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Abstract

Sprint and technique abilities of Para ice hockey players are of great importance to increase skating performance. To assess skating abilities, kinematics is widely used. This study had two purposes: (i) to assess 2D kinematics of Para ice hockey players' performance in the laboratory and on ice (sprint and agility) tests and (ii) to quantify the relationship between the laboratory and on ice performance. Seven athletes were recruited. In the laboratory, three alternated reach tests were performed in which athletes touched the ground as many times as possible with hands, elbows, or shoulders. The sprint test consisted of 30 m skating at the highest speed starting from standstill; whereas the agility test consisted of sprinting for four left curves and four right curves. Athletes' movements in the laboratory and on ice tests were acquired using a portable technology. In the laboratory, the best performance was realized when participants touched the ground with hand or elbow. In the sprint test, lower speed and trunk inclination were observed in the first 10 m. In the agility test, greater blade angle was observed in the left curves, compared to the right curves. Significant correlations were found between the laboratory and on ice test performance. Overall, these findings are a useful indicator of athletes' skating abilities and could be used to increase athletes' ability to accelerate rapidly and improve sledge manoeuvrability. For detailed player information, kinematics should still be evaluated using sport specific tests and video analysis.

Keywords: Paralympics; GoPro; sprint test; technique test; trunk kinematics

1. Introduction

Para ice hockey is a Paralympic discipline in which athletes with physical impairments of the lower body play while sitting on a sledge. The sledge is composed of a metallic frame and a bucket that is mounted on two ice hockey blades (Fig. 1). The frame, made of aluminium or steel, is curved in the front end with its height ranging from 8.5 cm to 9.5 cm.[1] The bucket, made of a plastic material, may be equipped with a backrest and cushion. The maximum height of the seat from the ice is 20 cm.[1] Straps are used to secure athletes to the seat and his/her lower limbs to the aluminium frame of the sledge. Propulsion is obtained by two wooden sticks. Each stick has metal picks at one end and a wooden blade to handle the puck at the other end (Fig. 1).[1] Propulsion is entirely performed by the upper limbs and trunk by using repetitive, cycling pushing movements.

****Figure 1 near here****

Para ice hockey is played in a rink measuring 30x60 m. The match consists of three 15-minute periods. Since the sport is physically demanding, athletes play for short intervals (3-4 minutes), then they are substituted.[2] During this time, they mainly alternate short sprints and recovery periods. This kind of activity, which is called repeated sprint activity, requires rapid accelerations to reach maximal speed in the shortest time possible. The repeated sprint activity is physically demanding.[3] In recent years, much research has focused on single and repeated sprint activities due to their importance in ice hockey. A good correlation of sprint activity performance was found with both upper-body strength and peak power assessed in the bench press, bench pull, and pull-down.[4,5] Single and repeated sprint activities also correlate with peak power measured in ergometer sprint tests.[6] During matches, able-bodied standing players spend little time skating straight.[7] Other activities, such as agility and acceleration, contribute to increasing the overall performance.[8,9] Good agility in handling the puck and manoeuvring the sledge is also required for Para ice hockey players in order to improve performance.[6] A technique test, with athletes skating while controlling the puck, has already been proposed in the literature.[6,10] The execution time was assessed and showed good reliability for performance[10] and correlated well with the maximal strength and power tests conducted in the laboratory.[6]

For Para ice hockey players, skating while controlling the puck, passing, receiving, and shooting have been identified as individual skills, which discriminate between successful and less successful players.[11,12] The efficiency of these individual skills has to be combined with good sprint and technique abilities while skating. Performance analysis has recently made progress in part due to the technological advances in slow-motion and high-speed cameras, which allow the kinematics and kinetic aspects of performance to be analyzed.[13,14] Because kinematic analysis is important for the evaluation of ice hockey players' skating abilities, able-bodied standing athletes have been extensively evaluated using a traditional video stereo-photogrammetric system.[15–17] Trunk movements also contribute to the generation of force in sitting sports.[18] Therefore, trunk kinematics would be important for the evaluation of Para ice hockey player propulsion. However, to the best of the authors' knowledge, in Para ice hockey, kinematic analysis of athletes' sprint and technique abilities is still lacking, despite its contribution to enhance the overall performance. This could be due to challenges associated with technology costs, lighting conditions, critical environmental conditions, large data collecting volume, and athletes' sitting position.[19]

The primary purpose of this study was to evaluate the 2D kinematics of Para ice hockey players in a laboratory and during sprint and agility tests on ice using a portable and easy to use device. In addition, the strength of the relationship between performance in the laboratory and on ice was evaluated. In order to address the primary purpose, a high-speed action camera was used to collect participants' movements. Free and open source software was used to evaluate execution times and trunk movements. Based on previous studies on wheelchair athletes[20], it was hypothesized that different 2D kinematics for acceleration would be observed from a stationary to a moving condition. Differences between left and right movements would also be expected because of dominant side[7] and physical impairment[21,22] that may induce asymmetry in movements.

2. Methods

2.1 Participants

Seven male Para ice hockey players (age 27 ± 3 years, height 167 ± 20 cm, weight 58 ± 12 kg, member of the Sportdipiù Tori Seduti team of Turin) volunteered to participate in this study. All the participants were well trained and right-handed. Five of the participants played for the Italian National team and one of them plays as a goalkeeper. All the participants had a physical impairment of the lower body. In particular, the following disabilities were represented: transfemoral left amputation (2 participants), paraplegia (3 participants), hemimelia (1 participant), phocomelia (1 participant). Data were taken from retrospective measurement. Each participant signed informed consent after being informed about the aim and nature of the study. The research methods and protocols were standard, and the procedures were performed in accordance with the Declaration of Helsinki.

2.2 Procedures

In order to assess performance of Para ice hockey players, three tests in the laboratory and two tests on ice were included in the protocol. All the tests were conducted at the Palatazzoli in Turin (Italy). The tests were conducted one month after the beginning of the training season to allow the participants time to recover for their training status.

2.2.1 Laboratory tests

The three alternating reach tests were conducted in the laboratory in order to assess participants' ability to recover the upright position. The three tests simulated typical technical gestures related to their agility abilities, such as puck handling (passing and receiving) and lateral fall. When athletes pass or receive the puck, they are in contact with the ice with hands or elbows; whereas in lateral fall they are in contact with the ice with shoulders before being able to regain the upright position. The three alternating reach tests were performed without the sledge and protective equipment. For the three alternating reach tests, the participants were seated on a sheet of paper (2x3 m) fixed to the tiled ground, with their trunk close to the vertical plane and the lower limb straight in front of them. The initial athletes' sitting position was marked on the sheet of paper to avoid great buttock displacement during the tests execution. The first alternating reach test (Fig. 2A) consisted of alternated lateral tilting to the left and right in order to reach a defined point on the left and a defined point on the right with hand palms (Lab_h). The two points were marked on the paper, aligned with the shoulders plane, at a distance with respect to the center of the buttock which is 30% greater than participant's arm length (measured from acromion to hand fingertips). The second alternating reach test (Fig. 2B) consisted of alternated lateral tilting to the left and right to touch the sheet of paper with the left and right elbows (Lab_e). In the third alternating reach test (Fig. 2C), participants performed alternated lateral tilting to the left and right to touch the sheet of paper with the left and right shoulders (Lab_s). In Lab_e and Lab_s, participants could touch the sheet of paper at a self-selected distance with respect to their buttock. In all three alternating reach tests, the participants were required to accomplish the highest number of repetitions possible in 30 s. A camera (GoPro HERO 3+ Silver, resolution of 1280x720 and sample frequency of 120 Hz) was placed in front of the participants during each test to collect the number of repetitions and qualitatively evaluate movements.

****Figure 2 near here****

2.2.2 On ice tests

The two on ice tests were conducted to assess performance in terms of sprint ability (sprint test) and agility ability to perform curves while skating at a high speed (agility test). For the tests on ice, participants were seated on their personal sledge with the pelvis and lower limbs strapped as would be the case during competitive events. They wore full hockey gear and a jersey, and carried sticks to maintain skating conditions similar to those experienced during a match or training session. The ice hockey rink was resurfaced before the beginning of the tests. Participants warmed-up for 10-15 min before starting the tests. The sprint test consisted of skating in a straight 30 m path in the shortest time possible. The start line and finish line were marked on the ice. The test was repeated three times[2] with 30 s of active recovery allowed in between test repetitions to return to the start line for the following sprint.[2] Sprint starting and recovery timing were given to the participants by an operator. To standardize the first pushing cycle among athletes, the three sprints started with the front of the sledge 5 cm behind the start line and the end of both sticks in contact with the ice. One camera (GoPro HERO 3+ Silver, resolution of 1280x720 and sample frequency of 120 Hz, narrow mode) was positioned 20 m parallel to the 30 m sprint path in alignment with the 10 m mark. This camera position allowed the sprint test path to be recorded from the start line to 20 m. Although only 20 m were recorded, the participants were directed to perform a 30 m sprint because this is an average distance usually covered during matches. This distance also avoids deceleration in propulsion within the 20 m recorded distance.

Sprint and agility tests were separated by 10 min of recovery. In order to guarantee the best ice condition, the agility test was conducted in the opposite part of the ice hockey rink with respect to the sprint test. The agility test was designed together with the coach and showed good results for reliability.[23] Two different acquisitions were done in order to collect a total of four curves performed to the left (Fig. 3A) and four curves performed to the right (Fig. 3B). Each acquisition was repeated three times with 30 s of active recovery in between. For the sprint test, the starting and recovery timing were given to the participant by an operator. The participant was requested to begin from the starting point (marked as (s) in Fig. 3) and perform the agility test in the shortest time possible. If a cone was touched by the sledge blades or sticks, the test was repeated. A GoPro camera, with the same setting as the sprint test (GoPro HERO 3+ Silver, resolution of 1280x720 and sample frequency of 120 Hz, narrow mode), was aligned with the row of dark disc cones (Fig. 3), positioned 3 m away from the first disc cone, and was fixed on a tripod 50 cm above the ice. In order to evaluate trunk movements, two adhesive markers were stuck on the participants' back. The first marker was positioned in the middle point between the two shoulders and the second marker was placed at the top, middle point of the sledge backrest.

****Figure 3 near here****

2.3 Data analysis

To identify temporal and 2D kinematic variables, the videos collected during the laboratory and on ice tests were analyzed using Kinovea software (https://www.kinovea.org). When necessary, videos were zoomed in to better identify the points to be tracked.[24] In the laboratory tests, the left lateral bending time, the right lateral bending time, and the total number of repetitions done in 30 s were calculated for all the three alternating reach tests.

In the sprint test, the time spent to cover the 20 m path ($time_{20}$) was calculated for each of the three repetitions. The starting time corresponded to the beginning of the participant's movement during the first pushing cycle and the finishing time was identified when the sledge front crossed the 20 m line. The fastest repetition was considered for the analysis. For the fastest repetition, the time to cover the first 10 m ($time_{10}$) was calculated. For $time_{10}$, the starting time corresponded to the starting time of the $time_{20}$ and the finishing time was the instant in which the sledge front crossed the 10 m line. Concerning the 2D kinematic analysis, the 20 m sprint track was divided into 5m-space intervals as follows: 0-5 m, 5-10 m, 10-15 m, 15-20 m. For each 5m-space interval, the average speed, average trunk angle ($trunk_{angle}$) at the beginning of the pushing cycle, and average trunk range of motion during the pushing cycle ($trunk_{rom}$) were calculated. The beginning and end of the pushing cycle were assumed, respectively, to be the instant in which the sticks impacted and were released from the ice. The trunk angle was calculated in the sagittal plane between a trunk line and the horizontal line. The trunk line was identified between: (i) the hip and the head, considering the trunk plus head as one rigid body ($trunk_{angle\text{-}h}$) (Fig. 4A) and (ii) the hip and the shoulder, considering the trunk as a rigid body ($trunk_{angle\text{-}s}$) (Fig. 4B). The hip point was identified on the shell bucket of the sledge and its position, together with the shoulder and head centre position, were tracked along all the pushing cycles using Kinovea. The $trunk_{angle\text{-}h}$ and $trunk_{angle\text{-}s}$ were both evaluated because the trunk has a major role in propulsion; however, athletes lacking abdominal muscles may use their heads to increase their propulsion.[25] To evaluate the contribution in propulsion of the trunk and head together, the $trunk_{rom\text{-}h}$ was calculated for $trunk_h$; whereas to evaluate the contribution of the trunk only, the $trunk_{rom\text{-}s}$ was calculated for $trunk_s$.

For the agility test, the total execution time was measured from the first curve (when the blades were almost parallel to the disc cones row) to the instant in which the front of the sledge aligned with the last cone (on the opposite disc cones row). For the fastest repetition, the first curve was discarded as previously recommended,[23] while the execution time for the second, third, and fourth left curves was calculated and averaged. Execution time for each left curve was calculated from the instant in which the blade ends were aligned with the cone (with blades almost orthogonal to the disc cones row) to the instant in which the blade ends were in the same position, but at the other side of the same cone. In addition, the left blade angle and left trunk angle in the coronal plane were evaluated when the participant was aligned with the disc cone and his back was in line with the camera (to reduce distortion due to perspective). To calculate left blade angle, a blade line was drawn between the contact point of the blade with the ice and the adhesive marker on the sledge backrest; whereas to calculate left trunk angle, a trunk line was drawn between the contact point of the blades with the ice and the adhesive marker on the athlete's back. The left blade angle was calculated as the angle between the blade line and the horizontal line (Fig. 4C), while the left trunk angle was calculated as the angle between the trunk line and the horizontal line (Fig. 4D). The same variables were calculated for the right curves: right execution time, right blade angle, and right trunk angle.

****Figure 4 near here****

2.4 Statistical analysis

Because the total number of athletes participated in this study was small, a non-parametric statistical analysis was carried out.

For the three alternating reach tests in the laboratory (Lab_h, Lab_e, Lab_s), the difference between left lateral bending time and right lateral bending time was evaluated using the Wilcoxon test. A Friedman test was used to assess statistical differences in the number of repetitions among the three tests. Tukey post hoc was used when necessary.

For the sprint test, statistical differences for the average speed, $trunk_{angle-h}$, $trunk_{angle-s}$, $trunk_{rom-h}$, and $trunk_{rom-s}$ between 5m-space intervals were evaluated using a Friedman test. When necessary, Tukey post hoc was used.

For the agility test, a Wilcoxon test was used to evaluate differences in execution time, blade angle, and trunk angle between the left curves and the right curves.

Finally, Spearman correlations between the three laboratory tests and the two on ice tests results were evaluated. Strength of correlation coefficients (r) were considered as: trivial ($r<0.1$), small ($0.1\leq r<0.3$), moderate ($0.3\leq r<0.5$), large ($0.5\leq r<0.7$), very large ($0.7\leq r<0.9$), nearly perfect ($0.9\leq r<1$) and perfect ($r=1$), according to Hopkins.[26]

The statistical analysis was done using Matlab (MatLab and Release 2015, The MathWorks, Inc., Natick, Massachusetts, United States) and the statistical significance was set as an alpha value of 0.05.

3. Results

3.1 Laboratory tests

Results for left lateral bending time, right lateral bending time, and number of executed repetitions of the three alternating reach tests are reported in Table 1 as mean ± standard deviation for each athlete. Comparing the left and right side, the Wilcoxon test showed no statistical differences between left lateral bending time and right lateral bending time in none of the three alternating reach tests. In contrast, a higher number of executed repetitions was found for Lab_h and Lab_e compared to Lab_s ($p<0.01$).

****Table 1 near here****

3.2 Sprint test

Overall, two to three pushing cycles were performed for each 5m-space interval. The first repetition was the fastest for six out of seven participants. For the fastest repetition, the $time_{10}$, $time_{20}$, average speed, $trunk_{angle-h}$, $trunk_{angle-s}$, $trunk_{rom-h}$, and $trunk_{rom-s}$ for all 5m-space intervals and participants are reported in Table 2 as mean ± standard deviation values. Average speed between 5m-space intervals showed statistical differences ($p<0.001$). Post hoc test showed lower average speed in 0-5 m than in 10-15 m and 15-20 m, and lower average speed in 5-10 m compared to average speed in 15-20 m. $Trunk_{angle-h}$ and $trunk_{angle-s}$ showed statistical differences between 5m-space intervals ($p<0.01$). In particular, $trunk_{angle-h}$ in 0-5 m was greater than $trunk_{angle-h}$ in 5-10 m and 10-15 m;

$trunk_{angle-s}$ was greater in 0-5 m than $trunk_{angle-s}$ in 10-15 m and 15-20 m. $Trunk_{rom-h}$ and $trunk_{rom-s}$ did not show statistical differences between 5m-space intervals.

****Table 2 near here****

3.3 Agility tests

For the fastest repetition, the total execution time and the left and right execution time, blade angle, and trunk angle values are reported for all participants in Table 3 as mean ± standard deviation. Greater blade angle was found for the left curves compared to the right curves ($p<0.01$); whereas no differences were found in the execution time and trunk angle between left and right curves.

****Table 3 near here****

3.4 Correlations

Spearman correlation results between the laboratory tests and tests on ice are reported in Table 4. All the correlations range from very high to nearly perfect. With respect to the alternating reach tests, the lateral bending time positively correlated and the number of repetitions negatively correlated with sprint time and trunk angle, and to all the variables of the agility test.

****Table 4 near here****

4. Discussion

Sprinting and agility are important factors that affect Para ice hockey performance; therefore, this study aimed to evaluate players' 2D kinematics during three laboratory tests (alternating reach tests) and two tests on ice (sprint and agility tests) with a portable and easy to use camera. The second purpose of the study was to evaluate the relationship between performance in the laboratory and on ice.

Since traditional video analysis systems are difficult to use on ice[19], in this study a GoPro high-speed action camera was adopted to collect participants' movements. The most important advantages of this collecting system are its portability, high resolution, and high sample frequency. To analyse and reconstruct movements in more than one plane, two synchronized and calibrated cameras are commonly used.[27] However, in the current work, the tests conducted on ice were mainly focused in one plane (sagittal for sprint tests and coronal for agility tests); therefore, the gestures can be assumed 2D and only one camera was used. A GoPro camera has previously been used to evaluate sport gestures and performance in both 2D and 3D.[27,28]

For Para ice hockey players, performance is a combination of sprinting and agility abilities, such as handling the puck and manoeuvring the sledge. Simulating typical technical gestures such as puck passing, puck receiving, and lateral fall, the three laboratory tests can be used to evaluate players' agility abilities. Overall, the laboratory tests showed that the participants can complete more reach and recovery repetitions by way of their hands or elbows than their shoulders. This finding confirms that recovering an upright position during puck passing and receiving, in which only hands or elbows are in contact with the ground, is less demanding for players compared to recovery to the upright position after falls (where the shoulders are in contact with the ice). Surprisingly, none of the three alternating reach tests showed a significant difference between the left and right lateral bending time. One might have expected a difference because the athletes involved in the current study have physical impairments of the lower limbs and spinal cord that usually cause asymmetry in movements.[21,22] A second possible reason that could induce a difference would be the dominant side, which was right-handed for all the participants. However, the absence of a difference between the left and right lateral bending times suggests that neither handedness nor lower body impairment favour one trunk side reach.

Concerning the sprint test, the fastest repetition was the first one for six out of seven participants. This result is similar to that found in a previous study of Para ice hockey, which suggested a decrease of phosphocreatine stores or slower resynthesis as possible causes for performance reduction.[2] The lower average speed in the first 10 m (0-10 m) compared to the second 10 m (10-20 m), together with the lack of differences in average speed between the last two 5m-space intervals (10-20 m), suggest that all the participants reached the greatest acceleration within the first 10 m and then continued with a smaller acceleration. As Table 2 shows, participants' velocities continued to increase throughout the 20 m path. This speed profile was because the participants started the test from a stationary position and accelerated to cover the entire distance in the shortest time possible. The average speed and kinematics corresponded with each other:

in the first pushing cycles (0-5 m) the trunk was more vertical; whereas in the second half of the path, participants assumed a greater trunk forward inclination and there were no differences in trunk angle between the last two segments (10-15 m and 15-20 m) (Table 2). These considerations were overall true for both trunk models (trunk plus head and trunk only), with a few small differences: the trunk plus head model showed differences between 0-5 m and 5-10 m and between 0-5 m and 10-15 m; whereas the trunk model showed differences between 0-5 m and 10-15 m and between 0-5 m and 15-20 m. Therefore, it seems that in order to generate propulsion, participants took advantage of head movements at lower speeds and then used mostly trunk movements. Trunk range of motion during the entire pushing phase did not show significant variations for the four 5m-space intervals. Similar findings, which involved less trunk inclination during the first pushing cycle compared to the following cycles and lower changes of trunk angle and trunk range of motion in the subsequent pushing cycles, have already been found in hockey players[29] and other Paralympic sitting sports, such as wheelchair racing.[20]

In the agility test, the lack of difference between left and right execution time was expected because the two setups were extremely similar. The significantly lower right blade angle compared to the left blade angle may be explained by the athletes' dominant side (right for all athletes), which may affect one curving side more than the other. A previous study on ice hockey players demonstrated that turning on the right was easier for right-handed shooters and vice versa.[7] When the kinematics of all four curves was considered, trunk angle showed a difference between the left curves and right curves[23]; however, discarding the first curve, trunk angle did not show statistical differences between the two sides. This finding would suggest that in the coronal plane, participants may bend the trunk towards the left or the right differently for the first curve (when starting from standstill), but when they are already moving, the difference between left and right trunk bending was negligible. The difference between the left and right blade angle may also be explained by asymmetrical movements due to participants' physical impairment.[21,22,30] It is possible that in order to keep the balance on the sledge during curves, participants compensated for their asymmetrical movements with a different lateral inclination of the sledge between left and right, but with no differences in the trunk. This control of the pelvis could be possible because of their residual voluntary control of the core muscles; in cases of more severe impact of impairment different findings would be expected.

Finally, the correlations found between the alternating reach test in which participants touched the ground with their elbows and the sprint test means that athletes who needed more time to recover the upright position in movements, such as puck passing and receiving, were the same as those who kept the trunk in a more vertical position at the beginning of the pushing phase. The correlations found between the alternating reach test in which participants touched the ground with their shoulders and both tests on ice (sprint and agility tests) suggest that participants who needed more time to recover the upright position after falling were the same as those who sprinted slower and had less sledge manoeuvrability in curves. Overall, the correlations found between the laboratory and the tests on ice may suggest that alternating reach tests could be used as a general index of the overall players' skating abilities. However, due to the importance of the trunk in sprint and manoeuvrability[31–33], the trunk kinematics should also be evaluated in order to have more detailed information of Para ice hockey players skating abilities. The current kinematic findings may also be used as baseline knowledge for specific considerations related to the impact of impairment on performance, possibly using specific software simulations.[34]

During the tests on ice, the participants were equipped with protective gear and a jersey, which may have affected the identification of the shoulder point, thereby possibly inducing relative movements between the body and the marker. Thus, it may have influenced trunk angle accuracy. Despite this possible limitation of the study, wearing protective gear and a jersey during the tests allowed for similar conditions to those encountered during a match or training session. The use of a high-speed action camera sharply reduced both acquisition and post-processing time, making these test protocols good tools to assess 2D kinematic aspects of athletes' performance during training throughout the season.

5. Conclusions

Sprint and sledge manoeuvrability are the two most important skills for Para ice hockey players. Kinematic analysis of athletes while skating is of great importance for the analysis of skating abilities and performance improvement. To assess an athlete's 2D kinematics, sport-specific tests and an acquisition technology were presented in this study that can be easily integrated into the training process, as well as used in difficult environmental conditions, such as an ice hockey rink. The agreement between the 2D kinematics in the laboratory and on ice were very good, suggesting that alternating reach tests may be an approximate indicator of overall athletes' skating abilities, but in order to have detailed kinematics information, video analysis is still required. Due to the importance of propulsion in increasing performance, the relationship between impairment and performance would be of great interest. Therefore, a future study including a larger number of participants with a wider range of physical impairments would aid in verifying this relationship. Specific considerations on how the impact of physical impairments on performance might also be addressed using software simulations.

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Declaration of Conflicting Interests

The authors declare that there is no conflict of interest

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Table 1. Laboratory test results for Alternating Reach Tests

Test	Variable	Participants							Mean±sd
		1	**2**	**3**	**4**	**5**	**6**	**7**	
Lab_h	**Left lateral bending time (s)**	1.4±0.1	1.4±0.1	1.3±0.1	1.1±0.1	1.6±0.1	1.7±0.2	1.5±0.2	1.4±0.2
	Right lateral bending time (s)	1.2±0.1	1.1±0.1	1.3±0.1	1.1±0.1	1.5±0.2	1.5±0.2	1.4±0.1	1.3±0.2
	Total number of left and right repetitions	23	25	24	28	20	19	21	**22±3***
Lab_e	**Left lateral bending time (s)**	1.0±0.0	1.2±0.1	1.0±0.1	1.0±0.1	1.5±0.1	1.2±0.1	1.2±0.1	1.2±0.2
	Right lateral bending time (s)	1.0±0.1	1.2±0.1	1.0±0.3	1.1±0.1	1.5±0.1	1.1±0.1	1.2±0.1	1.2±0.2
	Total number of left and right repetitions	30	25	31	28	20	27	26	**26±4***
Lab_s	**Left lateral bending time (s)**	1.7±0.1	2.1±0.1	1.4±0.1	2.2±0.1	2.5±0.2	3.0±0.5	1.6±0.2	2.1±0.6
	Right lateral bending time (s)	1.8±0.0	2.1±0.2	1.6±0.1	2.1±0.1	2.0±0.2	2.5±0.2	1.7±0.1	1.9±0.3
	Total number of left and right repetitions	18	15	20	14	14	11	19	16±3

Note. Three alternating reach tests: Lab_h in which athletes touched the ground with hands, Lab_e in which athletes touched the ground with elbows, Lab_s in which athletes touched the ground with shoulder. * statistically different from Lab_s (p<0.01).

Table 2. On ice sprint test results

Variable		**Participants**							**Mean±sd**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
time$_{10}$ (s)		2.8	2.9	2.8	3.0	3.3	3.4	3.5	3.1±0.3
time$_{20}$ (s)		4.6	4.7	4.6	4.8	5.3	5.4	6.2	5.1±0.6
Average speed (m/s)	**0-5 m**	3.5	3.5	3.7	3.7	3.6	3.1	3.1	**3.5±0.3**[a,b]
	5-10 m	5.1	5.0	5.2	4.9	4.5	4.3	3.4	**4.6±0.6**[b]
	10-15 m	5.4	5.2	5.6	5.5	4.9	4.8	3.7	5.0±0.7
	15-20 m	5.8	5.8	5.7	5.8	5.4	5.4	3.8	5.4±0.7
trunk$_{angle\text{-}h}$ (°)	**0-5 m**	48.3±4.7	63.3±4.0	57.8±4.9	61.8±4.2	69.5±4.2	59.7±4.7	53.7±1.5	59.2±6.8
	5-10 m	42.5±3.5	58.5±0.7	46.0±1.4	57.0±4.2	68.5±0.7	54.0±1.4	44.0±3.6	**52.9±9.4**[c]
	10-15 m	39.5±0.7	54.0±0.0	53.0±1.4	55.0±5.7	68.5±0.7	55.5±0.7	42.7±2.1	**52.6±9.5**[c]
	15-20 m	39.0±0.0	57.0±0.0	53.0±0.0	56.0±0.0	71.0±0.0	56.5±0.7	45.0±1.4	53.9±10.1
trunk$_{angle\text{-}s}$ (°)	**0-5 m**	58.7±4.5	69.0±2.6	67.8±8.3	68.5±3.9	86.3±3.9	75.0±2.6	60.7±4.2	69.4±9.2
	5-10 m	49.0±0.0	61.0±0.0	53.5±0.7	61.5±2.1	78.5±2.1	66.5±6.4	50.0±5.0	60.0±10.4
	10-15 m	44.0±1.4	57.0±0.0	55.5±0.7	57.0±5.7	74.0±0.0	66.0±0.0	47.3±1.5	**57.3±10.3**[c]
	15-20 m	45.0±0.0	58.0±0.0	56.0±0.0	59.0±0.0	74.0±0.0	65.5±0.7	45.5±2.1	**57.6±10.3**[c]
trunk$_{rom\text{-}h}$ (°)	**0-5 m**	12.0±5.6	10.7±3.5	9.8±2.4	9.0±3.2	10.3±3.9	3.7±0.6	9.3±3.2	9.3±2.6
	5-10 m	8.5±4.9	19.5±0.7	12.5±2.1	7.5±0.7	9.5±2.1	8.5±0.7	9.7±9.7	10.8±4.1
	10-15 m	9.5±9.5	19.0±2.8	11.0±2.8	10.0±1.4	11.5±4.9	8.0±0	7.7±4.0	11.0±3.8
	15-20 m	8.0±0.0	15.0±0.0	15.0±0.0	9.0±0	9.0±0.0	7.0±2.8	3.5±0.7	9.5±4.2
trunk$_{rom\text{-}s}$ (°)	**0-5 m**	12.0±5.2	7.3±2.5	9.5±1.7	8.5±2.4	9.0±1.6	9.3±3.5	10.0±1.0	9.4±1.4
	5-10 m	11.0±0.0	14.5±3.5	10.5±2.1	5.5±2.1	8.5±3.5	12.5±2.1	19.0±8.5	11.6±4.3
	10-15 m	13.5±3.5	16.0±1.4	6.5±2.1	5.5±4.9	11.0±5.7	11.5±0.7	22.3±4.0	12.3±5.7
	15-20 m	10.0±0.0	15.0±0.0	6.0±0.0	7.0±0.0	8.0±0.0	9.5±2.1	20.0±4.2	10.8±5.0

Note. Time at 10 m (time$_{10}$), time at 20 m (time$_{20}$) for the fastest repetition was reported for all athletes. In addition for all athletes, average speed, trunk plus head angle (trunk$_{angle\text{-}h}$), trunk angle (trunk$_{angle\text{-}s}$), trunk plus head range of motion (trunk$_{rom_h}$), and trunk range of motion (trunk$_{rom_s}$) were reported for each 5m-space interval (0-5 m, 5-10 m, 10-15 m, 15-20 m). Statistical differences in speed (p<0.001): [a] statistically different from average speed in 10-15 m; [b] statistically different from average speed in 15-20 m. Statistical difference in trunk angle (p<0.01): [c] statistically different from trunk angle in 0-5 m.

Table 3. On ice agility test results

	Variables	Participants						Mean±sd
		1	2	3	4	5	6	
	Total execution time (s)	9.9	10.1	10.1	11.1	10.9	15.2	11.2±1.9
Left	**Execution time (s)**	0.6±0.0	0.7±0.1	0.7±0.1	0.8±0.1	0.9±0.1	1.5±0.1	0.9±0.3
	Blade angle (°)	48.3±2.1	53.0±5.6	48.3±1.2	58.3±4.0	59.0±3.6	63.0±12.3	**55.0±7.6***
	Trunk angle (°)	48.7±0.6	55.7±2.1	59.7±0.6	63.0±3.0	62.7±3.2	66.0±4.0	59.3±6.3
Right	**Execution time (s)**	0.6±0.1	0.7±0.0	0.7±0.1	0.8±0.0	0.9±0.2	1.1±0.1	0.8±0.2
	Blade angle (°)	44.7±2.1	42.0±4.6	53.3±1.5	45.3±2.9	48.0±1.7	57.7±5.1	48.5±6.2
	Trunk angle (°)	57.7±2.1	57.0±1.7	55.3±2.5	57.7±3.8	55.3±2.5	66.7±2.5	58.3±4.5

Note. Statistical difference with right side: * $p<0.01$

Table 4. Correlation results

				Laboratory tests								
				Alternating reach tests								
				Lab$_h$			Lab$_e$			Lab$_s$		
				Left lateral bending time	Right lateral bending time	Total number of left and right repetitions	Left lateral bending time	Right lateral bending time	Total number of left and right repetitions	Left lateral bending time	Right lateral bending time	Total number of left and right repetitions
Ice tests	Sprint test	time$_{20}$		0.60	0.48	-0.46	0.69	0.66	-0.70	**0.99****	0.79	**-0.97****
		time$_{10}$		0.60	0.48	-0.46	0.69	0.66	-0.70	**0.99****	0.79	**-0.97****
		Average speed	0-5	-0.81	-0.27	0.62	-0.43	-0.14	0.35	-0.44	-0.54	0.40
			5-10	-0.64	-0.44	0.49	-0.68	-0.65	0.71	**-1.00****	**-0.81***	**0.99****
			10-15	**-0.93****	-0.53	0.71	**-0.84***	-0.62	0.77	-0.83*	-0.67	0.75
			15-20	-0.69	**-0.95****	0.80	-0.62	-0.30	0.34	-0.56	-0.13	0.45
		trunk$_{angle\text{-}h}$	0-5	0.20	0.03	0.09	0.77	**0.97****	**-0.89***	0.54	0.41	-0.49
			5-10	0.20	0.03	0.09	0.77	**0.97****	**-0.89***	0.54	0.41	-0.49
			10-15	0.49	0.50	-0.37	0.77	0.79	-0.77	**0.89***	0.58	**-0.84***
			15-20	0.49	0.27	-0.20	**0.93****	**0.97****	**-0.94****	0.66	0.49	-0.58
		trunk$_{angle\text{-}s}$	0-5	0.64	0.50	-0.43	**0.93****	**0.88***	**-0.89***	**0.83***	0.58	-0.75
			5-10	0.49	0.50	-0.37	0.77	0.79	-0.77	**0.89***	0.58	**-0.84***
			10-15	0.57	0.51	-0.41	**0.86***	**0.85***	**-0.84***	**0.87***	0.59	-0.81
			15-20	0.49	0.50	-0.37	0.77	0.79	-0.77	**0.89***	0.58	**-0.84***
		trunk$_{rom\text{-}h}$	0-5	-0.06	-0.32	0.14	-0.03	-0.03	-0.03	-0.54	-0.52	0.61
			5-10	0.13	0.02	0.03	0.36	0.24	-0.20	-0.38	-0.29	0.47
			10-15	-0.20	-0.29	0.43	0.37	0.56	-0.43	-0.26	-0.23	0.32
			15-20	-0.55	-0.44	0.65	-0.08	0.12	0.06	-0.59	-0.42	0.60
		trunk$_{rom\text{-}s}$	0-5	0.12	0.44	-0.49	-0.43	-0.77	0.66	-0.37	-0.58	0.41
			5-10	0.49	-0.03	-0.26	0.25	0.00	-0.14	-0.03	0.29	0.06
			10-15	0.52	-0.09	-0.26	0.34	0.15	-0.31	-0.03	0.17	0.09
			15-20	0.46	-0.24	-0.14	0.34	0.27	-0.43	0.14	0.38	-0.12
	Agility test	Left	Execution time	0.52	0.58	-0.46	0.61	0.55	-0.55	**0.90***	0.66	**-0.88***
			Blade angle	0.64	0.44	-0.49	0.68	0.65	-0.71	**1.00****	**0.81***	**-0.99****
			Trunk angle	0.35	0.54	-0.38	0.41	0.37	-0.35	**0.81***	0.60	**-0.82***
		Right	Execution time	0.52	0.58	-0.46	0.61	0.55	-0.55	**0.90***	0.66	**-0.88***
			Blade angle	0.64	**0.88***	**-0.83***	0.28	-0.18	0.09	0.20	-0.06	-0.12
			Trunk angle	0.78	0.48	-0.75	0.36	0.10	-0.32	0.64	0.47	-0.60

Note: Significant correlations between laboratory and ice performance: * $p<0.05$, ** $p<0.01$.

Figure 1. Para ice hockey player's equipment. Athletes play sitting on a sledge, which is made of a metallic frame and a bucket. The sledge is mounted on a couple of ice hockey blades and the bucket may be equipped with a backrest and a cushion. Straps are used to secure athletes to the sledge. The propulsion is obtained by a couple of wooden sticks.

Figure 2. Laboratory tests. Three alternating reach tests were performed in the laboratory in which the participants touched the ground respectively with: (A) hand palms, (B) elbows, (C) shoulders.

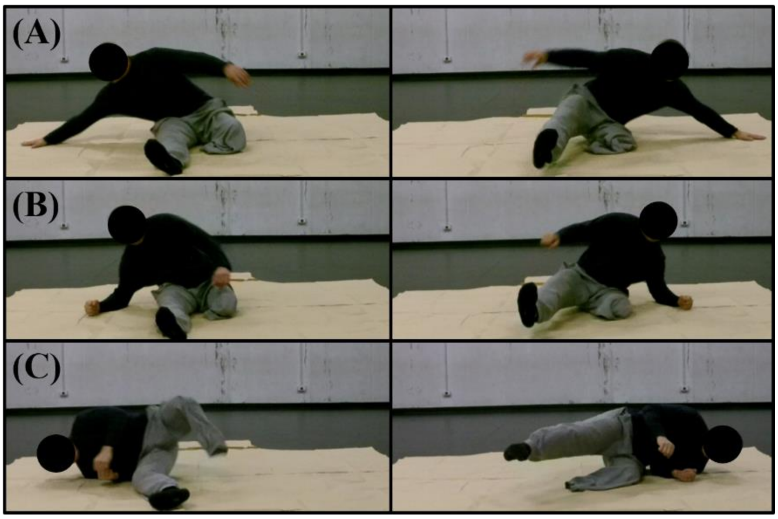

Figure 3. On ice agility test description. Participants performed four curves to the left (A) and four curves to the right (B). A GoPro camera was aligned with the row of dark disc cones, 3 m away from the first disc cone to collect the left (A) and right (B) curves, respectively.

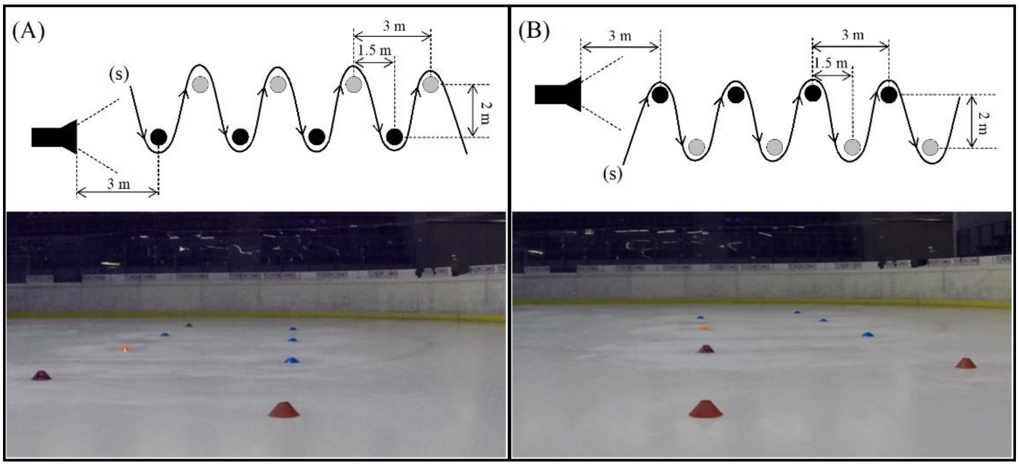

Figure 4. On ice tests analysis. In the sprint test, trunk angle was calculated between the trunk line and the horizontal line. The trunk line was drawn between: (A) the hip and the center of the head and (B) the hip and the shoulder. In the agility test, blade angle and trunk angle were calculated between the horizontal line and (C) the blade line and (D) the trunk line. Blade and trunk lines were drawn between ice-blade interface point and middle point of the backrest or middle point of the shoulders, respectively.