and body fat percentage correlated with total playing time during a season. Instead, aerobic capacity was in association with total scoring in the season. Authors suggested that players' fitness level and on-ice performance in games are in connection with each other and physiological testing helps coaches and trainers to develop players physical performance and performance in matches.

Despite the lack of studies investigating relationship between physical characteristics and match activities in ice hockey, many authors suggest that match-related indicators are in association with general physical qualities in other team sports (Krustrup et al. 2005; Rampinini et al. 2007; Souhail et al. 2010; Gabbett & Seibold 2013; Gabbett et al. 2013; Hogarth et al. 2015; Johnston et al. 2015; Krustrup & Mohr 2015; Black et al. 2018). Authors have observer lower limb strength to be highly associated with number of repeated high-intensity bursts and total covered distance during match in rugby players (Gabbett & Seibold 2013). Speed and power tests, such as 10-metre sprint, CMJ and change of direction speed have also been in connection with game activities when compared to tackling ability with 20 professional and 17 semi-professional rugby players (Gabett et al. 2011). Hogarth et al. (2015) made similar findings with elite tag-football players suggesting that vertical jump and 20-metre running speed are useful tools to assess match activities. However, when vertical jump ability has been compared to total distance or distance covered in high-speed running zones, no correlations have been occurred (Gabbett & Seibold 2013).

Repeated-sprint ability has also showed significant relationships with game activities with elite athletes. Prolonged high-intensity running ability, estimated with 8 × 12-second shuttle sprints have shown to correlate with running performance in match with 38 elite rugby players (Gabbett et al. 2013). In football, Rampinini et al. (2007) made similar findings suggesting that repeated sprint ability is in connection with match-related physical performance in football with professional elite players.

It seems that Yo-Yo intermittent recovery test, level 1 is useful test, not only in ice hockey to evaluate match performance. Several authors have investigated the relationship between Yo-Yo intermittent recovery, level 1 test and match-related indicators suggesting that the Yo-Yo test is valid method assessing match activities in football (Castagna et al. 2010; Castagna et al. 2009; Krustrup et al. 2005). For example, Krustrup et al. (2005) found that distance covered during match correlated with Yo-Yo test distance but not VO_2max with elite female football players. Dobbin et al. (2018) made similar findings with rugby players suggesting that covered distance in simulated rugby game-situation is in association with modified Yo-Yo intermittent recovery test, level 1. However, Gabbett & Seibold (2013) did not found any correlations between distances covered during a match and Yo-Yo intermittent recovery test, level 1 with rugby players. Authors suggested that non-existent relationship might be explained by the contact nature of rugby game when compared to many other team sports. Huge number of contacts and collisions make it impossible to cover great distances during a game affecting to relationships between covered distance and Yo-Yo intermittent recovery test, level 1.

Even though Krustrup et al. (2005) did not observed the relationship between VO_2max and Yo-Yo intermittent recovery test, level 1, most of studies suggest that aerobic capacity is highly in connection with game performance in team sports (Reilly 1997; Helgerud et al. 2001). Helgerud et al. (2001) investigated the effects of aerobic endurance training on performance in football match with 19 male elite junior players. Groups were divided into two groups, training group and control group. The training group practiced two times per week for eight weeks and the endurance training consisted of 4 times 4 minutes intervals at 90-95 % of maximal heart rate including 3-minutes active recoveries between sets. As a result, distance covered increased 20 % and number of sprints 100 % during the match in training group. The group also increased the number of involvements with ball by 24 % while no changes occurred in control group.

6 RESEARCH QUESTIONS

There is not comprehensive statistics about physical qualities of Finnish elite ice hockey players in modern ice hockey. In general, there is also lack of studies providing information about ice hockey players' sport-specific physical characteristics, and those studies have mainly used small sample sizes. Physical characteristics' associations with match activities have not been extensively studied previously in ice hockey. In addition, only a few studies have investigated differences between forwards and defensemen in match-related indicators.

Therefore, the aim of this study was to investigate the relationship between ice hockey players' physical characteristics and match-related performance indicators. The physical characteristics were divided into general (off-ice) and specific (on-ice) variables. Those two physical characteristic gategories were also compared to each others. In addition, the second aim was to find out if there are differences between the positions (forwards and defensemen) in physical qualities and game activities.

Research question 1: Are ice hockey players' physical characteristics associated with match-related performance indicators?

Hypothesis 1: Yes. Generally, players with better physical characteristics show superior match-related indicators.

Argument: According to Lignell et al. (2018) Yo IR1-IH_{SUB} correlates with high-intensity skating zones and the number of high-intensity skating bouts. In addition, they found that VO_2max is associated with high-intensity skating distance. To date, the research is only that has studied the relationship between the high-intensity game activities and physical characteristics in ice hockey. However, Peterson et al. (2015) observed that aerobic capacity is in connection with simulated game situation using the on-ice repeated shift test. In other team sports, many scientists have suggested physical performance qualities being in connection with match activities (Krustrup et al. 2005; Souhail et al. 2010; Gabbett & Seibold 2013; Gabbett et al. 2013; Hogarth et al. 2015; Johnston et al. 2015; Krustrup & Mohr 2015; Rampinini et al. 2007; Black et al. 2018).

Research question 2: Are ice hockey players' general physical variables associated with specific physical variables?

Hypothesis 2: Yes. General physical variables are in connection with specific physical variables.

Argument: Although ice hockey is a high skill game, high-level general physical characteristics emphasize with professional ice hockey players. Many tests have shown high correlation with on-ice performance, such as CMJ, sprint performance and Wingate test (Mascaro et al. 1992; Farlinger et al. 2007; Delisde-Houde et al. 2019). However, some conflicting findings have been done. For example, authors have observed that vertical jump is most usable test to indicate on-ice speed but running speed do not correlate with on-ice performance (Mascaro et al. 1992 Runner et al. 2015). Instead some other scientists have suggested that off-ice sprint performance is the best indicator of on-ice skating speed (Farlinger et al. 2007; Krause et al. 2012). Aerobic variables, such as VO_2max, have shown contradicting associations with on-ice tests (Durocher et al. 2008; Durocher et al. 2010; Lignell et al. 2018; Vigh-Larsen et al. 2019). Only isokinetic force production has observed to correlate with on-ice skating performance when considering strength (Mascaro et al. 1992; Potteiger et al. 2010).

Research question 3: Are there differences in physical characteristics and match-related performance indicators between the positions of players?

Hypothesis 3: Yes. Differences occur between forwards and defensemen in physical qualities and match-related indicators.

Argument: Many authors have observed differences between attackers and defenders when physical characteristics are considered (Montgomery 2006; Vescovi et al. 2006; Quinney et al. 2008). For example, according to Quinney et al. (2008) defensemen's overall musculoskeletal fitness is better and they are heavier and taller. Instead, forwards have higher relative VO_2peak values than defenders. However, also dissimilar findings have been reported. Vigh-Larsen et al. (2019) did not observe any differences between positions. In match-related indicators defensemen have been perceived to cover greater distances and having longer playing time than forwards. Instead, forwards spend more time in high-intensity skating zones. (Lignell et al. 2018.)

7 METHODS

7.1 Subjects

Four teams of Finnish Elite Ice Hockey League and one team of Finnish U20 Hockey League participated in this study (n = 140) (table 4). Finnish Elite Ice Hockey League (Liiga) is the highest elite level league in Finland meaning that most of the players were professional ice hockey players. All measurements were executed during autumn 2019. Analysed games were played in the beginning of season 2019-2020. All the players were either forwards or defensemen. Goalkeepers did not participate in this study.

TABLE 4. Descriptive characteristics of subjects.

	ALL		**FORWARD**		**DEFENSE**	
VARIABLES	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**
Experience (yr.)	3.1 ± 4.6	140	3.1 ± 4.5	89	3.2 ± 4.8	51
Age (yr.)	23.7 ± 5.1	140	23.5 ± 4.7	89	24.8 ± 6.0	51
BMI	25.5 ± 1.8	115	25.6 ± 1.9	74	25.3 ± 1.7	41

SD = standard deviation. Experience = years played in Finnish Elite Ice Hockey League. BMI = Body mass index (weight/height^2). Yr. = year.

The ethical committee of Central Finland Health Care District has given an approval for this study (appendix 1). All the subjects also signed an approval to particípe in the research. The written consent can be found from appendix 2.

This study was part of dissertation research project of Marko Haverinen (*Interactions between physical qualities, training, match loads and health profiles in ice hockey players during one-year follow-up*). The measurements presented below are part of the overall project. This study does not include all the measurements performed in the dissertation project.

7.2 Study design

General (off-ice) and specific (on-ice) variables were measured in autumn 2019. Analysed games were played 14.9 – 1.11.2019, in the beginning of the season 2019-2020. The game data was possible to use only in Finnish Elite Ice Hockey League games, so the Finnish U20 Ice Hockey League team did not participate in game analysis. Four Finnish Elite Ice Hockey League teams played once against each other, meaning that six games were used in game analysis. The aim of the study was to investigate the relationships between all variables: general tests-specific tests; general tests-match activities; specific tests-match activities. In addition, the second aim was to examine positional differences in general and specific physical qualities and match-related indicators. The course of the measurements is presented in figure 1. Teams were tested on separate days.

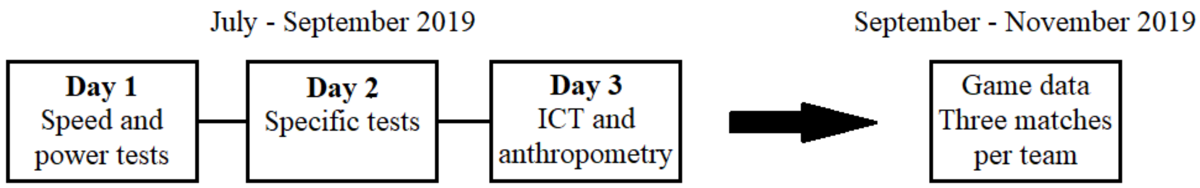

FIGURE 1. The course of the measurements for each team. ICT = Incremental cycle ergometer test.

7.3 Measurements

7.3.1 Off-ice tests

The general tests were performed between 8 am and 2 pm including separate testing days for speed-power tests and incremental cycle ergometer test. The measurements were preceded 30 minutes individual warm-up including low intensity running in aerobic endurance level and dynamic mobility exercises. During the speed-power tests the players were divided into groups of 4-5 individuals and the groups arrived in the tests graduated every half an hour. In addition, 30 minutes were booked to every test. Anthropometric tests were executed in the morning before incremental cycle ergometer test. In speed-power testing day the order of the measurements was 1. speed (pro agility (5-10-5-m) test by running (COD_{RUN}) and 30-metre linear acceleration with 5- and 10-metre splits), 2. jumps (countermovement jump (CMJ) without and with extra loads), 3. isometric leg press and 4. Wingate anaerobic test.

Pro agility (5-10-5-m) off-ice test (COD_{RUN}). The test assesses subject's change of direction ability and explosiveness of lower limbs. Time was measured by infrared gates (Spintest Oy, Tallinn, Estonia). The test was executed in the same way than the COD_{ICE} (see chapter 7.3.2) Subject started 20 centimetres behind the infrared gate (Spintest Oy, Tallinn, Estonia). He had to run 5 metres straight, make a turn (180 degrees) and run 10 metres to the second turning line (180 degrees). After second turn the finish line was 5 metres straight ahead. Three trials were measured with 3-5 minutes breaks between the trials. The chest line was pointed same way as in the pro agility (5-10-5-m) on-ice test (figure 6).

Thirty-metre linear acceleration. Thirty-metre running speed was used to measure players speed characteristics and lower limbs power output. Running times were measured by infrared gates (Spintest Oy, Tallinn, Estonia) over 5, 10, and 30 metres. Subject started standing, one metre behind the first gates. The subject was allowed to start without command or reaction. Every subject had three opportunities and there were 3-5 minutes breaks between trials.

Vertical jumps. A force plate was used to measure flight times of vertical jumps (ForcePlatform FP8, HUR, Finland). Vertical jumps were used to estimate power production of lower limbs. In *countermovement jump (CMJ)*, the subject's weight had to be on both feet and the hands remain on the hips throughout the jump. The subject had to flex the knee joint quickly, squatting to an angle of about 90 degrees. Thereafter, the subject had to extend the knees and hips maximally to jump up off the ground. Descending was done with straight legs on the ball of the feet. *The jumps with extra loads* (20, 40 and 60 kg) were performed the same way as CMJ but the hands on the barbell. (Figure 2.) The subjects had three performances in each jump tests and a one-minute recovery were allowed between the jumps.

FIGURE 2. Jump with the extra load. Subject had to squat down so the starting knee angle was 90 degrees and then extend the joint with maximal effort to jump up off the ground.

Isometric leg press. Maximum force and rate of force development (RFD) were measured in an isometric leg press (Performance Recorder 9200, HUR) (figure 3). The subjects performed a maximal isometric extension of the lower limbs on a force dynamometer with 90 degrees knee angle that was measured with a manual goniometer. Three location points used were greater throcanter, lateral epicondyle and lateral malleolus. Subsequently, the knee angle was set by the meter of leg press. HUR Performance Recorder software was used to record the maximum force output (F_{MAX}) and RFD from the force-time curve. Rate of force development describes how fast subject can develop force. Maximal RFD is the steepest point on the force-time curve and in this study, it was gathered from the beginning of 200 milliseconds of force generation. Rolling average of 40 milliseconds time window was used to determine maximal RFD. In force measurements, the 0-level of force was determined with feet relaxed on the force plate, whereupon the weight of the feet was pre-loaded on the plate.

In measurements, with the "Ready" command, the subject prepared for the test and five-seconds countdown was started. With command “Two seconds” subject took deep breath and hold the breath. With the "Press" command subject was asked to begin maximal isometric contraction. Maximal force generation was continued for 3 to 4 seconds to ensure maximum value was recorded. With the "Stop" command, the subject was allowed to stop. Three trials were performed with a one-minute recovery standardised between them.

FIGURE 3. Maximal isometric leg extension was executed with 90 degrees knee angle.

Wingate anaerobic test. Wingate test estimates subject’s anaerobic power and anaerobic capacity. Absolute and relative peak and mean power values were determined for the test by using Monark Peak Bike (Monark 894 E Peak Bike, Monark Exercise AB, Vansbro, Sweden). The test took 30 seconds and the used workload was 7.5 % of the body mass. Before the test, subject was asked to cycle for a few minutes with low resistance including two sprints of 2-6 seconds with gradual duration and intensity during which the workload was dropped. After the warm-up subject rested at least for one minute before starting of the test. The test started when the subject started to accelerate maximally for 3-4 seconds after which the workload was dropped and the 30 second test duration started. Subject was instructed to pedal with maximum power during the whole test against a constant braking force. After the test subject was asked to cool-down a couple of minutes pedaling without resistance. The scientist and two assistants hold on the cycle ergometer throughout the test to keep it in place (figure 4). The guide of Bar-Or (1987) was used in the test protocol.

FIGURE 4. Wingate anaerobic test.

Anthropometry. Anthropometric measurements included body weight, height, bodyfat-% and total muscle mass (TMM). Bodyfat-% was determined by two methods. First, it was measured by skinfold thickness with four-point method (Durnin & Rahaman 1967). Biceps, triceps, subscapular and suprailiac skinfold thicknesses were summed together. The fat percentages corresponding to this value were taken from the table of Durnin and Rahaman 1967 (appendix 3). The second way to determine bodyfat-% was bioelectrical impedance analysis (Tanita MC 780 MAS, Tanita Corporation, Tokyo, Japan). In addition, TMM was measured by the bioimpedance device.

Incremental cycle ergometer test. Aerobic capacity (VO_2max) was estimated and maximal power (ErMaxP) recorded by indirect maximal oxygen consumption test in cycle ergometer (Monark 894 E, Monark Exercise AB, Vansbro, Sweden). The course of the test and safety issues were discussed with the subject before the test. In this study, 75, 100 or 125 W was used as a starting load depending on which one was closest to subject's 1 × bodyweight. In determining the starting load, bodyweight was converted to watts. Two-minute incremental load steps were used, and the increment of each load was 25 W. Subject had to maintain 70-90 cranks per minutes. The test was performed until exhaustion. Theoretical maximal oxygen consumption was calculated by the following formula (in which VO_2max = theoretical maximal oxygen consumption (ml/kg/min), P = pedal power (W) and m = body weight (kg)) (ACSM 2000):

$$VO_2\,max = \frac{P}{m} \times 11.02 + 7$$

7.3.2 On-ice tests

The specific on-ice tests were performed between 9 am and 1 pm. The players were divided equally into two groups of 8-12 players. All on-ice tests were executed in full ice hockey equipment also with stick in hand. There were 90 minutes booked to perform the measurements preceded by preparing of the ice rink (figure 5). First six steps (until stage 14:7) of Yo-Yo intermittent recovery test, level 1 (Yo $IR1\text{-}IH_{SUB}$) was used as a warm-up. Test order was 1. pro agility (5-10-5-m) test (COD_{ICE}), 2. 30-metre linear skating speed test and 3. Yo-Yo intermittent recovery ice hockey test, level 1 (Yo IR1-IH). The tests were performed in the official ice-rinks.

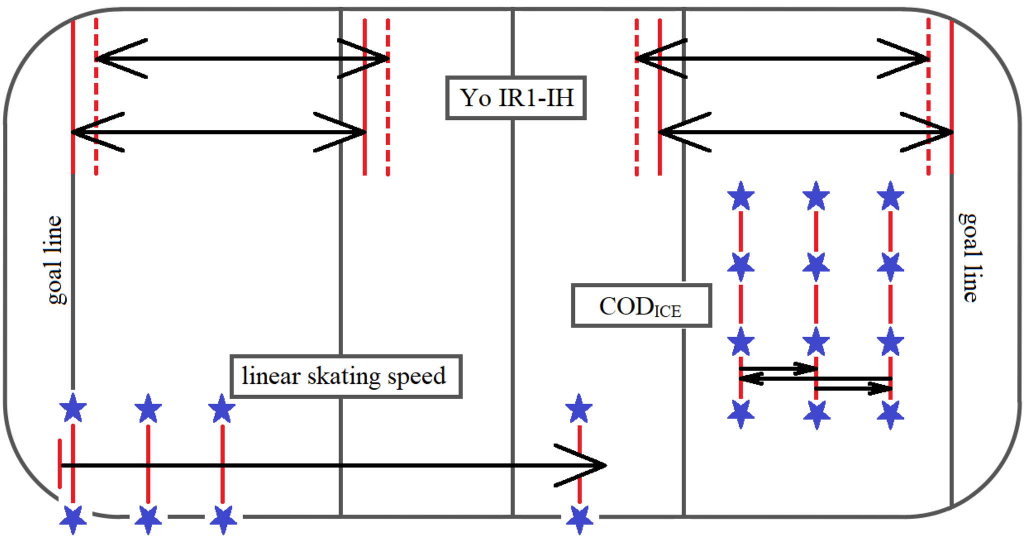

FIGURE 5. Illustrative diagram of the on-ice tests. All the specific tests were executed on-ice. Stars represent the infrared gates.

Pro agility (5-10-5-m) on-ice test (COD_{ICE}). The pro agility (5-10-5-m) test was used to estimate agility performance on ice. COD_{ICE} measures the explosiveness of lower limbs, change of direction ability and skating skills in specific manner. In the test, the player started 20 centimetres behind the infrared gates (Spintest Oy, Tallinn, Estonia). The player first had to skate five metres straight, followed by a stop-and-go turn (180 degrees). Then, the player skated 10 metres to the next line, making a similar turn (180 degrees) and skated over the finish line 5 metres away. There were three trials in the test. In the first run, the chest direction had to be pointed in the direction of the bench and in the second run in the direction of the penalty box. In the third run, the player was allowed to decide whether the chest was pointing in the direction of the bench or box, but in the same direction in both brakes. (Figure 6.) There were 3-5 minutes recovery periods between the trials. Overall time was measured in the test.

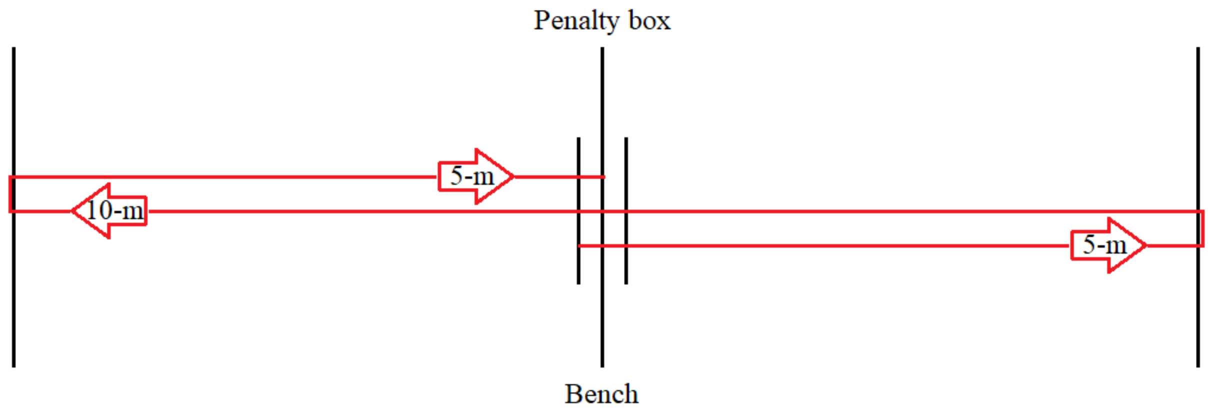

FIGURE 6. Pro agility (5-10-5-m) on-ice test. Subjects skated 5 + 10 + 5 metres with stop-and-go turns. Infrared gates were in the middle line.

30-metre linear skating speed. Forward skating speed was measured on-ice (figure 7). Infrared gates were used to measure the skating times (Spintest Oy, Tallinn, Estonia). Subjects started behind the goal line and the first gates located one meter in front of the line so that the players were not able to start the time accidentally too early. Players skated with maximal speed through the last gates that located 31 m from the goal line. 5-, 10- and 30-metre times were recorded. The subjects were allowed to start the test when ready without reactions. All the players had three trials and the time between the executions were 3-5 minutes.

FIGURE 7. 30-metre linear skating speed with five- and ten-metre splits.

Yo-Yo intermittent recovery ice hockey test, level 1 (Yo IR1-IH). The test was used to estimate players aerobic ability on-ice. The covered distance was measured. In the test, subjects had to skate 20-metre distance back and forth with gradual speed increments with 10 seconds recovery between the shuttles. Runs were signalled by audio beeps. Players had to reach both 20-metre lines (starting line and change of direction line that was set to the goal line) before the beep audio signal. Each subject was allowed to miss beep signal once and get the "warning". The test was finished when player did not across the line before audio signal second time or until exhausted. At the beginning of level 16 (in 9 minutes 17 seconds) of the test, place of starting and change of direction lines were changed 1.5 metre forward because of wearing of ice by breakings. However, 20-metre distance did not change. (Figure 5.)

7.3.3 Match-related indicators

Local Positioning System (LPS) (Quuppa Intelligent Locating System^{TM}) was used to analyse the performance of players during the game. The system of Quuppa uses Bluetooth Low Energy (BLE, Bluetooth 4.0 / Bluetooth Smart) technology. It is based on location algorithms and unique angle measurements, Angle-of-Arrival system.

Locators have been set up on the ceiling of ice hockey halls. Every player had a tag in their shoulder pads during games. A tag sent radio signal to the locators which measured the direction of the signal (Angle-of-Arrival). Locators sent measurement data to the Quuppa Positioning Engine. (Figure 8.) Frequency range used by Quuppa is 2.4 GHz and the delay of the system is 100 milliseconds. Capacity of the system is 400 functions in one second per channel.

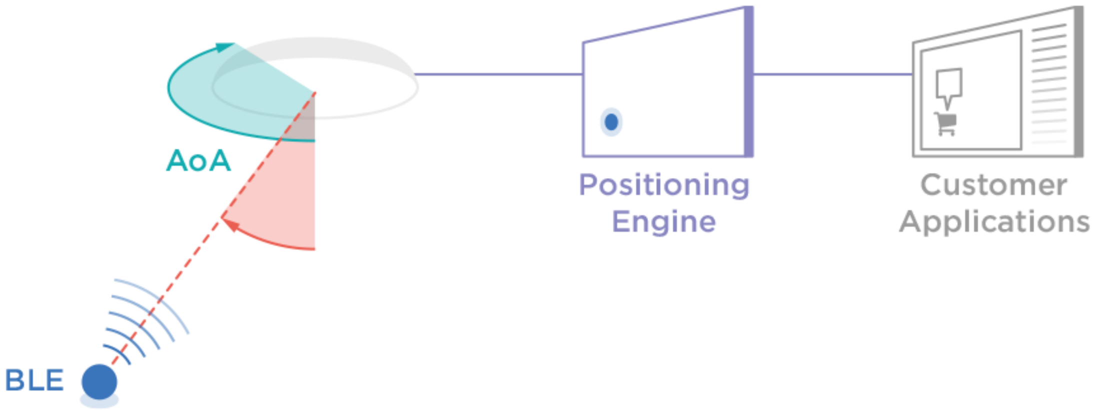

FIGURE 8. The principle of Quuppa Intelligent Locating System™. Bluetooth signal (BLU) in a tag send signal to locators which send data to Positioning Engine. Customer application (Wisehockey) further uses the data gathered by Positioning engine. (Quuppa Oy 2020.)

The data of Quuppa Positioning Engine was benefitted by using software (Wisehockey Oy) created by Bitwise Corporation. The LPS provides information about playing times, skating distances and velocities (table 5). Quuppa Intelligent Locating System™ has been suggested to be accurate enough in team sports in research use (Figueira et al. 2018).

TABLE 5. Match-related variables used in this study.

Main variable	Variable	Units
TIME	Playing time	min:ss
	Playing time per shift (avg.)	min:ss
	Shifts (qty.)	
DISTANCE	Skating distance	m
VELOCITY	Average speed	km/h
	Maximal speed	km/h

Abbreviations: avg. = average, qty = quantity.

7.4 Statistical analysis

IBM SPSS Statistics 24- software (International Business Machines Corp, New York, United States) and Microsoft Excel 2016 (Microsoft Corporation, Redmond, United States) were used for statistical analysis of the results. Shapiro-Wilk test was used to analyse normal distribution of the data. Independent samples T-test was used in analyses between forwards and defensemen. Pearson product-moment correlation coefficient (Pearson's r) was used to analyse the relationship between on-ice tests, off-ice tests and match-related indicators. Levels of significance were set to be $p < 0.05$*, $p < 0.01$** and $p < 0.001$***.

8 RESULTS

Total of 140 subjects participated in the study including 89 forwards and 51 defensemen. No significant differences were found in any body composition variables between forwards and defensemen. (Table 6.) All subjects did not participate in every test because of injuries and team-related differences in testing patterns.

TABLE 6. Body composition variables in subjects.

	ALL		FORWARD		DEFENSE		
VARIABLES	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**p-value[a]**
Height (cm)	182.2 ± 6.5	115	181.6 ± 6.6	74	183.5 ± 6.3	41	0.133
Weight (kg)	84.9 ± 8.3	115	84.6 ± 8.7	74	85.3 ± 7.5	41	0.660
Fat (%)	14.3 ± 2.3	89	14.4 ± 2.3	58	14.1 ± 2.4	31	0.613
Fat BIA (%)	14.4 ± 3.3	89	14.9 ± 3.3	58	13.6 ± 3.1	31	0.089
TMM (kg)	68.8 ± 6.8	88	68.4 ± 7.0	57	69.5 ± 6.3	31	0.506

a = Differences between forward and defense groups have been analysed with equal variances independent T-test. SD = standard deviation. Fat = Fat percentage with skinfold thickness four-point method (Durnin & Rahaman 1967). Fat BIA = Fat percentage in Tanita bioimpedance. TMM = total muscle mass in Tanita bioimpedance.

8.1 Off-ice and on-ice test results and match-related indicators

Off-ice test results are presented in table 7. Subjects' average peak power in Wingate test was 941.3 ± 135.8 W. In Incremental cycle ergometer test mean theoretical VO_2max was 51.6 ± 3.5 ml/kg/min. Forwards' average in CMJ was 42.9 ± 4.6 cm and defensemen's 44.4 ± 4.4 cm. However, no significant differences between positions occurred in any of the off-ice variables ($p > 0.05$).

TABLE 7. Off-ice test results in forward, defense and overall and the difference between positions.

	ALL		FORWARD		DEFENSE		
TEST	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**p-value[a]**
COD_{RUN} (s)	4.82 ± 0.17	54	4.82 ± 0.19	36	4.83 ± 0.14	18	0.876
CMJ (cm)	43.4 ± 4.5	86	42.9 ± 4.6	57	44.4 ± 4.4	29	0.165
CMJ20 (cm)	32.3 ± 3.7	81	32.2 ± 3.6	53	32.6 ± 4.0	28	0.622
CMJ40 (cm)	24.4 ± 3.3	79	24.2 ± 3.2	51	24.9 ± 3.6	28	0.390
CMJ60 (cm)	18.9 ± 3.1	77	18.8 ± 3.0	50	19.3 ± 3.3	27	0.507
PP_{ABS} (W)	941.3 ± 135.8	60	935.8 ± 131.0	39	951.5 ±147.2	21	0.673
PP_{REL} (W/kg)	11.3 ± 1.0	60	11.2 ± 0.8	39	11.4 ± 1.2	21	0.489
MP_{ABS} (W)	493.7 ± 77.6	60	493.2 ± 77.8	39	494.7 ± 79.3	21	0.945
MP_{REL} (W/kg)	5.9 ± 0.6	60	5.9 ± 0.6	39	5.9 ± 0.5	21	0.977
ErMaxP (W)	338.0 ± 32.4	67	339.7 ± 30.5	45	334.4 ± 36.5	22	0.532
VO_2max (ml/kg/min)	51.6 ± 3.5	67	51.9 ± 3.7	45	51.0 ± 3.2	22	0.326
run5m (s)	1.08 ± 0.10	57	1.07 ± 0.10	37	1.10 ± 0.09	20	0.296
run10m (s)	1.80 ± 0.10	57	1.79 ± 0.11	37	1.82 ± 0.09	20	0.381
run30m (s)	4.29 ± 0.15	37	4.29 ± 0.16	24	4.29 ± 0.14	13	0.869
F_{MAX} (kg)	270.9 ± 48.1	87	266.5 ± 49.7	52	277.3 ± 45.6	35	0.310
RFD (N/s)	1917.6 ± 571.9	87	1888.17 ± 535.9	52	1961.3 ± 627.1	35	0.562

a = Differences between forward and defense groups have been analysed with equal variances T-test. SD = standard deviation. COD_{RUN} = off-ice change of direction test. PP_{ABS} = absolute peak power in Wingate test. PP_{REL} = Peak power in relation to body weight in Wingate test. MP_{ABS} = Mean power in Wingate test. MP_{REL} = mean power in relation to body weight in Wingate test. ErMaxP = maximal power in cycle ergometer test. F_{MAX} = Maximal force in isometric leg press. RFD = Maximal RFD in isometric leg press.

Average 30-metre skating time was 4.07 ± 0.10 s (n=85). Absolute difference between forward and defense in Yo IR1-IH distance was 177 m. However, the difference was not significant (p = 0.061). Neither other variables showed significant differences. (Table 8.)

TABLE 8. On-ice results and differences between positions.

	ALL		FORWARD		DEFENSE		
TEST	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**p-value[a]**
skate5m (s)	0.98 ± 0.04	85	0.98 ± 0.04	52	0.98 ± 0.04	33	0.900
skate10m (s)	1.71 ± 0.05	85	1.71 ± 0.05	52	1.72 ± 0.05	33	0.531
skate30m (s)	4.07 ± 0.10	85	4.07 ± 0.10	52	4.08 ± 0.10	33	0.528
COD_{ICE} (s)	4.70 ± 0.13	84	4.69 ± 0.12	51	4.72 ± 0.14	33	0.256
yoyodist (m)	2799 ± 424	84	2868 ± 389	51	2691 ± 460	33	0.061

a = Differences between forward and defense groups have been analysed with equal variances T-test. SD = standard deviation. COD_{ICE} = on-ice change-of-direction test. Yoyodist = Distance in Yo-Yo intermittent recovery ice hockey test, level 1.

The average amount of shifts per game in Finnish elite ice hockey players was 20.3 ± 3.8 that is 6.8 shifts per period. Defenders' average playing time was 1:56 minutes more than that of attackers. The difference was significant ($p = 0.005$). (Table 9.) In addition, significant differences occurred in maximal and average speed between positions ($p < 0.001$ in both cases). The maximal speed for forward and defense were 32.7 ± 1.5 km/h (n = 53) and 31.4 ± 1.0 km/h (n = 31), respectively. In average speed corresponding values were 14.7 ± 0.8 km/h (n = 53) and 13.2 ± 0.6 km/h (n = 31). Overall maximal speed was 32.2 ± 1.4 km/h (n=84) and average speed 14.1 ± 1.1 km/h (n =84). (Figure 9.)

TABLE 9. Match-related indicators and the differences between positions.

	ALL		FORWARD		DEFENSE		
VARIABLES	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**p-value[a]**
Playing time (min:ss)	15:22 ± 3:04	83	14:39 ± 2:52	52	16:35 ± 3:03	31	0.005**
Shifts (qty.)	20.3 ± 3.8	84	19.8 ± 3.5	52	21.1 ± 4.3	32	0.136
Playing time/shift (min:ss)	0:45 ± 0:05	83	0:44 ± 0.05	52	0:47 ± 0:05	31	0.019*
Skating distance (m)	3600 ± 676	84	3579 ± 690	53	3635 ± 661	31	0.717
Maximal speed (km/h)	32.2 ± 1.4	84	32.7 ± 1.46	53	31.4 ± 0.1	31	<0.001***
Average speed (km/h)	14.1 ± 1.1	84	14.7 ± 0.8	53	13.2 ± 0.6	31	<0.001***

a = Differences between forward and defense have been analysed with equal variances T-test. SD = standard deviation. Qty = quantity. $p < 0.05$*, $p < 0.01$** and $p < 0.001$***.

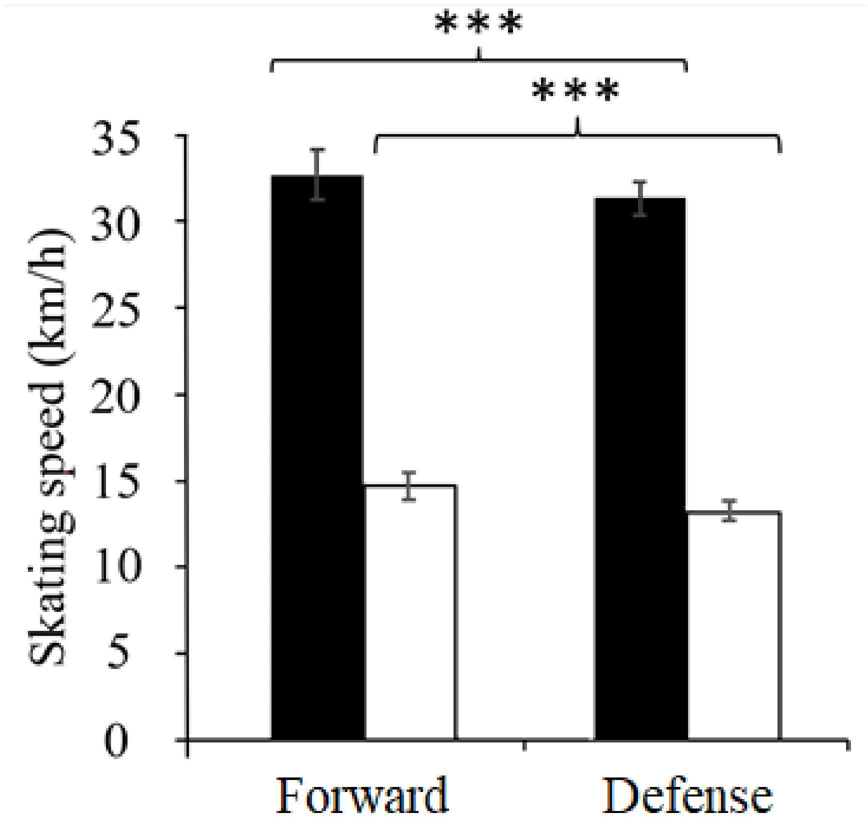

FIGURE 9. Overall, forwards' and defensemen's maximal and average speeds during game and the difference between positions. Black bar is presenting maximal and white bar average speed. $p < 0.001$***.

8.2 Relationships between off-ice tests, on-ice tests and match-related indicators

Relationships between general and specific tests are presented in table 10. Significant relationship occurred between all CMJ tests and skating times. CMJ and 30-metre skating time showed strong negative correlation ($r = -0.629$, $p < 0.001$) (figure 10). In addition, significant negative correlation was found between 30-metre skating time and Wingate peak power when in relation to body weight ($r = -0.588$, $p < 0.001$) (figure 11). On-ice and off-ice pro agility (5-10-5-m) tests showed also significant correlation ($r = 0.405$, $p < 0.01$) (Figure 12). Correlation between theoretical VO_2max and Yo IR1-IH distance are presented in figure 13. In addition, body composition variables showed weak, non-significant correlations with every on-ice variable ($p > 0.05$). Associations between off-ice tests and performance on-ice are demonstrated in figure 14.

TABLE 10. Correlations between on-ice and off-ice performance variables.

	skate5m	**skate10m**	**skate30m**	**COD_{ICE}**	**yoyodist**
COD_{RUN}	0.071	0.265	0.195	**0.405****	-0.311*
CMJ	-0.380**	-0.593***	**-0.629*****	-0.408**	0.139
CMJ20kg	-0.432**	-0.638***	-0.678***	-0.414**	0.203
CMJ40kg	-0.462***	-0.634***	-0.686***	-0.423**	0.140
CMJ60kg	-0.398**	-0.516***	-0.592***	-0.347**	0.143
PP_{ABS}	-0.153	-0.253	-0.437**	-0.244	-0.015
PP_{REL}	-0.290*	-0.410**	**-0.588*****	-0.488**	0.004
MP_{ABS}	0.058	0.003	-0.183	-0.070	0.042
MP_{REL}	0.087	0.034	-0.150	-0.187	0.106
run5m	0.085	0.316*	0.230	0.411**	-0.494***
run10m	0.164	0.403**	0.332*	0.468***	-0.473***
run30m	0.442**	0.593***	0.472**	0.457**	-0.308
ErMaxP	0.231	0.108	-0.035	-0.209	0.468***
VO_2max	0.196	0.099	0.017	-0.068	**0.514*****
F_{MAX}	-0.307*	-0.304*	-0.345**	-0.215	-0.167
RFD	-0.265	-0.191	-0.217	-0.116	-0.344*

$p < 0.05$*, $p < 0.01$** and $p < 0.001$***. Bolded values' correlations are also illustrated in figures 10, 11, 12 and 13. COD_{RUN} = off-ice change of direction test. PP_{ABS} = absolute peak power in Wingate test. PP_{REL} = Peak power in relation to body weight in Wingate test. MP_{ABS} = Mean power in Wingate test. MP_{REL} = mean power in relation to body weight in Wingate test. ErMaxP = maximal power in cycle ergometer test. F_{MAX} = Maximal force in isometric leg press. RFD = Maximal RFD in isometric leg press. COD_{ICE} = on-ice change-of-direction test. Yoyodist = Distance in Yo-Yo intermittent recovery ice hockey test, level 1.

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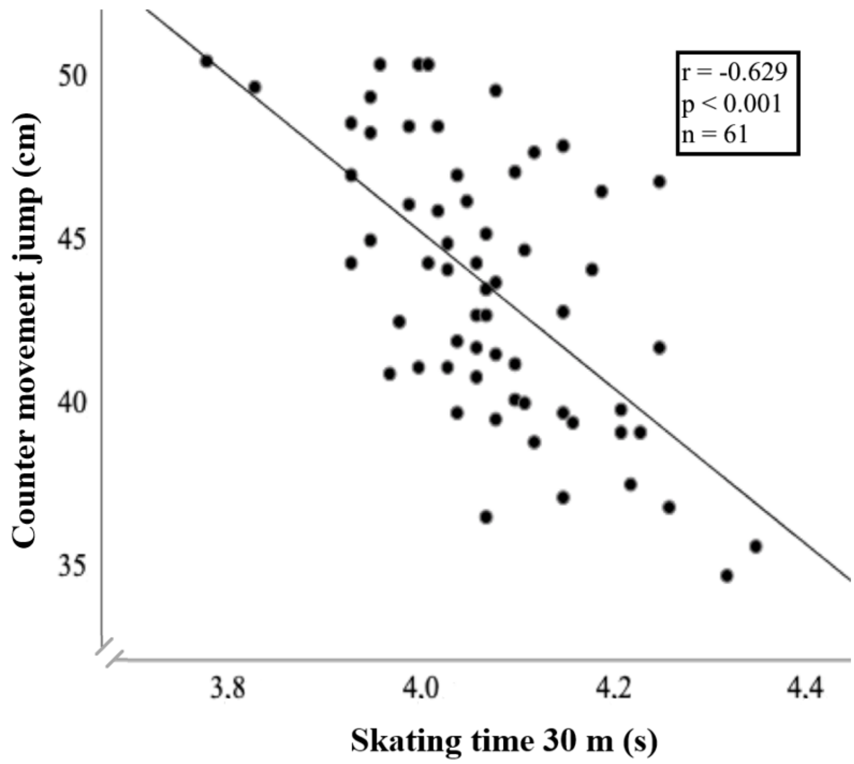

FIGURE 10. Relationship between countermovement jump and 30-metre skating time.

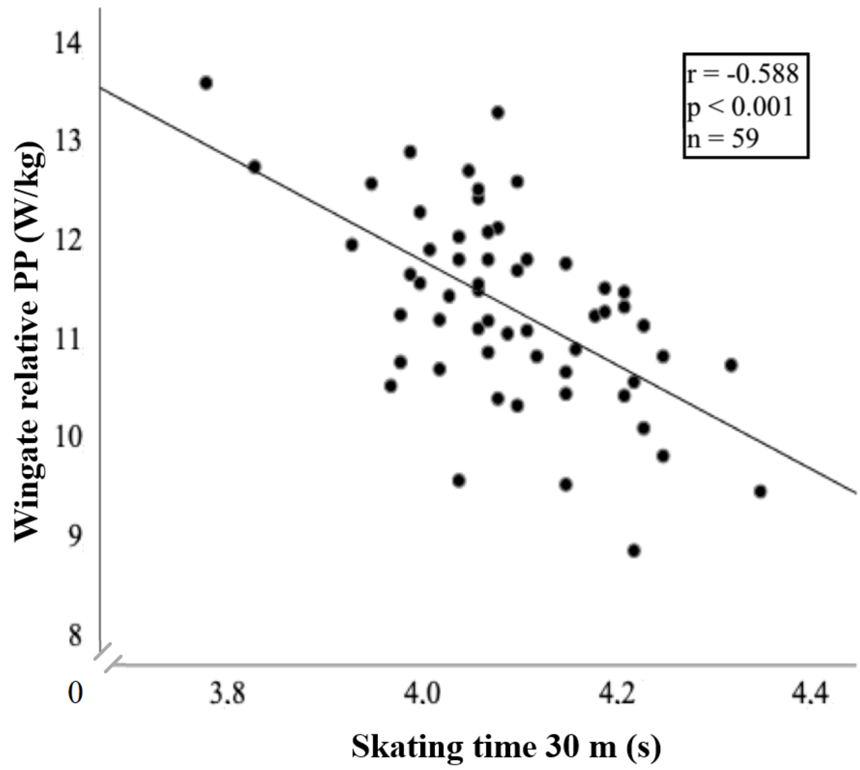

FIGURE 11. Relationship between relative peak power in Wingate test and 30-metre skating time. PP = peak power.

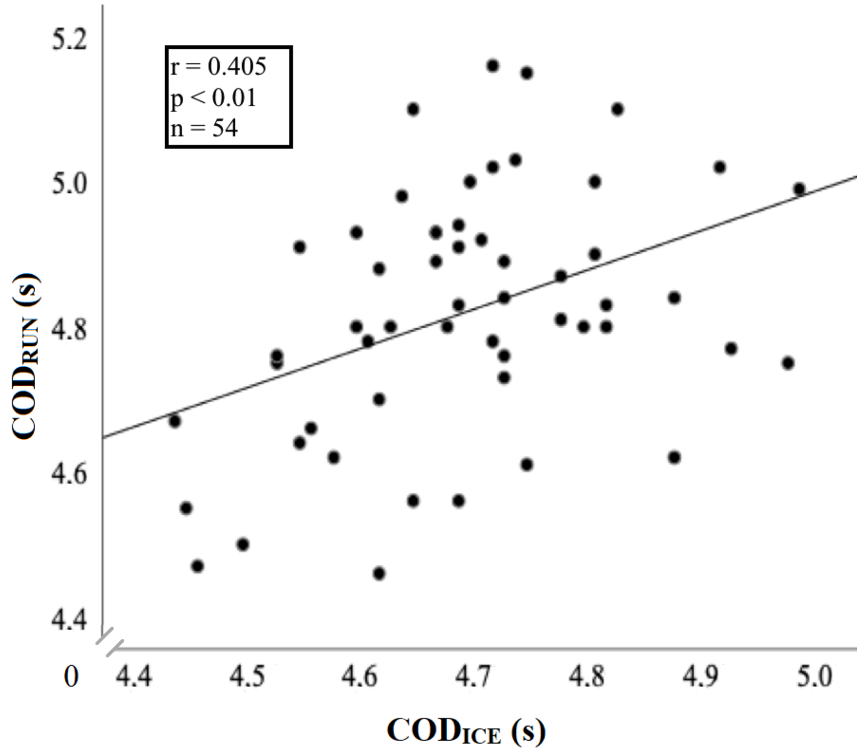

FIGURE 12. Relationship between off-ice (COD_{RUN}) and on-ice (COD_{ICE}) change of direction tests.

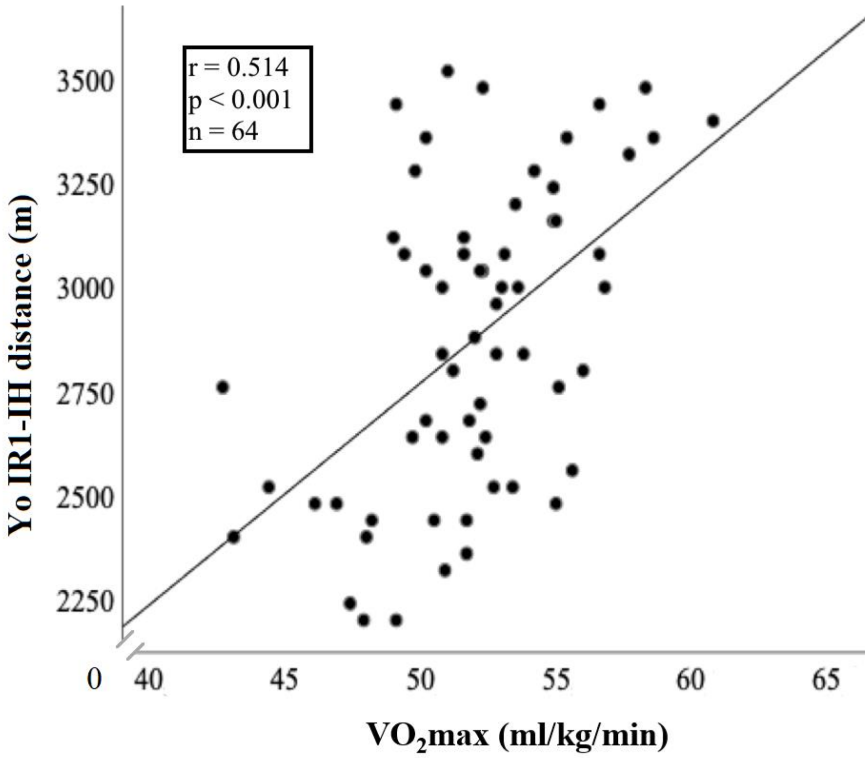

FIGURE 13. Relationship between distance of Yo-Yo intermittent recovery ice hockey test, level 1 (Yo IR1-IH) and theoretical VO_2max.

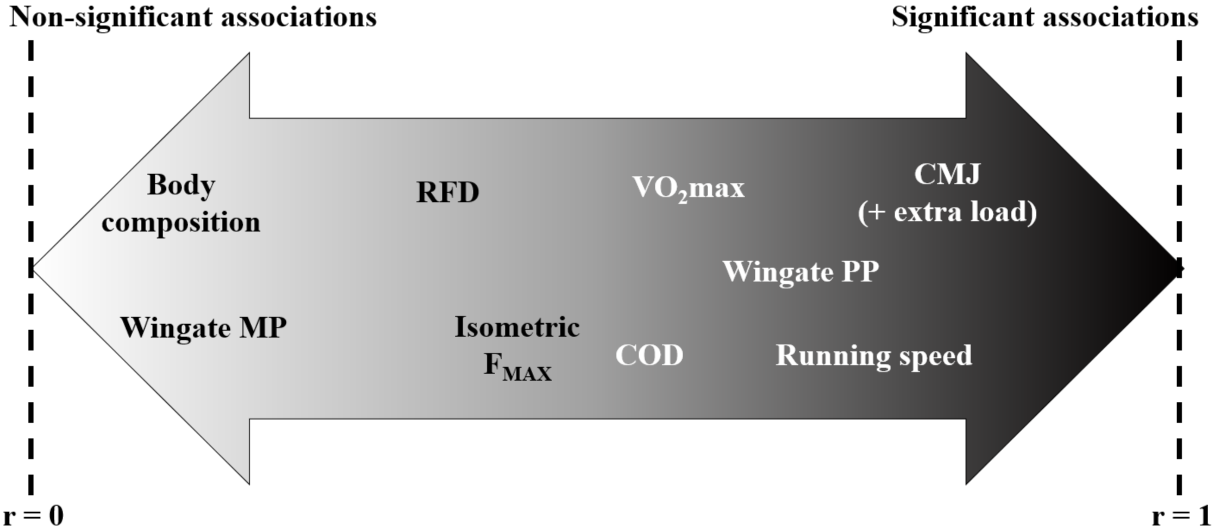

FIGURE 14. General tests' association with on-ice performance.

Strong significant correlations were found between playing time per shift and 5- and 10-metre running times ($r = -0.667$, $p < 0.01$ and $r = -0.622$ $p < 0.01$, respectively). Low-moderate correlation was found between relative peak power in Wingate test and skating distance ($r = -0.363$, $p < 0.05$). Low-moderate correlation occurred also between theoretical VO_2max and average speed ($r = 0.324$, $p < 0.05$). Maximal speed correlated with F_{MAX} and RFD ($r = 0.302$, $p < 0.05$ and $r = 0.304$, $p < 0.05$, respectively). (Table 11.) Most prominent correlations between off-ice tests and match activities are collected in figure 15.

TABLE 11. Correlations between off-ice tests and match-related indicators.

VARIABLE	Playing time	Shifts	Playing time / Shift	Skating distance	Maximal speed	Average speed
COD_{RUN}	-0.087	0.074	-0.284	-0.126	0.142	0.014
CMJ	0.129	0.062	0.103	0.070	0.161	-0.217
CMJ20kg	0.126	0.025	0.158	0.104	0.173	-0.095
CMJ40kg	0.093	-0.017	0.196	0.040	0.009	-0.150
CMJ60kg	0.037	-0.047	0.161	-0.018	-0.034	-0.157
PP_{ABS}	-0.233	-0.149	-0.150	-0.300	-0.099	-0.029
PP_{REL}	-0.260	-0.275	0.043	-0.363*	0.028	-0.117
MP_{ABS}	-0.180	-0.041	-0.215	-0.204	-0.074	0.095
MP_{REL}	-0.148	-0.061	-0.097	-0.171	0.076	0.091
run5m	-0.06	0.319	**-0.667*****	-0.092	-0.048	0.001
run10m	-0.005	0.348	**-0.622*****	-0.041	-0.037	-0.021
run30m	0.022	0.120	-0.310	0.035	-0.181	0.067
ErMaxP	0.318*	0.201	0.185	0.287	-0.094	-0.028
VO_2max	0.100	0.187	-0.095	0.276	0.226	**0.324***
F_{MAX}	0.109	0.170	-0.094	0.100	**0.302***	-0.047
RFD	0.137	0.104	0.050	0.150	**0.304***	-0.045

$p < 0.05$*, $p < 0.01$** and $p < 0.001$***. Bolded values' correlations are also illustrated in figure 15. COD_{RUN} = off-ice change of direction test. PP_{ABS} = absolute peak power in Wingate test. PP_{REL} = Peak power in relation to body weight in Wingate test. MP_{ABS} = Mean power in Wingate test. MP_{REL} = mean power in relation to body weight in Wingate test. ErMaxP = maximal power in cycle ergometer test. F_{MAX} = Maximal force in isometric leg press. RFD = Maximal RFD in isometric leg press.

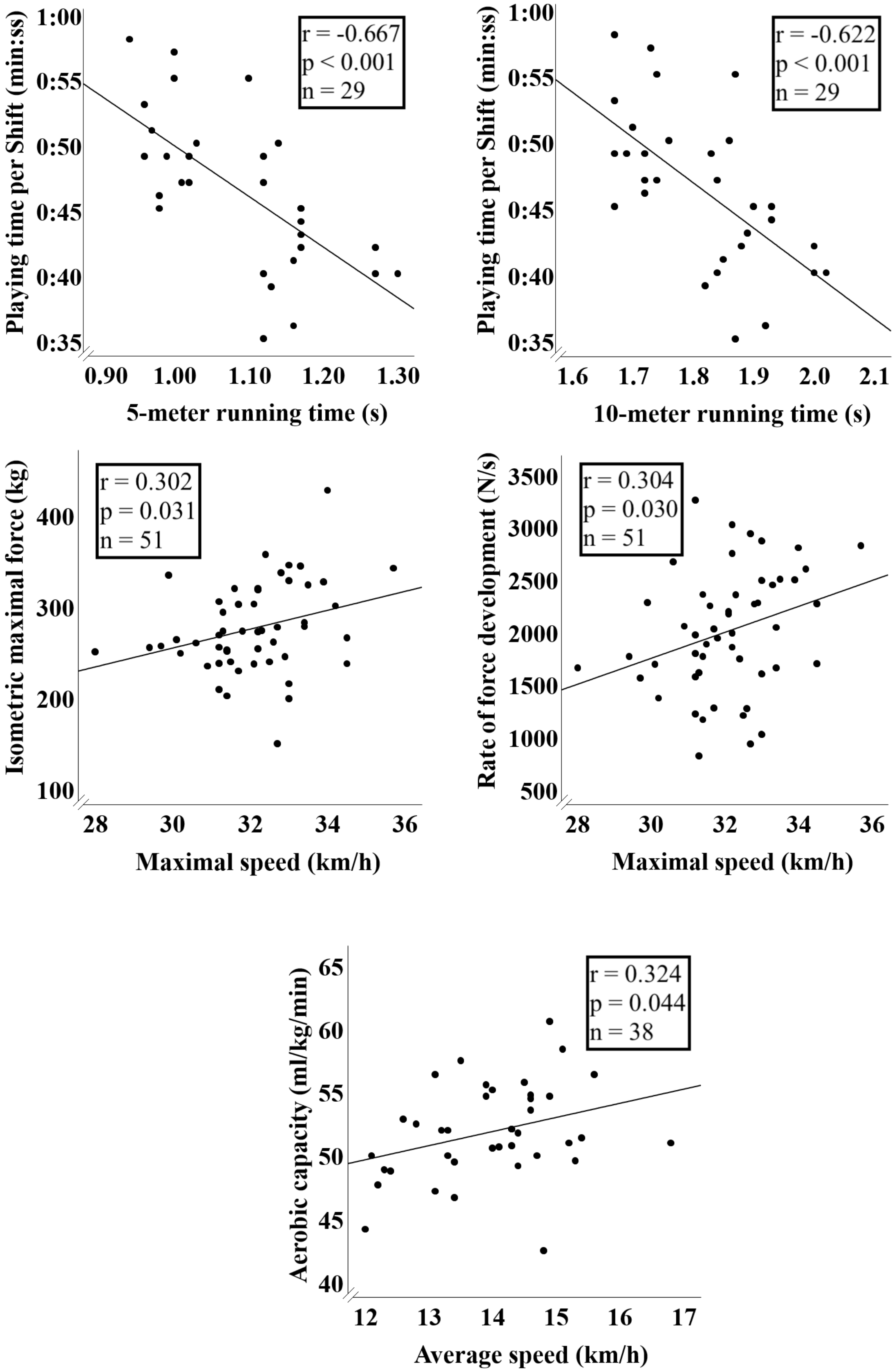

FIGURE 15. Correlation graphs of most prominent relationships between general tests and match-related indicators.

Any of body composition variables did not correlate significantly to match-related indicators ($p > 0.05$). Table 12 represents correlations between general tests and match-related indicators. No significant associations occurred between on-ice tests and match activities.

TABLE 12. Correlations between on-ice tests and match-related indicators.

VARIABLE	Playing time	Shifts	Playing time per Shift	Skating distance	Maximal speed	Average speed
skate5m	-0.100	-0.021	-0.119	-0.092	-0.266	0.048
skate10m	0.006	0.065	-0.083	0.000	-0.231	-0.037
skate30m	0.087	0.069	0.041	0.054	-0.254	-0.11
COD_{ICE}	-0.016	0.073	-0.141	-0.083	-0.208	-0.119
yoyodist	-0.091	-0.203	0.131	0.015	0.166	0.256

COD_{ICE} = on-ice change-of-direction test. Yoyodist = Distance in Yo-Yo intermittent recovery ice hockey test, level 1.

9 DISCUSSION

As main findings of this study, significant correlations were found between general and specific physical characteristics but no relationships between the physical qualities and match-related indicators. In addition, no significant differences were found between forwards and defensemen in general and specific performance variables. However, clear differences occurred in match activities when comparing positions.

9.1 Relationships between general and specific physical characteristics

Significant relationships were found between general and specific tests supporting hypothesis. In this study, speed and power tests seemed to have strong correlation between off-ice and on-ice tests. In addition, relationship occurred between general and specific endurance tests. Maximal force in isometric leg press showed low correlation with on-ice sprint performance. When body composition variables were compared to on-ice tests, no significant correlations were found.

Countermovement jump showed significant relationship with COD_{ICE} and all acceleration and speed tests on-ice. In addition, all CMJ tests with extra loads support the findings showing similar results. Most, but not all authors have showed relationships between CMJ and on-ice tests. However, when elite ice hockey players have been assessed, most of studies have shown the correlations (Mascaro et al. 1992; Peterson et al. 2015; Runner et al. 2015 Vigh-Larsen et al. 2019). Many authors have compared CMJ and on-ice agility tests but not many have used pro agility (5-10-5-m) change of direction test on-ice. However, Vigh-Larsen et al. (2019) observed moderate correlation between CMJ and COD_{ICE} supporting this study. In addition, in this study COD_{ICE} and COD_{RUN} showed moderate correlations between each other. It is obvious that specific biomechanical movement patterns of on-ice skating differ substantially from that of running, affecting to relationships between on-ice and off-ice tests.

Moreover, off-ice acceleration and speed tests showed relationships with on-ice speed and power tests. However, it seemed that 30-metre skating time has stronger connection with off-ice sprint ability than 5- or 10-metre times have. Five-, 10- and 30-metre linear skating times showed similar, moderate correlations with COD_{ICE}. Interestingly, 5- and 10-metre sprint times had moderate-strong correlation with Yo IR1-IH distance while 30-metre time did not show significant correlation at all. In Yo IR1-IH, first skating strides are crucial even though they are performed as fatigued and that might explain the findings. Altogether, earlier studies support the observation CMJ and sprint ability having high associations with on-ice performance (Behm et al. 2005; Farlinger et al. 2007; Krause et al. 2012; Haukali & Tjelta 2015; Janot et al 2015; Peterson et al. 2016; Boucher et al. 2017; Delisle-Houde et al. 2019; Vigh-Larsen et al. 2019).

In this study, Wingate test MP_{REL} and absolute mean power in Wingate anaerobic test (MP_{ABS}) did not show correlations with any of on-ice variables. However, PP_{REL} showed relationships with COD_{ICE}, 10- and 30-metre skating times. Absolute peak power also had moderate correlation with 30-metre skating time. Non-existent correlations between mean power variables and on-ice physical qualities might be explained by the factors of energy metabolism. Speed and power tests on-ice were short, approximately one to five seconds. In that kind of performances main energy source is ATP-PCr system and that also support the relationship between peak power and on-ice speed-power tests. However, mean power indicates about the average local muscle endurance and gives assessment of anaerobic capacity because of high correlation with maximal accumulated oxygen deficit (Vescovi et al. 2010). In this study, none of the on-ice tests really assessed the speed endurance leading to high accumulated lactate levels. That might be explaining the non-existent relationships between mean power and any of the on-ice variables. In future, it would be beneficial to compare Wingate test mean power to repeated sprint ability test on-ice estimating associations with on- and off-ice speed endurance tests. In this study, using repeated sprint ability test on-ice was not possible due to time resources.

Distance in Yo IR1-IH showed significant correlation with assessed VO_2max in cycle ergometer test. The relationship indicates about aerobic component of the Yo IR1-IH and consequently supports the test being useful when assessing players' specific aerobic capacity. Some earlier studies have investigated relationship between on-ice and off-ice endurance in elite ice hockey players (Lignell et al. 2018; Peterson et al. 2015; Durocher et al. 2010). However, contradictory findings have been done and only Lignell et al. (2018) have used Yo

IR1-IH test but submaximal version when comparing aerobic capacity and on-ice endurance capabilities. They compared the heart rate values to match-related intensity zones and found that heart rate correlated negatively to frequency of high intensity skating bouts and concluded that Yo IR1-IH_{SUB} should be used to indicate match-related performance. In addition, they found significant relationship between VO_2max in cycle ergometer test and Yo IR1-IH_{SUB} supporting this study. As mentioned, the test did not correlate with match-related indicators in this study, however skating zones were not analysed.

Maximal force and RDF in isometric leg press showed low correlations with on-ice tests. Only few studies have investigated the relationship of strength and on-ice performance in elite ice hockey players (Mascaro et al. 1992; Runner et al. 2015). However, authors have used squat, dynamic leg press and isokinetic devices determining force and power and they have reported conflicting findings. Behm et al. (2005) used maximal force in leg press when compared to on-ice skating speed. They did not find correlation; however, the subjects were young and not elite ice hockey players. In this study, F_{MAX} showed low connection with on-ice sprint performance. However, RFD did not correlate with on-ice speed-power tests. One explanation might be the lack of isometric movements in on-ice tests and in the game of ice hockey overall. However, because of the lack of studies with similar testing patterns, these results cannot be compared to other studies. Also, in this study F_{MAX} values had to be rejected for one team because of technical problems of isometric leg press.

According to this study, body composition variables do not correlate with any on-ice variables. That contrasts with study of Vigh-Larsen et al. (2019), who found small correlations between body fat-% and Yo IR1-IH, sprint time and COD_{ICE}. In their study, similar correlations occurred between muscle mass and those on-ice variables. However, not many studies have been done to investigate relationships between on-ice tests and body composition variables. Instead, studies have investigated the relationship between body composition and success on-ice principally with sub-elite ice hockey players. Those studies have shown very different findings (Roczniok et al. 2016; Roczniok et al. 2013; Green et al. 2006; Peyer et al. 2010; Hoff et al. 2005). For example, Roczniok et al. (2016) observed that players who were taller and had lower body fat percentage were more capable and more often selected to higher level team in Poland.

Instead, Green et al. (2006) found that lower body percentage was in association with total playing time but not with total scoring during a season.

9.2 Relationships between physical characteristics and match-related indicators

Interestingly, any of specific tests did not show correlations with match-related indicators. In addition, only some significant relationships were found between general tests and match-related indicators. It is possible that the nature of the game including lot of technical and tactical elements affect to relationships between physical fitness and match-related indicators. Low-moderate correlations were found between VO_2max and average speed; ErgoMaxP and playing time; F_{MAX} and maximal skating speed; RFD and maximal skating speed. Moreover, low-moderate negative correlation occurred between PP_{REL} and skating distance, and 5- and 10-metre skating times correlated strongly with playing time per shift. However, no reasonable explanations are observed for those relationships.

Relationship between VO_2max and average speed indicates that players with better aerobic capacity are more capable to maintain the higher skating speed during the match. The relationship is possibly explained by the reduced fatigue and consequently allowing to skate with higher skating speed thus increasing average speed. The reduced fatigue by better aerobic capacity can be explained by many different mechanisms. According to Tomlin & Wenger (2001) high aerobic power enhance the recovery from repeated bouts of anaerobic exercise. Consequently, the association between VO_2max and fatigue index for repeated sprints in ice hockey have been observed (Stanula et al. 2014). With improved aerobic capacity, buffering capacity is enhanced and lactate removal is increased. Capillary density increases enhancing nutrients and oxygen movement to muscle cells, and hydrogen ions and lactate removal from muscles. (Holloszy & Coyle 1984.) These mechanisms are partly explaining the relationship between VO_2max and average speed.

In isometric leg press, F_{MAX} and RFD showed low correlations with maximal speed during game. Even though speed power tests did not show significant correlations with skating speed, the finding supports that maximal strength and power generation are in connection with skating speed abilities during the match. There are no earlier studies compared any speed, power and strength characteristics on match activities.

On-ice tests did not correlate with match-related indicators. According to Montgomery (1988) one shift contains about 5-7 burst each lasting 2-3.5 seconds. Consequently, it is possible that not many players really reach the maximal speed during the match explaining the non-existent correlations between maximal speed during game and speed in specific tests. As mentioned, ice hockey game does not only demand high physical qualities for the players but also high technical skills and a lot of tactical aspects. In this study, specific tests measured purely speed and power production and aerobic capacity on-ice. However, in real game situation speed endurance and anaerobic glycolysis play huge role (Leger et al. 1979). That is why it would be beneficial to investigate the relationship between well implemented repeated sprint ability test and game activities.

9.3 Positional differences

In many, but not all earlier studies, authors have observed significant differences between positions when physical characteristics have been considered (Houston & Green 1976; Vescovi et al. 2006; Quinney et al. 2008). However, in this study no differences were observed between players in any of those variables that is in contrary to hypothesis. One explanation might be that in some of those earlier studies, subjects have been NHL-players or drafted players in NHL Entry draft. In those studies, more positional differences have been occurred (Rhodes et al. 1986; Vescovi et al. 2006; Quinney et al. 2008; Burr et al. 2008). Cox et al. (1995) have considered differences being due to conditioning techniques that have been varying between forward and defense. It is possible that in Finnish Elite Ice Hockey League teams the implementation of conditioning is nearly same regardless position and conditioning techniques have been created to develop only to enhance players weaknesses. However, recently published broad study (n = 275) investigated positional differences in the best and second-best Danish ice hockey divisions. They did not observe any differences between forwards and defensemen supporting this study (Vigh-Larsen et al. 2019).

On the other hand, many of studies exploring positional differences have been done years ago. It cannot be excluded that the differences between forward and defense would have been narrowed when the sports of ice hockey has been developed. According to Montgomery (2006) physical size and other physical characteristics of elite ice hockey players have been enhanced over the last century. In addition, Cox et al. (1995) have noted that the physical fitness of players has become wore over the past years.

In this study one of the five participating team was Finnish elite junior ice hockey team. It is possible that younger players do not show great differences between positions because of lesser background of physical conditioning. Therefore, it might affect to the overall data by lowering the differences between positions. However, Vescovi et al. (2006) observed that young 18.0 ± 0.6 years old players at NHL scouting combine showed differences in body composition defensemen being heavier and taller than forward but no differences in performance.

When comparing results of this study to investigations accomplished with NHL-players or players at the NHL entry draft combine, approximately clear differences can be seen. For example, Burr et al. (2008) observed that average measures for weight and height were 93.8 kg and 187.6 cm in defense and 89.8 kg and 184.1 cm in forward, respectively in young elite drafted players by NHL. In this study corresponding values for Finnish elite ice hockey players were 85.3 kg and 183.5 cm in defense and 84.6 kg and 181.6 cm in forward. Additionally, in physical performance NHL-players have showed significantly higher values (Montgomery 2006; Burr et al. 2008). However, differences in testing methods must be considered when comparing laboratory fitness tests.

Regardless there were no differences in general and specific physical characteristics, obvious differences were found between positions in match-related indicators. Consequently, the findings support the hypothesis. In this study, the defenders' playing time was significantly greater than that of the attackers (difference 1:56 min). This is likely to be explained by the fact that teams have typically four forward lines and three pairs of defensemen plus possible one extra defender in the line-up, which logically means more playing time for the defenders than the attackers. The defenders also had a longer playing time per shift, which is explained by the fact that there was no difference in the number of shifts between the positions. However, although the defenders spent more time on-ice, there were no differences in the distance covered between the positions. Skating speed explains the non-existent difference, as the average speed of the defensemen during the game was significantly lower than that of forwards. The difference could be possible explained by tactical elements between the positions. For example, defenders skate much more often and longer times backwards during the game than forwards (Nightingale 2014). That logically affects to the average skating speed and still to the distance covered in the match.

In this study, overall skating distance of player was 3600 ± 676 m. In the study of Lignell et all. (2018) when analysing one NHL-game, player's average covered skating distance was 4606 ± 219 m meaning that the difference is over 1000 m and 22 %. The difference indicates that game in NHL is remarkably more strenuous and intensive than in Finnish Elite Ice Hockey League. However, the number of players in the game roster was significantly smaller when compared to this study and that logically decreases the difference. When the average skating distance is in relation to playing time, it still shows significant difference between players' total skating distance in different leagues being over 13 % higher in NHL than in Finnish Elite Ice Hockey League (average speed = (4606 m / 1038 s) * 3.6 = 15.974... ≈ 16.0 km/h vs. 14.1 km/h). The study of Lignell et al. (2018) also supports that defensemen spend more time on ice than forwards, however the difference is much greater than in this study. They also observed that defenders covered significantly greater distances than forwards (5445 ± 337 m vs. 4237 ± 248 m, respectively). That contrasts with this study, but the number of players in line-up, the ratio of positions and differences in measuring devices must still be considered between studies.

9.4 Strengths and limitations

Strengths. Unlike in earlier study of Lignell et al. (2018) in which only one game was analysed, six games were used in analyses in this study. That logically decreased the possibilities of coincidences providing more reliable data. This study was executed with elite athletes and the overall number of subjects was 140. In addition, all teams had nearly equivalent background except the elite junior ice hockey team. The sample is large and valid enough to represent the level of Finnish elite ice hockey and that can be mentioned as a strength of this study. The study also allowed a broad testing pattern providing comprehensive information about physical characteristics of subjects and the relationships between general tests, specific tests and match-related indicators.

Limitations. Even though the sample size of the study was large (n = 140), not all players participated in all tests depending on injuries and differences in testing patterns between teams. In addition, match-related indicators were able to collect only for players who played in games (n = 84). Furthermore, one of the teams was elite junior ice hockey team. However, several of the team's players played also in Finnish Elite Ice Hockey League indicating that the level of the team is high and the advantage of increasing the number of data was concluded to be greater than possible handicaps. In isometric leg press force values had to remove by one team because of technical problems of the press and hence affecting to the total data. However, F_{MAX} and RFD data is still large (n = 87). In addition, theoretical VO_2max values had to be used because of temporal challenges to accomplish direct cycle ergometer test to all subjects.

9.5 Conclusion

The purpose of this study was to investigate the relationships between general and specific physical qualities and match-related indicators. In addition, the aim was to study the positional differences in general and specific physical characteristics. The goal was also to examine, if there are distinctions in match activities between forwards and defensemen. This kind of broad research has not been previously done with Finnish Elite Ice Hockey League players in modern ice hockey providing insight to players' physical characteristics. This study is also unique because game activities are compared to physical qualities.

According to this study, general tests are mainly in association with specific tests. Speed, power and endurance tests indicates on-ice performance. Maximal force and RFD in isometric leg press show also low correlations with specific tests. However, body composition variables do not correlate with specific physical characteristics. When compared to match activities, specific tests do not indicate match-related indicators and general physical characteristics show only weak-moderate associations with those indicators.

The findings of this study suggest that no differences occur between positions when off-ice and on-ice physical characteristics are considered. Findings contrast with the hypotheses that are based on earlier studies. Even though clear differences have been observed between positions, authors have found opposite results concerning differences between forwards and defensemen (Vigh-Larsen 2019; Montgomery 2006; Vescovi et al. 2006; Quinney et al. 2008; Twist & Rhodes 1993b; Green et al. 1976). However, differences are obvious in match-related indicators between attackers and defenders supporting the hypothesis. Defensemen spend more time on ice overall and per shift, but maximal speed and average speed are superior in forwards. Nevertheless, no differences were observed in distance covered in match between positions. Lignell et al. (2018) support differences, even though the differences were major in their study. However, the dissimilarities in measuring devices must be considered.

In this study, none of the tests really assessed speed endurance capabilities on-ice. However, anaerobic capacity plays crucial role in game performance. That is why it would be beneficial to study the relationship between well-implemented repeated sprint ability test and general tests and between the test and match activities. In addition, because of high tempo and intermittent nature of game scientist should investigate skating speed zones and high-intensity activities during ice hockey match in the future.

9.6 Practical applications

Findings of this study demonstrate that coaches must be aware of testing patterns used when determining players physical capabilities. For example, CMJ and sprint performance are suitable tools when assessing performance on-ice. Instead, the use of an isometric leg press should be considered when estimating on-ice performance. Even though all the physical characteristics do not directly indicate basic match-related indicators, coaches should ensure adequate fitness conditioning for players. For instance, it is obvious that high endurance capacity allows players to recover rapidly and hence accomplish more high-intensity bursts.

Furthermore, physical conditioning is crucial not only for success but also preventing injuries being one reason for versatile conditioning.

In addition, no positional differences occur in physical characteristics in elite Finnish ice hockey players. However, the differences are obvious when tactical elements and match-related indicators are considered. Consequently, that leaves to wonder, if coaches and trainers should pay more attention in positional differences in physical conditioning. In general, the developed characteristics should be same with both, forwards and defensemen but the ratio of conditioned physical characteristics should be considered between positions. Individual aspects must also be considered when planning conditioning programs.

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APPENDICES

APPENDIX 1. An approval of the ethical committee of Central Finland Health Care District.

ksshp
Keski-Suomen sairaanhoitopiiri

TUTKIMUSEETTINEN TOIMIKUNTA
LAUSUNTO

19.6.2019

21U/2019

Interactions between physical qualities, training, match loads and health profiles in ice hockey players during one-year follow-up

Fyysisten ominaisuuksien, pelikauden aikaisen kuormittumisen ja terveysprofiilin väliset yhteydet jääkiekkoilijoilla – Kuormittuminen jääkiekossa (HOCKEY LOAD) – tutkimus

Tutkimuskeskukset
Jyväskylän yo: Kyröläinen Heikki, LitT, prof.; Haverinen Marko, LitM (testauspäällikkö Varalan urheiluopisto), jatko-opiskelija; Avela Janne, LitT, prof.; Virmavirta Mikko, LitT, yliopistotutkija
Tampereen urheilulääkäriasema (TaULA) / UKK – instituutti: Parkkari Jari, LT, EL, ylilääkäri; Leppänen Mari, TtT, tutkimus- ja kehittämispäällikkö; Hänninen Timo, LT, EL
Medisport, Suomen jääkiekkoliitto, Kansainvälinen jääkiekkoliitto: Tuominen Markku, LT, EL
Kilpa- ja huippu-urheilun tutkimuskeskus (KIHU): Ihalainen Simo, LitT, asiantuntija; Vänttinen Tomi, LitT, johtava asiantuntija
University of Calgary: Pasanen Kati, PhD, PT, MSc, assistant prof.
Canadian Sport Institute Calgary: Jordan Matt, PhD, sport science director

Toimitetut asiakirjat: Lausuntohakemus tutkimuseettiselle toimikunnalle (3.6.19), Saatekirje korjauksista (3.6.19), Tutkimussuunnitelma, versio 5.0 (3.6.19), Tutkimussuunnitelman tiivistelmä, versio 5.0 (3.6.19), TVH:n lausunto tutkimuksen eettisyydestä 3, versio 5.0.(3.6.19), Tiedote tutkittavalle osatutkimuksesta 1, versio 5.0 (3.6.19), Tiedote tutkittavalle osatutkimuksesta 2, versio 5.0 (3.6.19), Tiedote tutkittavalle osatutkimuksesta 3, versio 5.0 (3.6.19), Suostumus osatutkimukseen 1, versio 5.0 (3.6.19), Suostumus osatutkimukseen 2, versio 5.0 (3.6.19), Suostumus osatutkimukseen 3, versio 5.0 (3.6.19), Tietosuojaseloste, versio 5.0 (3.6.19), Tietoturvariskien itsearviointi tutkimuksessa, versio 5.0 (3.6.19), Tietojenkäsittelysopimus (DPA), versio 5.0 (3.6.19), Liite 1 – Henkilötietojen käsittelyn yksityiskohdat, versio 5.0 (3.6.19), Liite 2 – Tekniset ja organisatoriset toimenpiteet, versio 5.0 (3.6.19), Salassapito- ja tietoturvasitoumus, versio 5.0 (3.6.19), Sopimus tutkimusaineistojen käytöstä, versio 5.0 (3.6.19)

Keski-Suomen sairaanhoitopiirin tutkimuseettisen toimikunnan lausunto

Toimikunta katsoi tutkimussuunnitelman täyttävän lääketieteellisestä tutkimuksesta annetun lain (488/1999 muutoksineen) edellytykset ja päätti antaa siitä suunnitelman mukaan toteutettuna puoltavan lausunnon.

Lausunnosta lisätietoja antaa tutkimuseettisen toimikunnan sihteeri Päivi Lampinen (paivi.lampinen@ksshp.fi, puh. 014 269 5134).

Päivi Lampinen

Päivi Lampinen, tutkimuseettisen toimikunnan sihteeri

Jakelu Kyröläinen Heikki

Keskussairaalantie 19 | 40620 Jyväskylä | Puh. (014) 269 1811 | www.ksshp.fi

APPENDIX 2. An approval form of the study.

SUOSTUMUS TUTKIMUKSEEN 20.08.2019

KUORMITTUMINEN JÄÄKIEKOSSA (HOCKEY LOAD) -TUTKIMUS
Liikuntabiologia, Liikuntatieteellinen tiedekunta, Jyväskylän yliopisto

Minua ______________________________ *(kirjoita nimesi)* on pyydetty osallistumaan yllämainittuun tieteelliseen tutkimukseen, jonka tarkoituksena on selvittää fyysisten ominaisuuksien, pelikauden aikaisen kuormittumisen ja terveysprofiilin välisiä yhteyksiä jääkiekkoilijoilla. Olen lukenut ja ymmärtänyt saamani kirjallisen tutkimustiedotteen. Tiedotteesta olen saanut riittävän selvityksen tutkimuksesta ja sen yhteydessä suoritettavasta tietojen keräämisestä, käsittelystä ja luovuttamisesta. Tiedotteen sisältö on kerrottu minulle myös suullisesti, minulla on ollut mahdollisuus esittää kysymyksiä ja olen saanut riittävän vastauksen kaikkiin tutkimusta koskeviin kysymyksiini. Tiedot antoi ______________________________ ___/___2019. Minulla on ollut riittävästi aikaa harkita osallistumistani tutkimukseen. Olen saanut riittävät tiedot oikeuksistani, tutkimuksen tarkoituksesta ja sen toteutuksesta sekä tutkimuksen hyödyistä ja riskeistä. Minua ei ole painostettu eikä houkuteltu osallistumaan tutkimukseen.

Ymmärrän, että osallistumiseni on vapaaehtoista. Olen selvillä siitä, että voin peruuttaa tämän suostumukseni tai keskeyttää tutkimuksen milloin tahansa syytä ilmoittamatta eikä peruutukseni vaikuta kohteluuni millään tavalla.

Tiedän, että minusta kerättyä tietoa ja tutkimustuloksia käsitellään luottamuksellisesti tietosuojalainsäädännön edellyttämällä tavalla eikä tietojani luovuteta sivullisille. Olen selvillä, että minusta kerätään tietoa useiden eri toimijoiden kautta tutkimustiedotteen, tietosuojaselosteen ja tämän suostumuslomakkeen mukaisesti siten, että kaikki tutkimukseen liittyvän tiedon keräämiseen osallistuvat toimijat sitoutuvat ehdottomaan vaitiolovelvollisuuteen ja luottamukselliseen tietojen käsittelyyn. Olen tietoinen siitä, että ko. toimijat hallitsevat ja käsittelevät minusta kerättyä yksilöityä tietoa ainoastaan heidän järjestelmillään kerätyn tiedon osalta eikä heillä ole pääsyä muiden toimijoiden keräämään tietoon. Olen selvillä, että tiedon yhdistämiseen liittyen eri toimijat siirtävät minusta kerätyn pseudonymisoidun eli koodatun tiedon suojatun yhteyden kautta Varalan urheiluopiston hallinnoimaan Microsoft Office 365 for Business -pilvipalveluun (One Drive for Business), jossa ainoastaan päätutkijalla on mahdollisuus käsitellä eri toimijoiden siirtämää tietoa. Olen tietoinen, että kaikille yksittäisille tutkittaville annetaan tiedon yhdistämisvaiheessa tutkimuskoodi, joten tiedon yhdistämisen jälkeen tapahtuva tiedon jatkokäsittely tapahtuu ryhmätasolla koodattuna eikä yksittäinen henkilö ole tunnistettavissa ilman koodiavainta, joka on ainoastaan päätutkijan hallussa. Tiedän, että lopulliset tutkimustulokset raportoidaan ryhmätasolla eikä yksittäisten tutkittavien tunnistaminen ole mahdollista.

Tiedän, että terveydentilaani ja tutkimuksen kannalta muita tarpeellisia tietojani voidaan kerätä myös muista terveydenhuollon toimintayksiköistä ja terveystietoja sisältävistä henkilörekistereistä (joukkueen terveydenhuollosta vastaavan henkilön [lääkäri, fysioterapeutti tai muu nimetty henkilö] täyttämä ja Medisport Oy:n ylläpitämä SM-liigan sähköinen Medhockey-vammarekisteri sekä tutkittavan itsearviointina täyttämä Tampereen Urheilulääkäriaseman ja UKK Instituutin ylläpitämä terveysseurannan rekisteri). Tutkimuksen päätutkija voi tällöin hankkia tarvitsemansa tiedot tutkittavalle annetun ID-numeron perusteella. Kaikissa tapauksissa tietoja käsitellään luottamuksellisesti.

Lisäksi olen tietoinen siitä, että mikäli keskeytän tutkimuksen tai peruutan suostumuksen, minusta keskeyttämiseen ja suostumuksen peruuttamiseen mennessä kerättyjä tietoja ja näytteitä voidaan käyttää osana tutkimusaineistoa lainsäädännön sallimissa tilanteissa.

Allekirjoituksellani vahvistan osallistumiseni ja suostun vapaaehtoisesti tutkimushenkilöksi.

	Tutkittava täyttää Kyllä	Ei
Allekirjoittamalla suostumuslomakkeen hyväksyn tietojeni käytön tiedotteessa kuvattuun tutkimukseen.	☐	☐
Suostun siihen, että tutkimuksessa käsitellään erityisiin henkilötietoryhmiin kuuluvia tietoja (terveyttä koskevat tiedot / ne tiedot, jotka tähän kuuluvat).	☐	☐
Annan suostumukseni minusta kerätyn tunnisteellisen tutkimusaineiston arkistointiin 10 vuodeksi.	☐	☐
Annan suostumukseni siihen, että minusta mobiilisovelluksen kautta kerättyä tunnisteellista kuormitus- ja terveysseurannan tietoa saa luovuttaa oman joukkueeni nimeämälle fysiikkavalmentajalle ja terveydenhuollon ammattihenkilölle/-henkilöille tiedon hyödyntämiseksi osana normaalia päivittäisharjoittelua ja mahdollista hoitoon ohjausta varten.	☐	☐
Minusta tähän tutkimukseen otettuja tunnisteellisia kuvia ja videotallenteita saa hyödyntää tutkimuksen esittelyn yhteydessä.	☐	☐
Minuun saa ottaa yhteyttä suostumuksen kysymiseksi tunnisteellisen tutkimusaineiston käyttöön tai luovutukselle muuhun kuin tässä tutkimuksessa kuvattuun tieteelliseen tai ei-tieteelliseen tarkoitukseen (esim. kaupallista hyödyntämistä varten).	☐	☐
Minuun saa ottaa yhteyttä suostumuksen kysymiseksi tunnisteellisen tutkimusaineiston käyttöön tai luovutukselle uusia tutkimusprojekteja varten.	☐	☐

Tutkittavan nimi

Tutkittavan syntymäaika

Tutkittavan osoite

Tutkittavan puhelinnumero

Tutkittavan sähköpostiosoite

Päivämäärä

Tutkittavan allekirjoitus

Suostumus vastaanotettu

Tutkijan nimi

Päivämäärä

Allekirjoitus (suostumuksen vastaanottaja)

Alkuperäinen allekirjoitettu tutkittavan suostumus sekä kopio tutkimustiedotteesta jäävät tutkijan arkistoon. Tutkimustiedote ja kopio allekirjoitetusta suostumuksesta annetaan tutkittavalle.

APPENDIX 3 A table of fat percentages (Durnin and Rahaman 1967).

Rasvaprosentti miesurheilijoilla. Neljän ihopoimun summaa vastaava rasvaprosentti miesurheilijoille (yli 16 v.).

Taulukko on yleisestikäytössä testausasemilla. *(Durnin & Rahaman, 1967)*

mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
10,0	2,0	20,0	9,0	30,0	13,5	40,0	17,0	50,0	20,0	75,0	25,0
2	2,1	2	9,1	2	13,6	2	17,1	5	20,1	5	25,1
4	2,3	4	9,2	4	13,7	4	17,1	51,0	20,2	76,0	25,2
6	2,4	6	9,3	6	13,7	6	17,2	5	20,3	5	25,3
8	2,6	8	9,4	8	13,8	8	17,2	52,0	20,4	77,0	25,4
11,0	2,7	21,0	9,5	31,0	13,9	41,0	17,3	5	20,5	5	25,5
2	2,8	2	9,6	2	14,0	2	17,4	53,0	20,6	78,0	25,6
4	3,0	4	9,7	4	14,1	4	17,4	5	20,7	5	25,7
6	3,1	6	9,8	6	14,1	6	17,5	54,0	20,8	79,0	25,8
8	3,3	8	9,9	8	14,2	8	17,5	5	20,9	5	25,9
12,0	3,4	22,0	10,0	32,0	14,3	42,0	17,6	55,0	21,0	80,0	26,0
2	3,5	2	10,1	2	14,4	2	17,7	5	21,1	5	26,1
4	3,7	4	10,2	4	14,5	4	17,7	56,0	21,2	81,0	26,2
6	3,8	6	10,3	6	14,5	6	17,8	5	21,3	5	26,3
8	4,0	8	10,4	8	14,6	8	17,8	57,0	21,4	82,0	26,4
13,0	4,1	23,0	10,5	33,0	14,7	43,0	17,9	5	21,5	5	26,5
2	4,2	2	10,6	2	14,8	2	18,0	58,0	21,6	83,0	26,6
4	4,4	4	10,7	4	14,9	4	18,0	5	21,7	5	26,7
6	4,5	6	10,8	6	14,9	6	18,1	59,0	21,8	84,0	26,8
8	4,7	8	10,9	8	15,0	8	18,1	5	21,9	5	26,9
14,0	4,8	24,0	11,0	34,0	15,1	44,0	18,2	60,0	22,0	85,0	27,0
2	4,9	2	11,1	2	15,2	2	18,3	5	22,1	5	27,1
4	5,1	4	11,2	4	15,3	4	18,3	61,0	22,2	86,0	27,2
6	5,2	6	11,3	6	15,3	6	18,4	5	22,3	5	27,3
8	5,4	8	11,4	8	15,4	8	18,4	62,0	22,4	87,0	27,4
15,0	5,5	25,0	11,5	35,0	15,5	45,0	18,5	5	22,5	5	27,5
2	5,6	2	11,6	2	15,6	2	18,6	63,0	22,6	88,0	27,6
4	5,8	4	11,7	4	15,6	4	18,6	5	22,7	5	27,7
6	5,9	6	11,7	6	15,7	6	18,7	64,0	22,8	89,0	27,8
8	6,1	8	11,8	8	15,7	8	18,7	5	22,9	5	27,9
16,0	6,2	26,0	11,9	36,0	15,8	46,0	18,8	65,0	23,0	90,0	28,0
2	6,3	2	12,0	2	15,9	2	18,9	5	23,1	5	28,1
4	6,5	4	12,1	4	15,9	4	18,9	66,0	23,2	91,0	28,2
6	6,6	6	12,1	6	16,0	6	19,0	5	23,3	5	28,3
8	6,8	8	12,2	8	16,0	8	19,0	67,0	23,4	92,0	28,4
17,0	6,9	27,0	12,3	37,0	16,1	47,0	19,1	5	23,5	5	28,5
2	7,0	2	12,4	2	16,2	2	19,2	68,0	23,6	93,0	28,6
4	7,2	4	12,5	4	16,2	4	19,2	5	23,7	5	28,7
6	7,3	6	12,5	6	16,3	6	19,3	69,0	23,8	94,0	28,8
8	7,5	8	12,6	8	16,3	8	19,3	5	23,9	5	28,9
18,0	7,6	28,0	12,7	38,0	16,4	48,0	19,4	70,0	24,0	95,0	29,0
2	7,7	2	12,8	2	16,5	2	19,5	5	24,1	5	29,1
4	7,9	4	12,9	4	16,5	4	19,5	71,0	24,2	96,0	29,2
6	8,0	6	12,9	6	16,6	6	19,6	5	24,3	5	29,3
8	8,2	8	13,0	8	16,6	8	19,6	72,0	24,4	97,0	29,4
19,0	8,3	29,0	13,1	39,0	16,7	49,0	19,7	5	24,5	5	29,5
2	8,4	2	13,2	2	16,8	2	19,8	73,0	24,6	98,0	29,6
4	8,6	4	13,3	4	16,8	4	19,8	5	24,7	5	29,7
6	8,7	6	13,3	6	16,9	6	19,9	74,0	24,8	99,0	29,8
8	8,9	8	13,4	8	16,9	8	19,9	5	24,9	5	29,9
20,0	9,0	30,0	13,5	40,0	17,0	50,0	20,0	75,0	25,0	100,0	30,0