applied sciences

MDPI

Article

Reference Data by Player Position for an Ice Hockey-Specific Complex Test

Stephan Schulze [1,*], Kevin G. Laudner [2], Karl-Stefan Delank [1], Richard Brill [3] and René Schwesig [1]

[1] Department of Orthopaedic and Trauma Surgery, Martin-Luther-University Halle-Wittenberg, Ernst-Grube-Str. 40, 06120 Halle, Germany; stefan.delank@uk-halle.de (K.-S.D.); rene.schwesig@uk-halle.de (R.S.)
[2] Department of Health Sciences, University of Colorado, Colorado Springs, CO 80918, USA; klaudner@uccs.edu
[3] University Clinic and Policlinic of Radiology, Martin-Luther-University Halle-Wittenberg, Ernst-Grube-Str. 40, 06120 Halle, Germany; richard.brill@uk-halle.de
* Correspondence: stephan.schulze@uk-halle.de; Tel.: +49-345-557-4897; Fax: +49-345-557-4899

Featured Application: Ice hockey is one of the fastest and most complex team sports in the world. However, the complexity of ice hockey is not adequately reflected in the performance diagnostic and the relationship between off-ice and on-ice performance is unclear. Consequently, the internal validity and the ability to predict on-ice performance for the majority of nonspecific off-ice tests is insufficient. The presented ice hockey-specific complex test (IHCT) is a reliable and valid assessment and helps to close this gap between performance diagnostic and match performance. Additionally, this investigation provides position-specific reference data for a fast and valid interpretation of the results in ice hockey practice.

Abstract: The aim of this study was to investigate position-specific (forwards, defenders) reference data for a scientifically evaluated (validity, reliability) ice hockey-specific complex test (IHCT). One hundred and four 3rd league professional ice hockey field players (mean ± standard deviations (SD); age: 26.4 ± 5.62 years) volunteered for the investigation. Players were categorized as forwards (n = 64) and defenders (n = 40). Data from the IHCT were collected over six seasons from three 3rd league teams. The IHCT included parameters for load (e.g., 10 m and 30 m skate times, transition and weave agility times with and without a puck, slap and wrist shots on goal) and stress (e.g., lactate, heart rate). The only significant ($p < 0.002$) difference between forwards and defenders for performance were found for weave agility with puck ($p < 0.001$). Forwards showed a higher average performance in this parameter than defenders. Differences were also found in weave agility without a puck ($p = 0.008$), 30 m backward sprinting without puck ($p = 0.012$) and goals after test ($p = 0.030$). This study provides position-specific reference data for a valid and reliable ice hockey-specific complex test for the 3rd league. These results may be used by coaches to judge player performance based on position (forwards vs. defenders). Moreover, coaches may use these data to evaluate the effectiveness of the most recent training period. Further research should extend this database to 1st and 2nd league players in order to enhance the scope of the test.

Keywords: on-ice performance; performance diagnostic; team sports; complexity; intermittent exercise

Citation: Schulze, S.; Laudner, K.G.; Delank, K.-S.; Brill, R.; Schwesig, R. Reference Data by Player Position for an Ice Hockey-Specific Complex Test. *Appl. Sci.* **2021**, *11*, 280. https://doi.org/10.3390/app11010280

Received: 4 November 2020
Accepted: 28 December 2020
Published: 30 December 2020

1. Introduction

Ice hockey is one of the fastest team sports in the world in relation to the player's speed on the ice, characterized by numerous high-intensity skating intervals and changes of direction (COD) combined with a multitude of body impacts while executing offensive or defensive actions. Considering this, the complexity of ice hockey is not adequately reflected in the literature, as there are various studies, focusing on isolated measurement of players' performance parameters [1–3]. With regard to the relationship between off-ice and on-ice performance, research has shown that the two are not uniform [4]. Some authors report that the use of laboratory off-ice tests does not correlate with on-ice performance [3,5–8] since important game-relevant motion sequences (e.g., skating, COD, puck handling, passing, shots on goal) can only be tested on-ice [1]. Consequently, the internal validity and the ability to predict on-ice performance for most nonspecific off-ice tests are insufficient [3,4,9–11]. To our knowledge, only a few studies have reported testing parameters in regards to match performance [9,10,12–16]. For example, Green et al. [14] explored the relationship between off-ice performance (e.g., standing long jump and Wingate) and body composition characteristics to on-ice match performance (e.g., time on-ice, scoring chances, skating performance). Legerlotz et al. [9] investigated a repetitive on-ice sprint shuttle test (RISS) and off-ice. The authors were able to show that although the off-ice test is measuring the same construct, the explained variance regarding on-ice performance was at most 51% of the on-ice test [9]. To date, there are no studies that have used a comparable on-ice complex test design, which may be critical for determining ice-hockey performance.

The intermittent characteristics of a hockey match, including typical movement patterns and playing durations, required during a game, were previously considered in order to create an ice hockey-specific complex test (IHCT) [10,17]. The validity of the IHCT revealed high determination coefficients with regards to match performance for changes of direction (transition agility test, weave agility test) and shooting a puck under fatigue (wrist shot). High interrelations (e.g., recovery heart rate (relative), recovery minute 0 to recovery minute 10: $r^2 = 0.153$) were also observed for post-exercise stress parameters, (e.g., blood lactate, heart rate), which can pertain to the players ability to recover [10]. Post-test measurements of heart rate and lactate (minute 6 and 10) provided explained variances to the match performance from 15 to 21% [10]. Reliability analysis displayed a high intrarater reliability (intraclass correlation coefficients (ICC) > 0.75) for 82% (18/22) of the measured loading parameters [17]. For the load parameters, the SEM ranged from 0.06 (10 m sprint without a puck) to 6.5 (slap shot 1 after test) and the corresponding values for the stress parameters ranged from 0.74 (resting lactate) to 8.7 (heart rate recovery minute 6) [17].

From a practical point of view (coaches, players), it is important to provide position-specific reference data. These data allow for a valid interpretation and the derivation of specific and individual training recommendations. Until now, a reliable, valid, and reference data-based ice hockey-specific complex test has not been available and therefore highly warranted by coaches and sports scientists.

The purpose of the present study was to analyze longitudinally collected reference data for this valid and reliable test by player position. We only considered field players (goalies were excluded) and differentiated between forwards and defenders. We hypothesized that forwards would be faster than defenders and show a higher performance level concerning skating skills. Furthermore, we hypothesized that defenders would have a faster shot velocity, especially with slap shots, and a higher performance in backward skating according to the position-specific demands. For example, defenders often have to take shots from the blue line when slap shot velocity is more important than for forwards (markedly shorter distance to the goal). On defense, typically, only defenders have to skate backward in the direction of their own goal. In this context, Montgomery et al. [18] reported a markedly higher percentage of time in backward skating for defenders (19%) than for forwards (5–6%).

2. Materials and Methods

2.1. Subjects

A total of 322 data sets were available for evaluation. Between players, the number of data sets differed from one to ten. In line with Schwesig et al. [19] and to avoid correlated observations, the median from different tests from the same player for every parameter was calculated. After this calculation, 104 professional (forwards: n = 64; defenders: n = 40) male ice hockey players (mean ± standard deviations (SD); age: 26.4 ± 5.62 years, height:

1.82 ± 0.06 m, body mass: 86.9 ± 8.70 kg, body fat: 16.2 ± 4.50% (BC 545 digital scale, Tanita, Tokyo, Japan)) were included in the statistical analysis.

All athletes (exclusion criteria: symptoms of illness or injury) were informed that they could withdraw from the project at any time without penalty. The experimental procedures and potential risks and benefits of the project were fully explained, and all subjects provided written informed consent prior to entering the study. One player was younger (17.2 years) than 18 years (age range: 17.2–42.1 years), so parental/guardian consent was obtained.

The study was approved by the local Ethics Committee of the Martin-Luther-University Halle-Wittenberg (Reference Number: 2013-13), conformed to the Declaration of Helsinki [20].

2.2. Study Design and Methodology

This cross-sectional study utilized data from the IHCT over six seasons (2015–2020) in the 3rd German ice hockey league (three teams). Only male field players (forwards and defenders) were included in the investigation. Before testing, all participants were carefully familiarized with the testing protocol of the IHCT (sketch, instructional video, demonstration on ice; Figure 1).

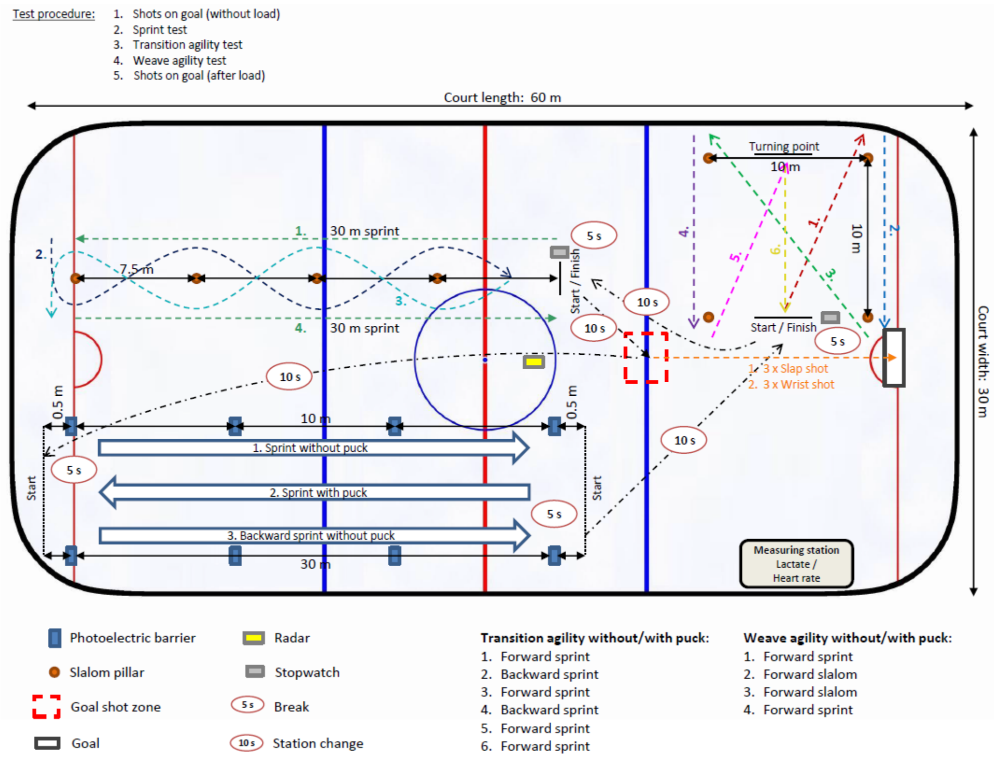

Figure 1. Schematic diagram of the ice hockey-specific complex test (IHCT) and description of the test sequences [10].

All players were assessed on the same day, and the tests were performed in the same order. The order of the different tasks had no influence on the intrarater reliability of the tasks and parameters. Schwesig et al. [17] found no differences for the last skating tasks (weave agility without and with the puck). Only the 10 m backward sprint without a puck displayed a markedly reduced reliability (ICC = 0.54, coefficient of variation (CV) = 9.2%). Reliability was slightly reduced for three parameters (10 m sprint with puck, slap shot 3 before test, slap shot 1 after test) (ICC: 0.60–0.73; CV: 5.0–8.3%) [17].

The preparation of the test (nutrition, warm-up, instructions) was standardized and has already been published [10,17].

The purpose of the IHCT (Figure 1) is to imitate essential match related ice hockey-specific demands and skills in a sequence of different on-ice tests using a complex test design [10]. The IHCT comprises the following five actions:

- shots on goal at the start of the test,
- a sprint test (without/with puck, forward/backward),
- transition agility test,
- weave agility test,
- shots on goal at the end of the test.

A detailed description regarding action sequences (e.g., explanation of the test selection, load, and recovery time) and parameters (e.g., measurement systems, reliability) has been previously published in Schwesig et al. [10,17].

To ensure strong interrater reliability, the same investigators (R.S.; S.S.) performed all the test measurements.

Heart rate was measured using a real-time monitoring system (Polar Team Pro System; Polar Electro GmbH, Büttelborn, Germany). Lactate concentrations were determined by an enzymatic analyzer (Super GL compact; Dr. Müller Gerätebau GmbH, Freital, Germany). Capillary blood samples were taken from the athlete's ear lobe before warm-up, and at 2, 6, and 10 min after finishing the test.

2.3. Statistics

Before the descriptive and inference statistical analyses were conducted, all data were checked for multiple player entries to avoid correlated observations. If there were more than one data set per player, the mean (even number of tests) or the median (odd number of tests) of the existing tests was calculated and used for statistical analysis. Results were analyzed for the total group and for field playing positions (forward and defender). Descriptive statistics (mean, standard deviation, percentile 10, 25, 50 (median), 75, 90) were ascertained for all test variables.

Before inference statistical analyses, all variables were tested for normal distribution (Shapiro–Wilk test) and assumption of variance homogeneity (Levene test for equality of variances). Mean differences between positions (forward vs. defender) were tested using a one-factorial univariate general linear model.

To estimate practical relevance and to quantify the performance differences between playing positions, effect sizes (partial eta squared, η_p^2; [21]; d; [22]) were calculated for the ANOVA main effects (η_p^2) and the mean differences divided by the pooled standard deviations (SD).

To evaluate effect sizes, d or η_p^2 were classified with $d \geq 0.2$, $d \geq 0.5$, $d \geq 0.8$, or $\eta_p^2 \geq 0.01$, $\eta_p^2 \geq 0.06$, $\eta_p^2 \geq 0.14$ indicating small, medium or large effects, respectively [23].

The level of significance was set at $p \leq 0.002$ ($p < 0.05/33$) after Bonferroni correction or for $\eta_p^2 \geq 0.10$ as an indicator of clinical relevance [21]. While the p-value determines the statistical significance, partial eta squared (η_p^2) as an effect size allows for the evaluation of the practical relevance.

All statistical analyses were performed using SPSS version 25.0 for Windows (IBM, Armonk, NY, USA).

3. Results

3.1. Normal Distribution and Variance Homogeneity

The parameters 10 m sprint without puck ($p = 0.014$), 10 m sprint with puck ($p = 0.018$), 10 m backward sprint without puck ($p < 0.001$), transition without puck ($p = 0.012$), transition with puck ($p < 0.001$), goals before test ($p < 0.001$), goals after test ($p < 0.001$), and lactate degradation rate per minute ($p = 0.011$) did not have a normal distribution.

Regarding variance homogeneity (Levene test for equality of variances), the p-values for the variable's goals after test ($p = 0.036$) and lactate recovery minute 2 ($p = 0.047$) were lower than 0.05. For all other parameters, p-values were higher than 0.080 (10 m backward sprint without puck), indicating that the variances of all variables in the different samples (playing positions) were significantly different.

3.2. Anthropometric Data

The descriptive statistical analysis (Table 1) did not display a significant difference between defenders and forwards. Defenders showed a higher average body mass (88.0 ± 8.65 kg) compared to forwards (86.2 ± 8.70 kg) (Table 1). The largest difference between defenders and forwards was found for height (p = 0.006, η_p^2 = 0.071).

Table 1. Demographic and anthropometric characteristics of ice hockey players (n = 104; body fat: n = 83) in relation to playing positions (Mean ± Standard Deviation).

	Defenders	Forwards	Total
Age [years]	26.1 ± 5.85	26.6 ± 5.51	26.4 ± 5.62
Height [m]	1.84 ± 0.06	1.81 ± 0.06	1.82 ± 0.06
Body mass [kg]	88.0 ± 8.65	86.2 ± 8.72	86.9 ± 8.70
Body fat [%]	17.2 ± 4.01	15.6 ± 4.72	16.2 ± 4.50
Resting heart rate [min^{-1}]	65 ± 8.38	65 ± 8.34	65 ± 8.31
Resting lactate [mmol/L]	1.04 ± 0.27	1.07 ± 0.30	1.06 ± 0.29

Resting lactate averaged between 1.04 mmol/L (defenders) and 1.07 mmol/L (forwards). Identical mean values were found for both positions for resting heart rate (65 min^{-1}).

3.3. Performance Data

The speed skating data (Table 2) revealed that forwards have a slightly higher (but not significant) performance level compared to defenders in four of the six parameters. According to the position-specific requirement profile for backward sprinting, defenders showed a higher performance level than forwards.

The agility performance tests (Table 3) showed the largest difference between both positions for weave agility without puck (p = 0.008; η_p^2 = 0.067; d = 0.59) and with puck (p < 0.001; η_p^2 = 0.122; d = 0.76). For the transition parameters, forwards and defenders moved on almost the same agility level.

Shot performance data (Tables 4 and 5) displayed slight advantages for the defenders. The largest difference (d = 0.47) between positions was calculated for the shot accuracy after testing (defenders: 4.70 ± 0.81 vs. forwards: 4.25 ± 1.12, Table 5).

There were no significant between-group differences for either lactate levels and heart rate (Tables 6 and 7). The effect sizes (d) ranged from 0 (lactate degradation rate, heart rate recovery minute 0) to 0.30 (heart rate recovery minute 10).

Table 2. Percentile data of linear forward sprint performance by playing position. Based on the 50th percentile, performance maxima marked in bold.

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
10 m sprint without puck [s]	P10	1.76	1.75	1.76
	P25	1.86	1.81	1.81
	P50	1.96	**1.88**	1.91
	P75	2.01	1.95	1.98
	P90	2.05	2.03	2.03
30 m sprint without puck [s]	P10	4.24	4.21	4.24
	P25	4.32	4.32	4.32
	P50	4.51	**4.43**	4.46
	P75	4.61	4.57	4.59
	P90	4.71	4.64	4.68

Table 2. *Cont.*

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
10 m sprint with puck [s]	P10	1.73	1.75	1.74
	P25	1.81	1.79	1.79
	P50	1.95	**1.90**	1.92
	P75	2.02	2.00	2.00
	P90	2.08	2.07	2.07
30 m sprint with puck [s]	P10	4.35	4.33	4.34
	P25	4.48	4.41	4.44
	P50	4.62	**4.56**	4.59
	P75	4.73	4.69	4.71
	P90	4.83	4.79	4.80
10 m backward sprint without puck [s]	P10	2.19	2.21	2.21
	P25	2.25	2.28	2.26
	P50	**2.31**	2.38	2.35
	P75	2.42	2.48	2.46
	P90	2.53	2.60	2.57
30 m backward sprint without puck [s]	P10	5.16	5.20	5.18
	P25	5.26	5.38	5.32
	P50	**5.38**	5.54	5.49
	P75	5.56	5.78	5.72
	P90	5.80	5.99	5.90

P = percentile.

Table 3. Percentile data of agility performance by playing position. Based on the 50th percentile, performance maxima marked in bold.

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Transition without puck [s]	P10	16.4	16.1	16.3
	P25	16.8	16.6	16.7
	P50	17.2	**17.1**	17.2
	P75	17.8	17.7	17.7
	P90	18.3	18.2	18.2
Transition with puck [s]	P10	17.5	17.7	17.7
	P25	18.3	18.1	18.1
	P50	**18.5**	18.6	18.6
	P75	19.4	19.1	19.2
	P90	19.9	19.6	19.9
Weave without puck [s]	P10	21.8	21.2	21.5
	P25	22.4	21.7	22.0
	P50	22.8	**22.5**	22.6
	P75	23.6	23.0	23.1
	P90	24.1	23.5	23.9
Weave with puck [s]	P10	22.7	22.0	22.2
	P25	23.2	22.6	22.8
	P50	23.7	**23.1**	23.3
	P75	24.3	23.5	23.9
	P90	24.7	24.3	24.6

Table 4. Percentile data of shot performance before the test by playing position. Based on the 50th percentile, performance maxima marked in bold.

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Slap shot 1 [km·h^{-1}]	P10	111	110	111
	P25	119	119	119
	P50	**126**	**126**	126
	P75	135	132	132
	P90	140	137	138
Slap shot 2 [km·h^{-1}]	P10	112	115	114
	P25	121	120	121
	P50	**127**	126	126
	P75	136	133	135
	P90	141	138	139
Slap shot 3 [km·h^{-1}]	P10	118	114	115
	P25	121	120	121
	P50	**128**	126	127
	P75	136	136	136
	P90	143	139	139
Wrist shot 1 [km·h^{-1}]	P10	96	94	96
	P25	100	99	99
	P50	**106**	**106**	106
	P75	109	110	109
	P90	116	113	114
Wrist shot 2 [km·h^{-1}]	P10	96	96	96
	P25	99	99	99
	P50	104	**105**	104
	P75	111	110	110
	P90	117	113	113
Wrist shot 3 [km·h^{-1}]	P10	97	94	96
	P25	100	100	100
	P50	**105**	**105**	105
	P75	111	110	110
	P90	114	114	114
goals	P10	3	3	3
	P25	4	4	4
	P50	**4**	**4**	4
	P75	5	5	5
	P90	6	6	6

Table 5. Percentile data of shot performance after test by playing position. Based on the 50th percentile, performance maxima marked in bold.

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Slap shot 1 [km·h^{-1}]	P10	106	102	105
	P25	111	108	110
	P50	**118**	117	117
	P75	123	122	122
	P90	131	130	130
Slap shot 2 [km·h^{-1}]	P10	109	102	105
	P25	114	110	112
	P50	**119**	118	118
	P75	126	125	125
	P90	132	131	131

Table 5. *Cont.*

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Slap shot 3 [km·h^{-1}]	P10	108	103	106
	P25	113	111	112
	P50	**120**	118	119
	P75	125	126	125
	P90	132	132	132
Wrist shot 1 [km·h^{-1}]	P10	86	87	86
	P25	91	92	92
	P50	**98**	**98**	98
	P75	103	101	103
	P90	107	106	107
Wrist shot 2 [km·h^{-1}]	P10	86	86	86
	P25	90	93	92
	P50	**99**	98	98
	P75	104	102	102
	P90	108	106	106
Wrist shot 3 [km·h^{-1}]	P10	87	87	88
	P25	92	92	92
	P50	**100**	97	99
	P75	105	103	103
	P90	109	107	108
goals	P10	4	3	3
	P25	4	4	4
	P50	**5**	4	5
	P75	5	5	5
	P90	6	6	6

Table 6. Percentile data of stress parameters (lactate, heart rate) by playing position. Based on the 50th percentile, maxima marked in bold.

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Lactate recovery minute 2 [mmol·L^{-1}]	P10	9.21	9.88	9.43
	P25	10.6	10.8	10.8
	P50	12.2	**12.3**	12.3
	P75	14.4	13.6	13.8
	P90	15.7	14.5	15.1
Lactate recovery minute 6 [mmol·L^{-1}]	P10	11.2	11.1	11.3
	P25	11.9	12.7	12.4
	P50	**15.0**	13.9	14.1
	P75	16.4	15.6	15.8
	P90	18.3	17.8	18.0
Lactate recovery minute 10 [mmol·L^{-1}]	P10	10.0	10.1	10.1
	P25	10.9	11.7	11.5
	P50	**13.5**	13.2	13.3
	P75	16.0	15.4	15.7
	P90	18.4	17.9	17.9
Heart rate recovery minute 0 [b·min^{-1}]	P10	168	170	170
	P25	175	175	175
	P50	**181**	180	180
	P75	186	185	186
	P90	192	192	192

Table 6. *Cont.*

		Defenders (n = 40)	Forwards (n = 64)	Total (n = 104)
Heart rate recovery minute 2 [b·min^{-1}]	P10	120	118	119
	P25	130	128	129
	P50	138	**139**	139
	P75	149	148	148
	P90	159	153	155
Heart rate recovery minute 6 [b·min^{-1}]	P10	96	93	96
	P25	105	102	102
	P50	**110**	107	109
	P75	116	114	115
	P90	124	118	121
Heart rate recovery minute 10 [b·min^{-1}]	P10	96	91	93
	P25	97	97	97
	P50	**107**	105	106
	P75	112	111	112
	P90	117	117	117
Lactate degradation rate per minute, recovery minute 6 to recovery minute 10 [mmol·L^{-1}/min]	P10	−0.20	−0.09	−0.13
	P25	0.01	0.05	0.04
	P50	0.20	**0.21**	0.20
	P75	0.36	0.30	0.32
	P90	0.45	0.38	0.41
Recovery heart rate (relative), recovery minute 0 to recovery minute 10 [%]	P10	34	36	36
	P25	38	39	39
	P50	41	**42**	42
	P75	45	45	45
	P90	47	48	48

Table 7. Differences in load and stress parameters (Mean ± standard deviations (SD)) by playing position. Significant differences ($p \leq 0.002$) and (performance) maxima marked in bold.

Parameters	Defenders (n = 40)	Forwards (n = 64)	p	η_p^2	d
Load parameters					
10 m sprint without puck [s]	1.93 ± 0.11	**1.88** ± 0.10	0.040	0.041	0.48
30 m sprint without puck [s]	4.49 ± 0.18	**4.44** ± 0.16	0.119	0.024	0.29
10 m sprint with puck [s]	1.92 ± 0.13	**1.90** ± 0.12	0.371	0.008	0.16
30 m sprint with puck [s]	4.60 ± 0.18	**4.56** ± 0.18	0.206	0.016	0.22
10 m backward sprint without puck [s]	**2.34** ± 0.12	2.40 ± 0.19	0.078	0.030	0.39
30 m backward sprint without puck [s]	**5.43** ± 0.23	5.57 ± 0.30	0.012	0.060	0.53
Transition without puck [s]	17.3 ± 0.72	**17.2** ± 0.92	0.505	0.004	0.12
Transition with puck [s]	18.8 ± 1.03	**18.7** ± 0.97	0.438	0.006	0.01
Weave without puck [s]	22.9 ± 0.83	**22.4** ± 0.86	0.008	0.067	0.59
Weave with puck [s]	23.7 ± 0.69	**23.1** ± 0.88	**<0.001**	**0.122**	0.76
slap shot 1 before test [km·h^{-1}]	**127** ± 10.4	124 ± 10.1	0.273	0.012	0.29
slap shot 2 before test [km·h^{-1}]	**127** ± 10.1	126 ± 9.68	0.464	0.005	0.10
slap shot 3 before test [km·h^{-1}]	**129** ± 9.33	127 ± 10.2	0.490	0.005	0.21
wrist shot 1 before test [km·h^{-1}]	**105** ± 6.67	105 ± 7.07	0.711	0.001	0
wrist shot 2 before test [km·h^{-1}]	105 ± 6.92	**105** ± 6.63	0.680	0.002	0
wrist shot 3 before test [km·h^{-1}]	**105** ± 6.70	105 ± 7.01	0.650	0.002	0
goals before test	4.19 ± 1.01	**4.26** ± 1.08	0.742	0.001	0.06

Table 7. *Cont.*

Parameters	Defenders (n = 40)	Forwards (n = 64)	p	η_p^2	d
slap shot 1 after test [km·h^{-1}]	**118** ± 8.58	116 ± 9.95	0.165	0.019	0.22
slap shot 2 after test [km·h^{-1}]	**119** ± 8.31	117 ± 10.5	0.300	0.011	0.32
slap shot 3 after test [km·h^{-1}]	**119** ± 8.79	118 ± 10.6	0.409	0.007	0.10
wrist shot 1 after test [km·h^{-1}]	97.2 ± 7.82	**97.2** ± 6.81	0.971	0.000	0
wrist shot 2 after test [km·h^{-1}]	**97.6** ± 8.05	97.0 ± 7.08	0.729	0.001	0.08
wrist shot 3 after test [km·h^{-1}]	**98.8** ± 7.84	97.1 ± 8.01	0.304	0.010	0.22
goals after test	**4.70** ± 0.81	4.25 ± 1.12	0.030	0.046	0.47
Stress parameters					
Lactate recovery minute 2 [mmol·L^{-1}]	**12.5** ± 2.51	12.2 ± 2.04	0.474	0.005	0.13
Lactate recovery minute 6 [mmol·L^{-1}]	**14.5** ± 2.72	14.1 ± 2.57	0.447	0.006	0.15
Lactate recovery minute 10 [mmol·L^{-1}]	**13.7** ± 2.97	13.4 ± 2.83	0.610	0.003	0.10
Heart rate recovery minute 0 [b·min^{-1}]	**180** ± 7.75	180 ± 8.63	0.973	0.000	0
Heart rate recovery minute 2 [b·min^{-1}]	**139** ± 12.6	137 ± 12.7	0.586	0.003	0.16
Heart rate recovery minute 6 [b·min^{-1}]	**110** ± 10.5	107 ± 9.64	0.188	0.017	0.30
Heart rate recovery minute 10 [b·min^{-1}]	**106** ± 10.3	104 ± 9.75	0.469	0.005	0.20
Calculated parameters					
Lactate degradation rate per minute, recovery minute 6 to recovery minute 10 [mmol·L^{-1}/min]	0.17 ± 0.23	**0.17** ± 0.19	0.956	0.000	0
Recovery heart rate (relative), recovery minute 0 to recovery minute 10 [%]	41.3 ± 4.95	**42.1** ± 4.34	0.405	0.007	0.17

4. Discussion

This study aimed to provide position-specific reference data for reliable and valid ice hockey-specific complex test (IHCT). The differentiation of the field players as defenders and forwards revealed a significant difference in weave agility with a puck ($p < 0.001$, $\eta_p^2 = 0.122$, d = 0.76) in favor of the forwards. Clear but insignificant (level of significance: $p < 0.002$) differences were also found in weave agility without a puck ($p = 0.008$), 30 m backward sprinting without a puck ($p = 0.012$) and goals after test ($p = 0.030$). For the anthropometric parameters, there was only a weak significant between-group difference ($p = 0.006$, $\eta_p^2 = 0.071$) in height. Again, the forwards (1.81 ± 0.06 m) displayed a lower height compared to defenders (1.84 ± 0.06 m). The findings from this investigation partially confirm the hypothesis that different field positions have different ice hockey-specific performance requirements. More specifically, forwards had the fastest forward skating performance without/with a puck and the highest level of skating skills with direction changes, but the performance levels were not significantly different. As expected, defenders showed small advantages for backward skating and shot velocity, but only with the slap shot. In this respect, these results reflect the differences required by the position.

This discussion must be preceded by the fact that there is no reference data for evaluated (validity and reliability) ice hockey-specific complex tests. Numerous ice hockey-related studies have investigated isolated performance test parameters based on playing position [4,9,11,12,16,24–31]. However, these studies' comparability is limited due to differences in test designs (e.g., sample size, age, gender, performance level, on-ice vs. off-ice tests, match performance vs. test performance).

The need for a complex on-ice diagnostic has been supported by the studies of Leger et al. [32] and Legerlotz et al. [9]. Both investigations showed that the specific technique (skating vs. running) [32] and the specific environment (off-ice vs. on-ice) [9] are critical factors for the functionality of the test results with regards to the prediction of the match performance. Similar to the findings of Schwesig et al. [10], the results of this study support and highlight the importance of ice-hockey-specific testing, ideally using position-specific reference data.

Only Kniffin et al. [15] investigated a comparable sample (n = 120 vs. n = 104) of male ice hockey players. Our sample showed a similar position distribution (62% forwards) to those of Kniffin et al. [15] (66% forwards). Goalkeepers were also excluded from their study. However, the performance was quite different between these studies, potentially because Kniffin et al. [15] only captured off-ice parameters as surrogate parameters for lower- (vertical jump) and upper-body (bench press) power and strength. The aim of the study from Kniffin et al. [15] was to judge the relationship between match performance by using points scored, comparable with Schwesig et al. [10], and the above off-ice parameters.

In contrast, Allisse et al. [5] investigated a much smaller (n = 18) and younger (aged 13–14 years old) population and only included forwards, but with a similar test design regarding the complexity of the performance diagnostic (on-ice and off-ice tests). The on-ice performance also included five skating tests: forward speed skating, backward speed skating, skating agility with a puck, skating agility without a puck, and a skating anaerobic power test. Additionally, and in contrast to the present study, the authors conducted some off-ice tests: push-ups, sit-ups, burpees, and treadmill tests. The authors chose a longitudinal approach (three sessions during the season) and found significant improvements in all skating performance tests during the hockey season.

Nightingale et al. [4] emphasized that traditional and often used tests, such as the Wingate 30-s anaerobic power test, a cycle ergometer VO_{2max} test, push-ups, sit-ups, grip strength, bench press, standing long jump, and vertical jump have only little predictive values. Consequently, and in line with our findings, the authors questioned the validity of these tests. For this reason, we used the IHCT, which, prior to our data collection and analysis, had been proven to be reliable [17] and valid [10]. In this context, Nightingale et al. [4] concluded that more effort and work for coaches and scientists is necessary to develop reliable on-ice repeated sprint and agility testing. In our opinion and according to the recommendations from Nightingale et al. [4], the IHCT is a sufficient option to improve on-ice performance diagnostics.

Roczniok et al. [29] also conducted a complex performance diagnostic using off-ice tests (e.g., Wingate 30-s anaerobic power test, a ramp ergocycle test to establish VO_{2max} and anaerobic threshold) and on-ice tests (30 m sprint forwards, 30 m sprint backwards, 6×9 m stops, 6×9 m turns, endurance test: 6×30 m). Forty-two male ice hockey players from the top division of the Polish ice hockey league were included. The aim was to identify suitable parameters in order to select powerful ice hockey players. The authors detected that the best predictors of success in top-level ice hockey players' scouting were relative peak power (Odds Ratio (OR) = 1.82, 95% CI: 0.98–3.36) and relative VO_{2max} (OR = 2.12, 95% CI: 1.11–4.05).

Lignell et al. [16] examined high-intensity activities in a top class ice hockey match (n = 36) and the effect of training status. Similar to Roczniok et al. [29], physical capacity was assessed off-ice using a submaximal Yo-Yo Intermittent Recovery Ice hockey test (level 1). The authors described performance differences between forwards and defenders for total distance and high-intensity skating per minute. Forwards performed more intense skating and repeatedly higher-intensity exercises than defenders. Therefore, coaches should consider offering a position-specific approach to physical preparation, depending on the different tactical roles [16]. Forwards need repeated and intensive cues, while defenders tend to need a higher level of endurance due to the lower number of defenders typically on a team. This results in shorter changes or recovery times for defenders. These authors also found a reduction of sprint skating speed in periods 1 and 2 compared with period 3 and overtime. Consequently, Lignell et al. [16] concluded that ice hockey players experienced fatigue in the latter half of a match and therefore, the training of elite ice hockey players should emphasize the ability for repeated high-intensity skating. This finding and recommendation highlight the design of the IHCT, which includes seven high-intensity actions (30 m sprint without and with puck, 30 m backward sprint, transition agility without and with puck, weave agility without and with puck) within a 2 to 3 min period.

Delisle-Houde et al. [12] explored the relationships between off-ice tests (e.g., Wingate test, jump performance, beep test), changes in body composition (e.g., body fat, lean tissue mass), and match performance (e.g., time on ice, shift length, power play time). These authors only found medium correlations ($r_{max} = -0.53$) between test performance (long jump) and match performance (shot differential) parameters. They suggested that such data be recorded regularly to monitor the players' performance and directly influence their weekly training plan. We agree, but based on our findings would also suggest integrating on-ice tests (e.g., IHCT) in the performance diagnostic. In our opinion, and in line with Nightingale et al. [4], the sole use of off-ice tests used by Delisle-Houde et al. [12] seems to be insufficient.

The main methodological limitation of the current study was the inclusion of players from only the 3rd league. However, the homogeneity of the large data set (n = 104) is very high and serves as an advantage of this investigation. Consequently, these data can only be interpreted for players from the 3rd league. Further research is needed to expand the database for the 1st and 2nd leagues, as well as players of different skill levels. Then, comparisons could be made between different leagues and different skill levels. The differences between forwards and defenders may only be detectable in lower levels (3rd league or below) and not in higher performance levels (1st and 2nd league). On the other hand, it could be possible that with an increased performance level, the position differences are larger due to the higher degree of specialization. This comparison would also provide insight into the differences (e.g., skating and shooting skills, physical dimensions, body composition aspects) between players of different leagues. These finding would be very valuable for scouting or selection of ice hockey players and the training process.

In preparation for testing, we provided strict instructions to all players regarding nutrition and a suitable lifestyle (e.g., sleep, workout) in order to minimize the influence of such variables and conditions on our results. In practice, it was not possible to verify subject compliance with these requirements. Players resting lactate can be used as a control parameter. These values ranged from 0.50 (minimum) to 2.17 mmol/L (maximum). Further, 50% of the players (interquartile range) varied from 0.87 to 1.03 mmol/L, and 80% of all players (interdecile range) differed between 0.68 and 1.38 mmol/L. Although the structure of the warm-up was provided, individual compliance could not be confirmed.

Another limitation was the difference in ice quality during the IHCT (duration on ice: 2 h). To reduce this influence and enhance inter-individual comparability of the test results, ice preparation was organized after every 10th player was tested.

Moreover, we had to exclude goalkeepers from testing because the position-specific demands are too varied compared to the IHCT requirements. In the future, coaches and scientists should develop a goalkeeper-specific test design.

From a statistical perspective, multiple data preparation should be discussed. We chose to calculate the median if there was more than one data set per player. Alternatively, the best or the worst trial could have been used. However, this could lead to an overestimation or underestimation of performance.

Another limitation was the large difference (n = 24) between the number of subjects by position (forwards: n = 64; defenders n = 40). It is well known that the larger the difference between the two groups, the lower the power of the variance analysis. This could be the reason for the small number of significant differences between positions (Table 7). Conversely, this distribution is conditioned by the structure of a team. Every line consists of two defenders and three forwards. Consequently, this normal ratio is 60% forwards and 40% defenders.

5. Conclusions

For training purposes and considering the results of Schwesig et al. [10], the findings of this study give valuable information for on-ice position-specific workouts. For example, backward sprinting and slap shot velocity were important characteristics for defenders but not as suitable for evaluating forwards. In contrast, forward sprinting, especially with a puck and direction changes, was more important for forwards than for defenders. Based on our own practical experiences, we recommend a combined aerobic endurance training (first step) and subsequent speed endurance training (second step) such as high-intensity intermittent training regimes (third step) for the physical preparation of ice hockey players.

This work provides reference data for a valid [10] and reliable [17] ice hockey-specific complex test in the 3rd league. Based on these data, coaches may validly interpret their own IHCT data. It is possible to judge the players' performance and on-ice training effectiveness across time in this context. Performance diagnostics should include the IHCT as an indicator for ice hockey-specific match performance. Furthermore, the IHCT can be used by coaches and sports scientists to develop enhanced on-ice tests. Data from a broader sample (1st and 2nd league) should be investigated in future research and would significantly expand the test's scope.

Author Contributions: Conceptualization, S.S. and R.S.; methodology, S.S., R.S., and R.B.; formal analysis, K.-S.D., R.S., and K.G.L.; investigation, S.S. and R.S.; resources, R.S.; data curation, R.S.; writing—original draft preparation, S.S., R.S., R.B., and K.G.L.; writing—review and editing, S.S., R.S., K.G.L., and K.-S.D.; visualization, S.S.; supervision, S.S. and R.S.; project administration, S.S., K.-S.D., and R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the local Ethics Committee of the Martin-Luther-University Halle-Wittenberg (Reference Number: 2013-13).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Acknowledgments: The authors would like to thank the ice hockey players of all teams used in this study (Saale Bulls, Blue Devils Weiden, Selber Wölfe), as well as their coaches, for their cooperation and outstanding efforts. We greatly appreciate the support provided by Ken Latta concerning the development of the IHCT, data collection, and lots of advice regarding the nature of ice hockey.

Conflicts of Interest: The authors declare no conflict of interest.

Ethical Standards: All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

1. Bond, C.W.; Bennett, T.W.; Noonan, B.C. Evaluation of skating top speed, acceleration, and multiple repeated sprint speed ice hockey performance tests. *J. Strength Cond. Res.* **2018**, *32*, 2273–2283. [CrossRef]
2. Dæhlin, T.E.; Haugen, O.C.; Haugerud, S.; Hollan, I.; Raastad, T.; Rønnestad, B.R. Improvement of ice hockey players' on-ice sprint with combined plyometric and strength training. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 893–900. [CrossRef]
3. Peterson, B.J.; Fitzgerald, J.S.; Dietz, C.C.; Ziegler, K.S.; Baker, S.E.; Snyder, E.M. Off-ice anaerobic power does not predict on-ice repeated shift performance in hockey. *J. Strength Cond. Res.* **2016**, *30*, 2375–2381. [CrossRef] [PubMed]
4. Nightingale, S.C.; Miller, S.; Turner, A. The usefulness and reliability of fitness testing protocols for ice hockey players: A literature review. *J. Strength Cond. Res.* **2013**, *27*, 1742–1748. [CrossRef]
5. Allisse, M.; Sercia, P.; Comtois, A.S.; Leone, M. Morphological, Physiological and Skating Performance Profiles of Male Age-Group Elite Ice Hockey Players. *J. Hum. Kinet.* **2017**, *58*, 87–97. [CrossRef]
6. Behm, D.G.; Wahl, M.J.; Button, D.C.; Power, K.E.; Anderson, K.G. Relationship between hockey skating speed and selected performance measures. *J. Strength Cond. Res.* **2005**, *19*, 326–331. [CrossRef]
7. Bracko, M.R. On-ice performance characteristics of elite and non-elite women's ice hockey players. *J. Strength Cond. Res.* **2001**, *15*, 42–47. [CrossRef]
8. Durocher, J.J.; Guisfredi, A.J.; Leetun, D.T.; Carter, J.R. Comparison of on-ice and off-ice graded exercise testing in collegiate hockey players. *Appl. Physiol. Nutr. Metab.* **2010**, *35*, 35–39. [CrossRef]
9. Legerlotz, K.; Kittelmann, J.; Dietzel, M.; Wolfarth, B.; Böhlke, N. Ice hockey-specific repeated shuttle sprint test performed on ice should not be replaced by off-ice testing. *J. Strength Cond. Res.* **2020**. [CrossRef]

10. Schwesig, R.; Hermassi, S.; Edelmann, S.; Thorhauer, U.; Schulze, S.; Fieseler, G.; Delank, K.-S.; Shephard, R.J.; Chelly, M.S. Relationship between ice hockey-specific complex test and maximal strength, aerobic capacity and postural regulation in professional players. *J. Sports Med. Phys. Fit.* **2017**, *57*, 1415–1423. [CrossRef]
11. Vescovi, J.D.; Murray, T.M.; Fiala, K.A.; VanHeest, J.L. Off-ice performance and draft status of elite ice hockey players. *Int. J. Sports Physiol. Perform.* **2006**, *1*, 207–221. [CrossRef]
12. Delisle-Houde, P.; Chiarlitti, N.A.; Reid, R.E.R.; Andersen, R.E. Relationship between physiologic tests, body composition changes, and on-ice playing time in canadian collegiate hockey players. *J. Strength Cond. Res.* **2018**, *32*, 1297–1302. [CrossRef]
13. Morgan, D.W.; Baldini, F.D.; Martin, P.E.; Kohrt, W.M. Ten kilometer performance and predicted velocity at VO_{2max} among well-trained male runners. *Med. Sci. Sports Exerc.* **1989**, *21*, 78–83. [CrossRef]
14. Green, M.R.; Pivarnik, J.M.; Carrier, D.P.; Womack, C.J. Relationship between physiological profiles and on-ice performance of a national collegiate athletic association division I hockey team. *J. Strength Cond. Res.* **2006**, *20*, 43–46. [CrossRef] [PubMed]
15. Kniffin, K.M.; Howley, T.; Bardreau, C. Putting muscle into sports analytics: Strength, conditioning, and ice hockey performance. *J. Strength Cond. Res.* **2017**, *31*, 3253–3259. [CrossRef] [PubMed]
16. Lignell, E.; Fransson, D.; Krustrup, P.; Mohr, M. Analysis of high-intensity skating in top-class ice hockey match-play in relation to training status and muscle damage. *J. Strength Cond. Res.* **2018**, *32*, 1303–1310. [CrossRef] [PubMed]
17. Schwesig, R.; Lauenroth, A.; Schulze, S.; Laudner, K.G.; Bartels, T.; Delank, K.-S.; Reinhardt, L.; Kurz, E.; Hermassi, S. Reliability of an ice hockey-specific complex test. *Sportverletz. Sportschaden* **2018**, *32*, 196–203. [CrossRef]
18. Montgomery, D.; Nobes, K.; Pearsall, D.; Turcotte, R. *Task Analysis (Hitting, Shooting, Passing, and Skating) of Professional Hockey Players. Safety in Ice Hockey: Fourth Volume*; Ashare, A., Pearsall, D., Eds.; ASTM International: West Conshohocken, PA, USA, 2004; pp. 288–295. [CrossRef]
19. Schwesig, R.; Schulze, S.; Reinhardt, L.; Laudner, K.G.; Delank, K.-S.; Hermassi, S. Differences in player position running velocity at lactate thresholds among male professional german soccer players. *Front. Physiol.* **2019**, *10*. [CrossRef]
20. Millum, J.; Wendler, D.; Emanuel, E.J. The 50th Anniversary of the Declaration of Helsinki. *JAMA* **2013**, *310*, 2143. [CrossRef]
21. Richardson, J.T.E. Eta squared and partial eta squared as measures of effect size in educational research. *Educ. Res. Rev.* **2011**, *6*, 135–147. [CrossRef]
22. Hartmann, A.; Herzog, T.; Drinkmann, A. Psychotherapy of bulimia nervosa: What is effective? A meta-analysis. *J. Psychosom. Res.* **1992**, *36*, 159–167. [CrossRef]
23. Cohen, J. Statistical Power Analysis for the Behavioural Sciences. In *Lawrence Earlbaum Associates*; Academic Press: Hillside, NJ, USA, 1988; pp. 278–280. [CrossRef]
24. Geithner, C.; Lee, A.M.; Bracko, M.R. Physical and performance differences among forwards, defensemen, and goalies in elite women's ice hockey. *J. Strength Cond. Res.* **2006**, *20*, 500–505. [CrossRef] [PubMed]
25. Burr, J.F.; Jamnik, R.K.; Baker, J.; Macpherson, A.; Gledhill, N.; McGuire, E.J. Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. *J. Strength Cond. Res.* **2008**, *22*, 1535–1543. [CrossRef] [PubMed]
26. Quinney, H.A.; Dewart, R.; Game, A.; Snydmiller, G.; Warburton, D.; Bell, G. A 26 year physiological description of a National Hockey League Team. *Appl. Physiol. Nutr. Metab.* **2008**, *33*, 753–760. [CrossRef]
27. Ransdell, L.B.; Murray, T.M.; Gao, Y. Off-ice fitness of elite female ice hockey players by team success, age, and player position. *J. Strength Cond. Res.* **2013**, *27*, 875–884. [CrossRef]
28. Stanula, A.; Roczniok, R.; Maszczyk, A.; Pietraszewski, P.; Zajac, A. The role of aerobic capacity in high-intensity intermittent efforts in ice-hockey. *Biol. Sport* **2014**, *31*, 193–199. [CrossRef]
29. Roczniok, R.; Stanula, A.; Gabryś, T.; Szmatlan-Gabryś, U.; Gołaś, A.; Stastny, P. Physical fitness and performance of polish ice-hockey players competing at different sports levels. *J. Hum. Kinet.* **2016**, *51*, 201–208. [CrossRef] [PubMed]
30. Boucher, V.G.; Parent, A.-A.; St-Jean Miron, F.; Leone, M.; Comtois, A.S. Comparison between power off-ice test and performance on-ice anaerobic testing. *J. Strength Cond. Res.* **2017**. [CrossRef] [PubMed]
31. Lamoureux, N.R.; Tomkinson, G.R.; Peterson, B.J.; Fitzgerald, J.S. Relationship between skating economy and performance during a repeated-shift test in elite and subelite ice hockey players. *J. Strength Cond. Res.* **2018**, *32*, 1109–1113. [CrossRef] [PubMed]
32. Léger, L.; Seliger, V.; Brassard, L. Comparisons among VO_2 max values for hockey players and runners. *J. Can. Sci. Appl. Sport* **1979**, *4*, 18–21.