

Article

Position-Specific Reference Data for an Ice Hockey-Specific Complex Test—An Update and Practical Recommendations

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Featured Application: Ice hockey is a very fast and complex team sport. Consequently, it is necessary to develop performance diagnostics further, considering complexity and quality criteria (validity, reliability, practicability). The introduced ice hockey-specific complex test (IHCT) is one of the few tests that meet all criteria. In particular, the continually growing reference database gives the test a unique selling point. The high number of reference data helps coaches and sports scientists in ice hockey practice to interpret and discuss all data quickly and consistently.

Abstract: This real-life data collection aimed to expand an existing reference database regarding an extensively evaluated ice hockey-specific complex test (IHCT). One hundred and thirty-eight third-league professional ice hockey field players (mean \pm SD; age: 26.4 ± 5.24 years; forwards: $n = 94$, defenders: $n = 44$) were investigated. IHCT data were collected over eight seasons from three third-league teams. The IHCT included parameters for the load (e.g., 10 m and 30 m sprint 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 relevant ($p < 0.002$, $\eta_p^2 \geq 0.10$) difference between forwards and defenders for performance was found for 30 m backward sprint without a puck ($p < 0.001$, $\eta_p^2 = 0.10$, $d = 0.74$). As expected, in this regard, defenders performed better than forwards. Significant differences were also found in 10 m backward sprint without a puck ($p = 0.005$), weave agility with a puck ($p = 0.014$), heart rate recovery minute 10 ($p = 0.057$), and goals after the test ($p = 0.041$). This study provides expanded position-specific third-league reference data for the IHCT. On this basis, coaches are able to evaluate players' performance (forwards vs. defenders) and the effect of the training periods. Further research is necessary to extend this database to first- and second-league players in order to enhance the scope of the IHCT.

Keywords: on-ice performance; team sports; speed; agility; shot performance; stress and load parameter



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1. Introduction

Ice hockey is a demanding team sport that is characterized by various athletic and technical components (e.g., linear speed, change of direction (COD), aerobic and anaerobic capacity, strength). The intensive body contact with the opponent is typical for ice hockey, comparable to rugby or football, and underlines the importance of core stability for ice hockey players.

In relation to the entire match duration (3×20 min), the player's effective operational time is 15–25 min [1,2]. The players perform in intervals determined by 30–60 s stints on

ice, with different recovery phases between these intensive intermittent actions [3,4]. The number of high-intensity actions (95–100% maximum heart rate) is 25% [5]. In relation to the maximal oxygen uptake from 55 and 60 mL*kg⁻¹*min⁻¹ [6], it is obvious that aerobic capacity is a very important precondition for professional ice hockey players. Montgomery et al. [7] reported position-specific differences in demand and load. Defenders, for example, spent significantly more time skating backwards than forwards (19% vs. 5–6%).

Unfortunately, the complexity of ice hockey is not adequately reflected in performance diagnostics (particularly on ice). Most studies preferred isolated measurements of physical performance parameters [8–11] or the sole use of off-ice testing. This implicates a major limitation because off-ice testing does not allow for replication of specific biomechanical aspects of on-ice skating [12]. Consequently, on-ice testing is indispensable for a valid evaluation of players, especially in a complex manner. Czeck et al. [11] described the effects of body composition on on-ice performance in male and female players. They used parkours, consisting of sprints, CODs and linear skating, arranged in a complex way (total distance: 148 m). Regrettably, data regarding puck handling or shot performance were not reported in this study, so relations to the body composition could not be quantified.

Numerous other authors [4,6,12] also pointed out the need for on-ice skating tests in order to assess important factors such as speed, agility, and repeated sprint ability as crucial preconditions for a successful match performance. In line with recommendations from Vigh-Larsen et al. [12] and Pelletier et al. [13], the IHCT also implemented the above-mentioned relevant skills and actions (e.g., sprinting and shooting performance, COD). In accordance with Hajek et al. [4], the authors referred to the importance of “specific” ice hockey skills such as shooting and stick handling. Hajek et al. [4] explicitly pointed out the contradiction between the complexity of the sport and the one-dimensionality of performance testing (e.g., straight skating speed as an indicator of overall skating performance). At this point, they also emphasized the relation between test and match performance. Schwesig et al. [14,15] considered this aspect and already proved the validity of IHCT using match performance.

Position-based training is able to provide a competitive advantage that coaches can exploit in a demanding team sport with specific requirements for different positions. However, underlying reference data for the respective player positions is necessary to exploit this. Such reference data can then be used to identify any deficits during the preparation phase and to adapt the training to the individual requirements from an athletic point of view.

Schulze et al. [16] already provided reference data for the IHCT [17,18] based on a first sample of 104 third-league professional ice hockey field players.

The first aim of the study was to significantly extend the reference data to enhance their meaningfulness by player position. The second aim was to provide a valid, practical, and self-explanatory analysis matrix for coaches to enable easier data handling. We hypothesized that the standard deviation of all parameters would decrease. That would be advantageous for the significance of all results and derived findings.

2. Materials and Methods

2.1. Subjects

A total of 347 data sets from third-league players were used for the reevaluation (second evaluation; Figure 1). A large number of players ($n = 199$) were tested twice or more (range of data sets per player: 1 to 10). In line with Schulze et al. [16], a median analysis was conducted to avoid correlated observations. Consequently, 138 professional (forwards: $n = 94$; defenders: $n = 44$) male ice hockey players (mean \pm SD; age: 26.4 ± 5.24 years, height: 1.82 ± 0.06 m, body mass: 85.9 ± 8.55 kg) were selected for the statistical analysis.

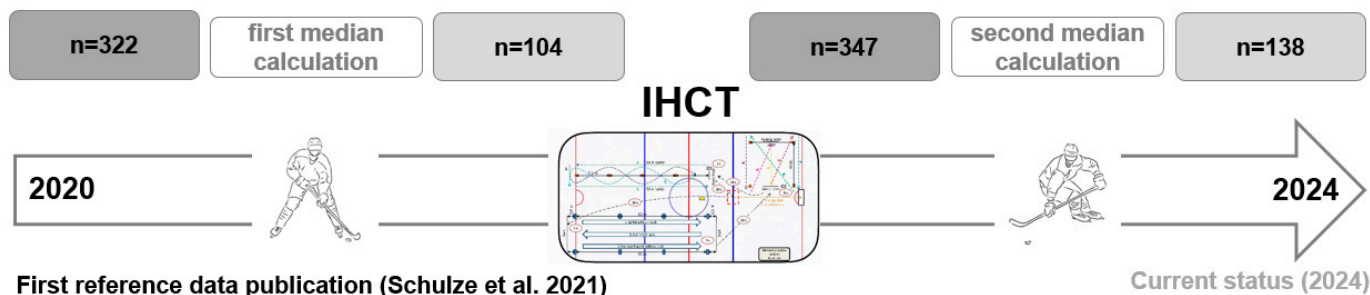


Figure 1. Reevaluation of the IHCT regarding reference data based on a second median calculation [16].

All players knew that they could withdraw from the project at any time without mentioning reasons. Before the test, all contents, risks as well as advantages were described in detail. Written consent was necessary to participate in the study. For players younger than 18.0 years ($n = 1$; age range: 17.2–42.1 years), 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) and conformed to the Declaration of Helsinki [19].

2.2. Study Design and Methodology

The second cross-sectional data collection utilized data from the IHCT over ten seasons (2015–2024) in third-league German ice hockey players (three teams). Solely male field players (forwards and defenders) were investigated. Before the conduction of the IHCT, all players were carefully familiarized with the test-specific details of the IHCT [15]. The following possibilities were used in this context: sketch, instructional video, demonstration on ice. Additionally, we organized the testing process so that players who were familiar with the test were the first to be tested. Moreover, the investigator (R.S.) gave further instructions during the short test breaks (5–10 s) when necessary.

To secure a high level of reliability, all athletes were judged at the same time and they were given the same standardized preparation (nutrition, warm-up, instructions) [14,17]. Schwesig et al. [17] investigated the interrater reliability of the tasks and parameters. They detected 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, CV = 9.2%). There was decreased reliability for slap shot 3 before the test, slap shot 1 after the test, and the 10 m sprint with a puck (ICC: 0.60–0.73; CV: 5.0–8.3%) [17].

The purpose of the IHCT is to mimic essential and complex match-related ice hockey-specific requirements and activities in order to reduce the gap between test and match performance [14,16]. Vital information (e.g., used assessments and parameters, detailed description) regarding the IHCT has been previously published elsewhere [14,17].

To guarantee strong interrater reliability, the same investigators (R.S.; S.S.) carried out all test procedures in the same manner. This reliability was additionally ensured using instruments for the measurement of the objective, physical variables (time, speed, heart rate, lactate), and the clear definition of the results (goal or no goal).

2.3. Statistics

All data were checked before the statistical analysis (descriptive presentation and inference tests) to avoid correlated observations. The median analysis was indicated if there was more than one data set per player. One data set was created for each player using the mean (even number of tests) or median (odd number of tests). We used the median instead of the mean (exception: even number of tests), because the mean can be strongly influenced by outliers. This is especially true when there is a small number of measured values.

Results were presented for the total group and only for the field players. Goalies were excluded based on their clearly different demands. Descriptive statistics contained mean, standard deviation (SD), and percentiles (10, 25, 50 (median), 75, 90) for all test variables.

The Shapiro–Wilk test for normal distribution and the Levene test for equality of variance (assuming homogeneity of variance) were used for all variables prior to statistical analysis. A one-factorial univariate general linear model was used to compare the mean differences between defenders and forwards.

In order to assess the practical relevance and quantify the differences in performance between playing positions, effect sizes (partial eta squared, η_p^2 ; [20]; d ; [21]) were calculated for the ANOVA main effects (η_p) resulting from the number of playing positions and the number of players in each playing position. The effect size d was calculated as a quotient of the mean differences divided by the pooled SD [21].

To judge d or η_p^2 , the following classifications were used: $d \geq 0.2$, $d \geq 0.5$, $d \geq 0.8$, 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 [22].

To avoid an overestimation of mean differences, the level of significance was reduced using Bonferroni correction at $p \leq 0.002$ ($p < 0.05/33$) or for $\eta_p^2 \geq 0.10$. In this context, partial eta squared (η_p^2) was used to indicate clinical relevance [16,20].

Pearson's product–moment correlations were used to calculate the interactions between anthropometric and physical performance parameters. A determination coefficient of at least $r^2 > 0.5$ was defined as relevant and only reported [22]. The critical value for the product–moment correlation, based on a two-tailed t-test and alpha = 5%, is $r \approx 0.160$ for the sample size of $n = 148$ used [23].

All statistical analyses were realized using SPSS version 28.0 for Windows (IBM, Armonk, NY, USA).

3. Results

3.1. Normal Distribution and Variance Homogeneity

The parameters of resting lactate ($p < 0.001$), 10 m sprint without puck ($p = 0.033$), 10 m backward sprint without puck ($p < 0.001$), 30 m backward sprint without puck ($p = 0.039$), transition without puck ($p < 0.001$), transition with puck ($p < 0.001$), and both goals before ($p < 0.001$) and following testing ($p < 0.001$) were not normally distributed.

Concerning the results for the Levene test for equality of variances (variance homogeneity), the p -values for the variables of 10 m backward sprint without puck ($p = 0.031$), goals after test ($p < 0.001$), and recovery heart rate (relative; $p = 0.043$) were less than 0.05. The p -value was greater than 0.055 (lactate recovery minute 2) for all variables, indicating that the variances of all variables for the playing positions (forwards, defenders) were significantly different.

3.2. Anthropometric Data

Descriptive data (Table 1) did not show any relevant ($p \leq 0.002$ and $\eta_p^2 \geq 0.10$) position-specific differences. Defenders showed a higher average body mass (87.1 ± 8.48 kg) than forwards (85.3 ± 8.56 kg; Table 1). The largest difference ($p = 0.004$, $\eta_p^2 = 0.060$) between defenders and forwards was detected in height (significant, but not relevant).

Table 1. Anthropometric parameters and age of the investigated sample ($n = 138$) in relation to playing positions (mean \pm standard deviation). Maxima are marked in bold.

	Defenders	Forwards	Total
Age [years]	25.7 \pm 5.17	26.7 \pm 5.27	26.4 \pm 5.24
Height [m]	1.84 \pm 0.06	1.81 \pm 0.05	1.82 \pm 0.06
Body mass [kg]	87.1 \pm 8.48	85.3 \pm 8.56	85.9 \pm 8.55
Resting heart rate [min^{-1}]	65 \pm 9.27	64 \pm 7.62	64 \pm 8.16
Resting lactate [mmol/L]	1.07 \pm 0.25	1.05 \pm 0.29	1.06 \pm 0.28

Resting lactate moved in a very small range of between 1.05 mmol/L (forwards) and 1.07 mmol/L (defenders). Resting heart rate was very similar for both positions (64 and 65 min⁻¹).

3.3. Performance Data

The results for speed skating (forward, backward) show that the forwards performed slightly (but not significantly) faster than the defenders in four of the six parameters (Table 2). Regarding backward sprinting, a typical defensive action, defenders showed a markedly higher performance level than forwards. These were also the largest differences over all parameters (10 m: $d = 0.57$; 30 m: $d = 0.74$).

Table 2. Speed skating percentile by playing position. Performance peaks are highlighted in bold based on the 50th percentile (P50 = MEDIAN).

		Defenders ($n = 44$)	Forwards ($n = 94$)	Total ($n = 138$)
10 m sprint without puck [s]	P10	1.76	1.73	1.74
	P25	1.82	1.79	1.80
	MEDIAN	1.95	1.87	1.89
	P75	1.99	1.95	1.97
	P90	2.05	2.02	2.03
30 m sprint without puck [s]	P10	4.24	4.19	4.20
	P25	4.32	4.30	4.31
	MEDIAN	4.49	4.41	4.44
	P75	4.57	4.56	4.56
	P90	4.71	4.64	4.64
10 m sprint with puck [s]	P10	1.71	1.73	1.73
	P25	1.79	1.77	1.78
	MEDIAN	1.91	1.88	1.88
	P75	2.00	1.98	1.99
	P90	2.08	2.05	2.06
30 m sprint with puck [s]	P10	4.31	4.27	4.29
	P25	4.47	4.37	4.40
	MEDIAN	4.58	4.52	4.55
	P75	4.69	4.66	4.66
	P90	4.82	4.78	4.80
10 m backward sprint without puck [s]	P10	2.17	2.18	2.18
	P25	2.23	2.28	2.24
	MEDIAN	2.29	2.37	2.33
	P75	2.37	2.47	2.44
	P90	2.47	2.58	2.53
30 m backward sprint without puck [s]	P10	5.12	5.19	5.18
	P25	5.23	5.36	5.29
	MEDIAN	5.35	5.54	5.48
	P75	5.49	5.76	5.66
	P90	5.74	5.95	5.85

P = percentile.

The agility performance tests (Table 3) displayed the largest differences between forwards and defenders for weave agility with the puck ($p = 0.014$; $\eta_p^2 = 0.043$; $d = 0.46$). Both position groups moved on almost the same performance level for the transition parameters.

Shot performance data (Tables 4 and 5) displayed small advantages for the defenders. A total of 79% (11/14) of all maxima were found for defenders. The largest difference ($d = 0.41$) between positions was calculated for shot accuracy with preload (after finishing the sprints and agility runs); defenders: 4.86 ± 0.74 vs. forwards: 4.49 ± 1.06 , Table 5).

Table 3. Agility percentile by playing position. Performance peaks are highlighted in bold based on the 50th percentile (P50 = MEDIAN).

		Defenders (<i>n</i> = 44)	Forwards (<i>n</i> = 94)	Total (<i>n</i> = 138)
Transition without puck [s]	P10	16.3	16.3	16.3
	P25	16.7	16.7	16.7
	MEDIAN	17.1	17.1	17.1
	P75	17.6	17.6	17.6
	P90	17.9	18.1	18.0
Transition with puck [s]	P10	17.5	17.6	17.6
	P25	18.0	18.0	18.0
	MEDIAN	18.5	18.4	18.5
	P75	19.1	19.0	19.1
	P90	19.8	19.6	19.6
Weave without puck [s]	P10	21.5	21.4	21.5
	P25	22.1	21.7	21.9
	MEDIAN	22.6	22.5	22.5
	P75	23.1	23.0	23.0
	P90	23.9	23.7	23.8
Weave with puck [s]	P10	22.6	21.9	22.1
	P25	23.1	22.5	22.6
	MEDIAN	23.6	23.1	23.2
	P75	24.1	23.7	23.9
	P90	24.6	24.6	24.5

Table 4. Shot performance without preload percentile by playing position. Performance peaks are highlighted in bold based on the 50th percentile (P50 = MEDIAN).

		Defenders (<i>n</i> = 44)	Forwards (<i>n</i> = 94)	Total (<i>n</i> = 138)
Slap shot 1 [km·h ⁻¹]	P10	115	111	112
	P25	122	119	120
	MEDIAN	129	126	126
	P75	137	132	133
	P90	140	138	140
Slap shot 2 [km·h ⁻¹]	P10	116	115	116
	P25	122	120	121
	MEDIAN	127	126	126
	P75	136	134	135
	P90	142	139	139
Slap shot 3 [km·h ⁻¹]	P10	114	117	117
	P25	121	121	121
	MEDIAN	128	127	127
	P75	136	135	136
	P90	142	140	140
Wrist shot 1 [km·h ⁻¹]	P10	96	96	96
	P25	102	101	101
	MEDIAN	106	107	107
	P75	110	111	111
	P90	116	115	115
Wrist shot 2 [km·h ⁻¹]	P10	97	96	96
	P25	102	100	100
	MEDIAN	105	107	107
	P75	111	111	111
	P90	117	114	115
Wrist shot 3 [km·h ⁻¹]	P10	97	96	96
	P25	101	102	101
	MEDIAN	107	106	106
	P75	112	111	111
	P90	115	114	114
goals	P10	3	3	3
	P25	4	4	4
	MEDIAN	5	5	5
	P75	5	5	5
	P90	6	6	6

Table 5. Shot performance with preload percentile by playing position. Performance peaks are highlighted in bold based on the 50th percentile (P50 = MEDIAN).

		Defenders (<i>n</i> = 44)	Forwards (<i>n</i> = 94)	Total (<i>n</i> = 138)
Slap shot 1 [km·h ⁻¹]	P10	106	106	106
	P25	112	111	111
	MEDIAN	120	118	118
	P75	125	124	124
	P90	134	130	130
Slap shot 2 [km·h ⁻¹]	P10	109	106	107
	P25	112	113	113
	MEDIAN	120	119	119
	P75	126	125	126
	P90	135	132	132
Slap shot 3 [km·h ⁻¹]	P10	108	107	107
	P25	113	113	113
	MEDIAN	121	119	120
	P75	128	126	127
	P90	132	132	132
Wrist shot 1 [km·h ⁻¹]	P10	86	89	87
	P25	93	93	93
	MEDIAN	99	99	99
	P75	104	105	104
	P90	108	108	108
Wrist shot 2 [km·h ⁻¹]	P10	86	88	87
	P25	94	93	94
	MEDIAN	99	99	99
	P75	104	104	104
	P90	108	108	108
Wrist shot 3 [km·h ⁻¹]	P10	87	89	89
	P25	94	94	94
	MEDIAN	101	99	100
	P75	105	106	105
	P90	109	109	109
goals	P10	4	3	3
	P25	4	4	4
	MEDIAN	5	5	5
	P75	5	5	5
	P90	6	6	6

No relevant position-specific differences existed between the measured stress parameters of lactate and heart rate (Tables 6 and 7). All maxima were captured for defenders. The ability to recover was slightly higher for the forwards, especially for the cardiac recovery ($41.1 \pm 5.04\%$ vs. $42.6 \pm 4.04\%$; $d = 0.33$).

Table 6. Stress parameters (heart rate, lactate) percentile by playing position. Performance peaks are highlighted in bold based on the 50th percentile (P50 = MEDIAN); recovery minute = rm.

		Defenders (<i>n</i> = 44)	Forwards (<i>n</i> = 94)	Total (<i>n</i> = 138)
Lactate rm 2 [mmol·L ⁻¹]	P10	9.11	9.11	9.19
	P25	10.4	10.6	10.5
	MEDIAN	11.9	12.0	12.0
	P75	14.4	13.3	13.4
	P90	15.8	14.3	14.8

Table 6. Cont.

		Defenders (n = 44)	Forwards (n = 94)	Total (n = 138)
Lactate rm 6 [mmol·L ⁻¹]	P10	11.3	10.2	10.2
	P25	11.8	12.0	11.9
	MEDIAN	14.4	13.8	13.9
	P75	16.4	15.0	15.5
	P90	18.6	17.3	17.5
Lactate rm 10 [mmol·L ⁻¹]	P10	9.92	9.05	9.72
	P25	11.0	11.0	11.0
	MEDIAN	13.5	13.1	13.2
	P75	16.2	14.7	15.0
	P90	18.4	16.7	17.4
Heart rate rm 0 [b·min ⁻¹]	P10	171	169	170
	P25	175	173	174
	MEDIAN	181	179	180
	P75	186	185	185
	P90	194	191	191
Heart rate rm 2 [b·min ⁻¹]	P10	125	118	120
	P25	131	128	130
	MEDIAN	139	139	139
	P75	149	147	147
	P90	160	151	154
Heart rate rm 6 [b·min ⁻¹]	P10	97	93	95
	P25	104	101	102
	MEDIAN	110	108	108
	P75	116	112	114
	P90	126	118	120
Heart rate rm 10 [b·min ⁻¹]	P10	94	90	93
	P25	98	96	97
	MEDIAN	107	103	104
	P75	113	110	111
	P90	118	115	116
Lactate degradation rate per minute, rm 6 to rm 10 [mmol·L ⁻¹ /min]	P10	-0.08	-0.04	-0.05
	P25	0.02	0.05	0.04
	MEDIAN	0.20	0.22	0.20
	P75	0.34	0.30	0.30
	P90	0.41	0.40	0.40
Recovery heart rate (relative), rm 0 to rm 10 [%]	P10	34	38	36
	P25	38	40	39
	MEDIAN	41	43	43
	P75	45	45	45
	P90	47	48	48

Table 7. Differences in load and stress parameters (mean ± SD) by playing position. Bold fonts indicate performance maximums and significant differences ($p \leq 0.002$); recovery minute = rm.

Parameters	Defenders (n = 44)	Forwards (n = 94)	p	η_p^2	d
Load parameters					
10 m sprint without puck [s]	1.91 ± 0.11	1.87 ± 0.11	0.058	0.026	0.36
30 m sprint without puck [s]	4.47 ± 0.17	4.42 ± 0.18	0.173	0.014	0.34
10 m sprint with puck [s]	1.90 ± 0.14	1.88 ± 0.12	0.484	0.004	0.15
30 m sprint with puck [s]	4.58 ± 0.19	4.52 ± 0.19	0.087	0.021	0.32
10 m backward sprint without puck [s]	2.30 ± 0.11	2.38 ± 0.17	0.005	0.058	0.57
30 m backward sprint without puck [s]	5.37 ± 0.21	5.55 ± 0.28	<0.001	0.097	0.74
Transition without puck [s]	17.1 ± 0.66	17.2 ± 0.82	0.538	0.003	0.14
Transition with puck [s]	18.6 ± 0.90	18.6 ± 0.94	0.968	0.000	0.00

Table 7. Cont.

Parameters	Defenders (n = 44)	Forwards (n = 94)	p	η_p^2	d
Load parameters					
Weave without puck [s]	22.7 ± 0.82	22.5 ± 0.88	0.242	0.010	0.24
Weave with puck [s]	23.5 ± 0.77	23.1 ± 0.96	0.014	0.043	0.46
Slap shot 1 before test [km·h ⁻¹]	129 ± 10.1	125 ± 10.1	0.065	0.025	0.40
Slap shot 2 before test [km·h ⁻¹]	128 ± 9.46	127 ± 9.66	0.303	0.008	0.11
Slap shot 3 before test [km·h ⁻¹]	129 ± 10.0	128 ± 9.60	0.611	0.002	0.10
Wrist shot 1 before test [km·h ⁻¹]	106 ± 6.53	106 ± 7.07	0.958	0.000	0
Wrist shot 2 before test [km·h ⁻¹]	106 ± 6.87	106 ± 7.16	0.982	0.000	0
Wrist shot 3 before test [km·h ⁻¹]	106 ± 7.03	106 ± 6.86	0.830	0.000	0
Goals before test	4.45 ± 1.01	4.40 ± 1.00	0.785	0.001	0.05
Slap shot 1 after test [km·h ⁻¹]	120 ± 9.61	117 ± 9.22	0.134	0.016	0.32
Slap shot 2 after test [km·h ⁻¹]	120 ± 9.29	119 ± 9.76	0.395	0.005	0.11
Slap shot 3 after test [km·h ⁻¹]	120 ± 9.39	119 ± 10.0	0.555	0.003	0.10
Wrist shot 1 after test [km·h ⁻¹]	98 ± 7.58	99 ± 7.57	0.826	0.000	0.04
Wrist shot 2 after test [km·h ⁻¹]	98 ± 7.78	99 ± 7.57	0.737	0.001	0
Wrist shot 3 after test [km·h ⁻¹]	99 ± 7.78	99 ± 8.01	0.986	0.000	0
Goals after test	4.86 ± 0.74	4.49 ± 1.06	0.037	0.032	0.41
Stress parameters					
Lactate rm 2 [mmol·L ⁻¹]	12.3 ± 2.58	11.8 ± 2.08	0.211	0.011	0.22
Lactate rm 6 [mmol·L ⁻¹]	14.4 ± 2.77	13.7 ± 2.55	0.137	0.016	0.26
Lactate rm 10 [mmol·L ⁻¹]	13.7 ± 3.00	13.0 ± 2.85	0.173	0.014	0.24
Heart rate rm 0 [b·min ⁻¹]	181 ± 7.54	180 ± 8.42	0.365	0.006	0.13
Heart rate rm 2 [b·min ⁻¹]	140 ± 12.5	137 ± 12.0	0.175	0.013	0.25
Heart rate rm 6 [b·min ⁻¹]	110 ± 10.1	107 ± 9.46	0.052	0.028	0.31
Heart rate rm 10 [b·min ⁻¹]	107 ± 9.70	103 ± 9.47	0.057	0.026	0.42
Calculated parameters					
Lactate degradation rate per minute, rm 6 to rm 10 [mmol·L ⁻¹ /min]	0.17 ± 0.20	0.19 ± 0.19	0.765	0.001	0.10
Recovery heart rate (relative), rm 0 to rm 10 [%]	41.1 ± 5.04	42.6 ± 4.04	0.060	0.026	0.33

We did not find any relevant ($r > 0.7$) interactions between anthropometric parameters or age on one side and the IHCT performance (load and stress parameters) on the other side.

4. Discussion

This study aimed to provide position-specific (defenders vs. forwards) reference data for the IHCT. The comparison of the field players revealed only one relevant difference in the 30 m backward sprint without a puck ($p < 0.001$, $\eta_p^2 = 0.097$, $d = 0.74$) in favor of the defenders (5.37 ± 0.21 s vs. 5.55 ± 0.28 s). Clear ($d > 0.4$) but not relevant differences were also found in 10 m backward sprint without a puck ($d = 0.57$), weave agility with a puck ($d = 0.46$), heart rate recovery minute 10 ($d = 0.42$), and goals after test ($d = 0.41$). In general, forwards seem to have advantages regarding speed, agility parameters, and the ability to recover. In contrast, defenders showed more frequently higher slap shot velocities. For the anthropometric parameters, there was only a weak group difference ($p = 0.004$, $\eta_p^2 = 0.060$) in height. Forwards (1.81 ± 0.05 m) displayed a lower height compared to defenders (1.84 ± 0.06 m). The same is valid for body mass (85.3 ± 8.56 kg vs. 87.1 ± 8.48 kg).

At the start of the discussion, it should be mentioned that this is an update from the already published reference data for the ice hockey-specific complex test [16]. Previous studies examined individual player position-specific load parameters [2,3,5,24–29]. However, their results are difficult to compare due to differences in study methodology (e.g., sample size, length of career, class of competition, location of tests, definition of performance). Most importantly, however, the validation of these tests based on the match performance during prospective data collection has been missing so far.

Legerlotz et al. [29] supported the need for implementing the technical aspect [13,30] in a complex on-ice diagnostic. The authors postulated that the specific technique (skating vs.

running) and the specific environment (off-ice vs. on-ice) are critical [29] but necessary [30] factors for the functionality and validity of the test results.

The results from this real-life data collection underline the findings from different studies [11,12] that show that the differences between field positions are minor. Defenders only showed advantages for backward skating and shot velocity, especially concerning the slap shot. Vigh-Larsen et al. [12] investigated the largest sample with 145 elite and 111 sub-elite male ice hockey players from the Danish ice hockey division. From a practical point of view, that means that there is no need to strictly distinguish forwards and defenders within the physical on-ice workout.

Kniffin et al. [31] recruited a comparable sample ($n = 120$ vs. $n = 138$) of male ice hockey players (National Collegiate Athletic Association (NCAA) Division 1). Our data showed a similar position distribution (62% defenders vs. 66% forwards) to previous studies [31]. Goalkeepers were also excluded from their study. However, it should be noted that our results differ significantly from the previously mentioned results of the study by Kniffin et al. [31]. This may be due to the fact that this study group only measured performance data (such as vertical jump or bench press) off-ice and used it as a substitute parameter for lower/upper body strength in ice hockey. This is in line with the study of Nightingale et al. [24], who pointed out that classically used performance tests such as the Wingate 30 s test (anaerobic performance), cycle ergometer test (aerobic performance; VO_{2max}), or push-ups, sit-ups, grip strength, bench press, standing long jump, and vertical jump (strength performance) have only a low predictive value in ice hockey, although they are regularly performed. The authors pointed out that there is an urgent need to develop and establish hockey-specific tests with a higher predictive value and relevance.

Roczniok et al. [1,2] also conducted complex off-ice performance diagnostics, which consisted of tests to determine aerobic and anaerobic capacity, anaerobic threshold, and specific strength. The authors' findings were that the best predictor of success for elite hockey players was relative peak power (OR = 1.82, 95% CI: 0.98–3.36) and relative VO_{2max} (OR = 2.12, 95% CI: 1.11–4.05). It is critical to note that the authors did not use the match performance as an objective, and unfortunately there is no alternative, gold standard for the validation process in order to differentiate between successful and unsuccessful but an expert ranking based on the opinion of coaches. Presumably, this methodological weakness could be the surprising reason for detecting off-ice parameters as the best predictors of success. The development of a match performance score [14,15] based on the match performance over a season could be a sufficient solution within the validation process.

Hajek et al. [4] stated that for better standardization of specific tests, skating with the puck should be excluded (confounding factor). At the same time and in contradiction to the used approach, the authors pointed out that puck handling is essential for the ice-hockey match performance [4]. To our knowledge, this should also be regarded as critical. The highest degree of standardization is relatively useless if validity suffers disproportionately as a result. Both test requirements should be well balanced, but with priority given to validity.

Lignell et al. [3] also examined the skating performance during a top-class ice hockey match ($n = 36$) comparable with Roczniok et al. [1,2]. They assessed physical capacity using a submaximal Yo-Yo Intermittent Recovery Ice hockey test (level 1) in contrast to our results and those of other authors [11,12,16]. In contrast to our findings, Lignell et al. [3] described performance differences between forwards and defenders. Accordingly, forwards performed more intense skating and repeatedly higher-intensity exercises than defenders. The largest position-dependent difference regarding the necessary skills and abilities is how much more defenders skate backwards compared to forwards. Consequently, this was the only significant difference found (30 m backward sprint without puck: $p < 0.001$, $\eta_p^2 = 0.74$). Therefore, coaches should consider the position-specific and tactical roles within training sessions [3]. The test design from Lignell et al. [3] emphasizes the concept of the IHCT, which includes seven high-intensity actions [16].

Czeck et al. [11] analyzed male and female college players' anthropometric parameters and body composition. With respect to on-ice performance, they observed relationships between body fat and performance in COD demands and total test time in a complex test design. In line with the present study results, the authors did not report any relationship between anthropometric parameters and on-ice performance results.

The correlations between off-ice tests (e.g., Wingate test, jumping performance, beep test), changes in body composition (e.g., body fat, lean mass), and match performance (e.g., shift length, playing time) have been analyzed by previous study groups [27]. According to Nightingale et al. [24], the exclusive use of off-ice tests, however, is not preferable. Therefore, we preferred in our study the approach of complex performance diagnostics [14,15], in which off-ice tests were always combined with on-ice tests (e.g., IHCT).

The most important methodological limitation of the current study was that only players from the third-league German ice hockey were included in the study, which limits the significance to a comparable level of performance. Based on the currently very large sample size ($n = 138$), the meaningfulness of the data is very high. Nevertheless, the database should be expanded to the first and second leagues as well as male players from different countries and female players in order to reduce the selection bias. As such, there is limited generalizability of our data and findings. At the same time, our data did have high power for the judgement of third-league ice hockey players in Germany. Consequently, it would be possible to compare players of different performance and skill levels [16]. However, the IHCT can also be used in all professional divisions due to similar requirement profiles.

Another statistical limitation was the large position-specific difference ($n_{Diff} = 50$; forwards: $n = 94$; defenders $n = 44$). Such a large difference between groups is disadvantageous for the power of the variance analysis. This could be a reason for the small number of relevant position differences (Table 7). Conversely, this distribution is justified by the ice hockey team structure (two defenders and three forwards per line). That means a ratio of 60% forwards and 40% defenders is close to real life [16].

From a practical point of view, the reference data presented in this study offer a matrix for intraindividual, interindividual, and team comparison depending on position (Figure 2). Consequently, coaches can get an overview summarized on one page regarding all necessary information for evaluating every player and the whole team based on a comprehensive position-specific reference database.

dimensions/ parameters		percentiles		forwards							defenders					Σ P25	Σ P75	
				best	...	...	...	...	...	worst	best	...	...	...	...			worst
without puck	10 m	1.97	1.80														5	2
	30 m	4.56	4.31														7	2
	10 m backwards	2.44	2.24														8	2
	30 m backwards	5.66	5.29														7	3
	transition	17.6	16.7														8	0
weave	23.0	21.9														11	0	
with puck	10 m	1.99	1.78														9	3
	30 m	4.66	4.40														10	3
	transition	19.1	18.0														8	1
	weave	23.9	22.6														12	1
shots	slap shot max before test	121	136														5	3
	slap shot max preloaded	113	127														6	2
	slap shot diff max	11	5														5	5
	wrist shot max before test	101	111														7	1
	wrist shot max preloaded	94	105														12	0
	wrist shot diff max	10	4														7	3
	goals before test	4	5														11	4
	goals preloaded	4	5														8	7
rec.	heart rate	39	45														5	2
	lactate	0.04	0.30														4	5
Σ																155	49	

Figure 2. Example of an analysis matrix to judge players and teams. max = maximal, diff = difference, rec = recovery, heart rate = recovery heart rate (relative), rm 0 to rm 10 [%], lactate = lactate degradation rate per minute, rm 6 to rm 10 [mmol*L⁻¹/min], red = P75 = percentile 75 = underperformance, green = P25 = percentile 25 = excellent performance, yellow = interquartile range = normal performance.

5. Conclusions

The updated results provide valuable information for specific workouts related to on-ice positions. It seems that the position-specific differences were smaller than expected. Only for backward sprinting without a puck were relevant differences between defenders and forwards observed. In combination with our practical experience, we recommend sufficient aerobic endurance training combined with core stability and strength endurance workouts for the physical preparation of ice hockey players.

Finally, it should be emphasized that the IHCT is a reliability-proved assessment that has been validated two times, and is now also equipped with a large reference database for third-league field players. Based on the updated comparable scientific literature, the IHCT is the only scientifically evaluated (validity, reliability, reference data) on-ice test for professional ice hockey players.

The IHCT is useful for scouting (e.g., talent identification) and evaluating the effectiveness of longitudinal interventions. The introduced analysis matrix offers a valuable possibility for sufficient intra- and interindividual player and team judgement.

Further research is needed to expand the validity and scope (second- and first-league players, teams from different countries, female players) of the IHCT.

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