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ORIGINAL ARTICLE

Ground reaction forces produced by two different hockey skating arm swing techniques

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Abstract
The arm swing in hockey skating can have a positive effect on the forces produced by each skate, and the resulting velocity from each push off. The main purpose of this study was to measure the differences in ground reaction forces (GRFs) produced from an anteroposterior versus a mediolateral style hockey skating arm swing. Twenty-four elite-level female hockey players performed each technique while standing on a ground-mounted force platform, and all trials were filmed using two video cameras. Force data was assessed for peak scaled GRFs in the frontal and sagittal planes, and resultant GRF magnitude and direction. Upper limb kinematics were assessed from the video using Dartfish video analysis software, confirming that the subjects successfully performed two distinct arm swing techniques. The mediolateral arm swing used a mean of 18.38° of glenohumeral flexion/extension and 183.68° of glenohumeral abduction/adduction while the anteroposterior technique used 214.17° and 28.97° respectively. The results of this study confirmed that the mediolateral arm swing produced 37% greater frontal plane and 33% less sagittal plane GRFs than the anteroposterior arm swing. The magnitudes of the resultant GRFs were not significantly different between the two techniques; however, the mediolateral technique produced a resultant GRF with a significantly larger angle from the direction of travel (44.44°) as compared to the anteroposterior technique (31.60°). The results of this study suggest that the direction of GRFs produced by the mediolateral arm swing more closely mimic the direction of lower limb propulsion during the skating stride.

Keywords: *Hockey skating, arm swing, ground reaction forces*

Highlights

- The most effective arm swing in hockey skating is controversial.
- The side to side arm swing produces forces in the same direction as the pushing skate.
- The GRF's in the pushing direction were increased using the side to side arm swing.
- This arm swing is recommended to ice hockey players to improve skating speed and push off force.

Introduction

Arm movements in travelling sport skills, such as running, jumping and skating where the primary force producing action occurs in the legs, can contribute to performance. The trunk and upper limbs facilitate ideal lower body mechanics by opposing and stabilising the rotational movements of the lower body (Miller, Caldwell, Van Emmerik, Umberger, & Hamill, 2009; Umberger, 2008). Forceful upward movement of the upper limbs can produce ground reaction forces (GRFs) that if used properly can help increase propulsive forces used for travelling sport skills (Dapena, 1988; Harman, Rosenstein, Frykman, & Rosenstein, 1990; Payne, Slater, & Telford, 1968; Shetty & Etnyre, 1989). Studies show that the faster and more powerful the arm swing, the greater the resultant forces that can be used to propel the athlete in the direction of desired travel (Feltner, Bishop, & Perez, 2004; Hara, Shibayama, Takeshita, & Fukashiro, 2006; Lees, Vanrenterghem, & De Clercq, 2006).

Two styles of arm swing are commonly taught to hockey players although controversy exists as to which style is more likely to result in faster skating.

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Figure 1. Peak upswing for the right arm during the anteroposterior and mediolateral arm swing techniques.

The mediolateral arm swing uses glenohumeral flexion and adduction on the forward movement and extension and abduction on the backward movement, it occurs in both the frontal and sagittal planes (see Figures 1 and 2). This style of arm swing is easily observed in speed skaters who swing the arms sideways, wide of the body corresponding to the sideways push of the skates on the ice (Alexander & Hayward, 2010). The shoulders must abduct and adduct to counter the direction of push of the skates in the sideways directions, this will help 'maintain balance, momentum, and increased velocity' (Edwards, 2009). The anteroposterior arm swing is comprised of almost entirely sagittal plane glenohumeral flexion and extension (see Figures 1 and 2). This technique is taught by many hockey coaches (Bracko, 1999) and more closely mimics that seen in running (Glantz, 2010; Nauman, 2009; Rhoads, 2010; Stamm, 2000).

Advocates for the anteroposterior technique of arm swing claim that it helps the athlete to produce 'momentum in the same way that swinging your

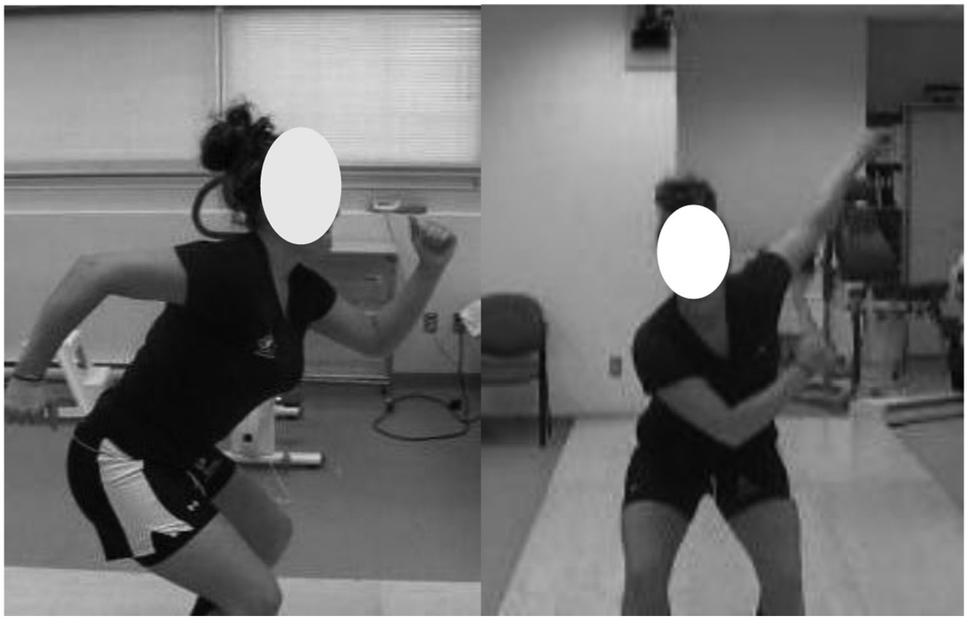

Figure 2. Peak down swing for the right arm during the anteroposterior and mediolateral arm swing techniques.

arms does while running' (Nauman, 2009). It is believed that this forward momentum may contribute to forward translation in hockey skating just as it does during running and sprinting. It is sometimes argued that the sideways movement of the arms as used in the mediolateral technique is a waste of energy and power, perhaps even contributing to a loss of balance (Rhoads, 2010).

There has been very limited study of the biomechanics of the arm swing in hockey. One study (Bracko et al., 1996) examined acceleration of ice hockey players using three different arm swing techniques. These techniques included (i) flexion and extension of the glenohumeral joint, (ii) abduction and adduction of the glenohumeral joint and (iii) 45 degree angle movements of the glenohumeral joint. The study included two groups based on playing experience, divided into less than five years of playing experience and more than five years of playing experience. Although results did not show statistical significance, the mean velocity in all groups was faster when using the abduction/adduction arm swing.

An important aspect of the arm swing is the timing of the movements of each of the arms relative to the legs. Extensive observation of skilled hockey skaters and speed skaters by the researchers have indicated that the timing of the arms is closely synchronised with that of the legs. As the arms move from adduction to abduction, they are synchronised with the abduction/adduction movements of the legs. As the right skate begins to push sideways on the ice, the left arm begins movement to the left in the abduction direction.

The timing of the arm swing relative to the legs in the vertical jump was examined using two types of arm swing: the simultaneous arm swing and the early arm swing (Gutierrez-Davila, Amaro, Garrido, & Rojas, 2014). No difference was found in jump height between techniques, suggesting that slight variations in arm swing timing may not significantly affect the outcome of a skill.

In order to optimise the effects of the sideways arm swing on the forces exerted on the ice by the skate, the arm swing sideways should occur in the same frontal plane as the skate leg is pushing sideways. The plane of the leg during the abduction and knee extension during push off should be close to the plane of the arm as it swings in the opposite direction.

The reaction force from the ice on the skate lies in a plane perpendicular to the gliding direction of the skate (van Ingen Schenau, De Boer, & De Groot, 1989). The optimal angle of the pushing skate at top speed appears to be close to an angle of 45° to the gliding direction down the track. This angle is seen to decrease at the start of the race and during the curves and to increase during the straights and as speed approaches maximal.

The primary purpose of the study was to determine the differences in GRFs produced from an anteroposterior versus a mediolateral style arm swing. Participants performed the two contrasting styles of arm swing while standing on a force plate. A secondary purpose was to relate the findings of this study to ideal forward hockey skating technique.

Methods

Participants

Elite-level female hockey players were asked to perform two contrasting styles of hockey skating arm swing while standing on a force platform. This study received human ethics approval from the University of Manitoba Education/Nursing Research Ethics Board. All subjects submitted completed consent forms prior to testing, those not yet 18 years of age or older required parental/guardian consent in order to volunteer for this study. Twenty-four female participants aged 16–25 years were recruited from elite-level hockey teams including high school, university and national team programmes. The high school team used for recruitment competes in a North American Junior Women's Hockey League that is committed to the highest level of competition. All other subjects recruited for this study played at the Canadian Interuniversity Sport (CIS) or the National Collegiate Athletic Association (NCAA) Division I level (USA). All participants were volunteers for this study, no compensation was offered.

Data collection

Participants' leg dominance (right or left), preferred shooting hand (right or left), age, height, mass, reported number of years of hockey experience and level of hockey experience was recorded prior to the onset of testing. Leg dominance was determined by asking subjects which side they preferred to use in a one-legged hopping task, a brief trial was performed by each subject to confirm their preference. Of the 24 subjects, 14 were high school players and 10 were CIS/NCAA level players. The mean age, height and mass of the subjects were 18.17 years, 1.68 m and 69.1 kg, respectively. The mean number of years of hockey experience was 12.17 years. Support leg dominance opposite to the preferred shooting side was reported by 58.33% of subjects.

A 10-min training session was conducted to demonstrate and allow the participants to practice the anteroposterior and mediolateral arm swing techniques. During the training session, subjects were shown video clips of the arm swing techniques being performed both on ice and in the laboratory setting. A metronome was also used at this time to allow subjects to practice the arm swings at a uniform speed of 1 Hz, approximating typical moderately high velocity ice skating strides (Upjohn, Turcotte, Pearsall, & Loh, 2008). The metronome was also used during data collection.

During data collection, two video cameras recorded all trials from an anterior view and a sagittal view for subsequent analysis of upper body kinematics using Dartfish (2014) motion analysis software. Subjects stood with their dominant foot on top of the ground-mounted force platform wearing athletic shoes with feet slightly wider than shoulder width and the knees and hips flexed close to 90°. The subjects were randomly assigned to perform 10 repetitions of either the anteroposterior or mediolateral arm swing to the pace of the metronome. Force platform data was collected for the duration of the 10 repetitions. Following a brief rest, the subject repeated this procedure for a total of three trials. Following a resting period, the subject was asked to complete the same test procedure while performing the remaining arm swing technique. Each subject completed three anteroposterior trials and three mediolateral trials that were included in the analysis.

Force platform and video analysis

Force data for this study was collected using an OR-6 model Biomechanics Force Platform manufactured by Advanced Mechanical Technology Inc. (2010) and located at the Pan Am Clinic Foundation, David and Ruth Asper Biomechanics Research Centre. The force platform data collection was conducted by the technician from the Biomechanics Research Centre who had expertise and experience. Force platform data was amplified with an MSA-6 Mini Amp strain gauge amplifier with a gain of 4000, the recorded sampling rate was 1000 Hz. The recorded data includes GRFs in each of the three planes measured in Newtons as well as moments about the three axes measured in Newton-metres.

The frontal (F_X) and sagittal (F_Y) plane GRFs were scaled by dividing them by the corresponding vertical (F_Z) force at each time point. The X and Y components of the GRFs were divided by the Z component, so that these force values were corrected for the body weight of each participant. These corrected GRF components then represented the scaled values of the forces in the X and Y directions.

Two Canon GL2 standard definition digital video camcorders were used to film the participants performing all trials during data collection. Kinematic analysis of the video footage was performed using Dartfish TeamPro software version 6.0 (2014). Dartfish is a video analysis provider based in Switzerland, which enables detailed analysis of video files by use of on screen graphics, text, voice-over, frame selection and kinematic analysis. Using the Dartfish digitising programs, it is possible to estimate linear and angular displacements and velocities, and to graphically display these values from Excel files.

Shoulder and elbow measurements of the ipsilateral arm were taken at peak upswing and peak downswing for the mediolateral and anteroposterior arm swing trials of each subject. Peak upswing occurs at the point when the shoulder reaches its maximum angle of flexion (anteroposterior arm swing) or abduction (mediolateral arm swing). Peak down swing occurs when the shoulder reaches its maximum angle of extension (anteroposterior arm swing) or adduction (mediolateral arm swing), see Figures 1 and 2. One arm swing was considered as the motion from peak upswing to peak downswing, the time taken to complete this motion was measured for confirmation of adherence to the metronome timing of 1 Hz. The frequency of 1 Hz was chosen as it closely resembled the stroke frequency during actual skating races and the arm movements could be controlled by the participants. The average stroke frequency of elite speed skaters has been reported to be 1.5 Hz regardless of the skill or training of the participants (de Boer, Schermerhorn, Gademan, de Groot, & Schenau, 1986; van Ingen Schenau et al., 1989). A higher frequency, such as 2 Hz would be difficult to control and would require more stabilising effort and muscle control from the participants.

Shoulder flexion and extension were measured as the angle between the long axis of the humerus and the long axis of the trunk in the sagittal plane. Total range of motion of the glenohumeral joint through flexion/extension was calculated from peak upswing to peak downswing for inclusion in the statistical analysis.

Shoulder abduction and adduction were measured as the angle between the long axis of the humerus and the long axis of the trunk in the frontal plane. Total range of motion of the glenohumeral joint through abduction/adduction was calculated from peak upswing to peak downswing for inclusion in the statistical analysis. Elbow range of motion was measured using the angle between the long axis of the humerus and the long axis of the forearm. Total range of motion of the elbow joint through flexion/extension was calculated from peak upswing to peak downswing for inclusion in the statistical analysis. The angular velocity of glenohumeral flexion/extension, glenohumeral abduction/adduction and elbow flexion/extension were calculated in deg/s using the measured joint range of motion and the time from peak upswing to peak downswing.

Statistical analysis

The critical *p*-value for all statistical tests was set at <.05. Mean peak scaled GRFs in the frontal and sagittal planes and resultant GRF angle were assessed using one-tailed paired *t*-tests. Resultant GRF magnitude was analysed using a two-tailed paired *t*-test. Kinematic measurement variables for statistical analysis include the time of the arm swing and joint ranges of motion of the glenohumeral and elbow joints at peak upswing and peak downswing. Paired *t*-tests were used to determine significant differences between the two arm swing techniques performed during the study.

Results

The resulting peak scaled frontal and sagittal plane GRFs for the two arm swing techniques are summarised in Table I, the results of the one-tailed paired *t*-test are recorded in Table II.

The one-tailed paired *t*-test revealed a statistically significant difference between the mean ($\bar{x}$) peak scaled frontal plane GRFs produced by mediolateral ($\bar{x} = 0.45,\ s = 0.22$) and the anteroposterior ($\bar{x} = 0.28,\ s = 0.20$) arm swing techniques $t(23) = 2.87,\ p = .004,\ \alpha = 0.05$. This indicates that the mediolateral arm swing produced significantly higher GRFs in the frontal plane than the anteroposterior arm swing.

The two-tailed paired *t*-test failed to reveal a statistically significant difference between the magnitudes of the resultant GRFs produced by mediolateral ($\bar{x} = 0.60,\ s = 0.23$) and the anteroposterior ($\bar{x} = 0.61,\ s = 0.25$) arm swing techniques $t(23) = -0.122,\ p = .904,\ \alpha = 0.05$. This indicates that the mediolateral and anteroposterior arm swings produced resultant GRFs of similar magnitude.

The one-tailed paired *t*-test revealed a statistically significant difference between the resultant GRF angles produced by mediolateral ($\bar{x} = 44.44,\ s = 17.84$) and the anteroposterior ($\bar{x} = 31.6,\ s = 19.14$) arm swing techniques $t(23) = 2.48,\ p = .01,\ \alpha = 0.05$. This indicates that the mediolateral arm swing produced significantly larger resultant GRF angles from the sagittal plane than the anteroposterior arm swing.

The time for one arm swing was defined as the time between peak upswing and peak downswing. The two-tailed paired *t*-test failed to reveal a statistically significant difference between the mediolateral ($\bar{x} = 1.00,\ s = 0.0110$) and the anteroposterior ($\bar{x} = 0.999,\ s = 0.0125$) arm swing techniques $t(138) = 0.626,\ p = .532,\ \alpha = 0.05$. This indicates that the mediolateral and anteroposterior arm swings were performed in the same amount of time during testing suggesting that the time of arm swing was successfully controlled by the use of the metronome.

Peak upswing of the mediolateral technique occurs when the dominant side arm reaches maximum abduction. The typical mediolateral arm swing as performed during testing consisted of 16.72° of glenohumeral extension ($s = 6.58$), 129.82° of glenohumeral abduction ($s = 16.5$) and 2.56° of elbow flexion ($s = 2.60$) at peak upswing.

Peak downswing of the mediolateral arm swing occurs when the dominant side arm reaches maximum adduction. The typical mediolateral arm

Table I. Descriptors of the force platform data from the anteroposterior (AP) and mediolateral (ML) arm swing techniques

		N	Mean	Standard deviation
Frontal plane GRF	ML	24	0.445	0.215
	AP	24	0.281	0.199
Sagittal plane GRF	ML	24	0.396	0.183
	AP	24	0.526	0.233

Table II. The results of the one-tailed paired *t*-test of the frontal and sagittal plane GRFs during the mediolateral (ML) and anteroposterior (AP) arm swing, $p < .05$.

		Paired differences							
					95% Confidence interval of the difference				
		Mean difference	Standard deviation	Standard error of the mean	Lower	Upper	*t*	df	*p*-Value (one-tailed)
Pair 1	ML – AP Frontal	0.164	0.279	0.057	0.046	0.282	2.87	23	.004*
Pair 2	ML – AP Sagittal	−0.130	0.285	0.058	−0.251	−0.010	−2.24	23	.018*

swing as performed during testing consisted of 12.13° of glenohumeral flexion ($s = 5.90$), 53.75° of glenohumeral adduction ($s = 4.99$) and 101.66° of elbow flexion ($s = 9.53$) at peak downswing.

The typical anteroposterior arm swing consisted of 74.35° of glenohumeral extension ($s = 6.03$), 4.68° of glenohumeral adduction ($s = 4.12$) and 24.66° of elbow flexion ($s = 6.42$) at peak downswing.

The two-tailed paired *t*-test revealed a statistically significant difference between the glenohumeral flexion/extension range of motion between the mediolateral ($\bar{x} = 28.97,\ s = 8.78$) and the anteroposterior ($\bar{x} = 214.17,\ s = 12.12$) arm swing techniques, $t(138) = -139.51,\ p \leq .001,\ \alpha = 0.05$. This finding indicates that the mediolateral arm swing had a significantly smaller range of motion through glenohumeral flexion and extension than the anteroposterior arm swing.

The two-tailed paired *t*-test revealed a statistically significant difference between the glenohumeral flexion/extension angular velocities of the mediolateral ($\bar{x} = 28.87,\ s = 8.85$) and anteroposterior ($\bar{x} = 214.46,\ s = 12.50$) arm swing techniques, $t(138) = 148.60,\ p \leq .001,\ \alpha = 0.05$. The mediolateral arm swing had significantly lower angular velocity in glenohumeral flexion and extension.

The two-tailed paired *t*-test revealed a statistically significant difference between the abduction/adduction range of motion between the mediolateral ($\bar{x} = 183.68,\ s = 18.60$) and the anteroposterior ($\bar{x} = 18.38,\ s = 4.84$) arm swing techniques, $t(138) = 103.23,\ p \leq .001,\ \alpha = 0.05$. This indicates that the mediolateral arm swing had a significantly larger range of motion through glenohumeral abduction and adduction than the anteroposterior arm swing.

The two-tailed paired *t*-test revealed a statistically significant difference between the glenohumeral abduction/adduction angular velocities of the mediolateral ($\bar{x} = 183.59,\ s = 18.60$) and anteroposterior ($\bar{x} = 18.33,\ s = 4.84$) arm swing techniques, $t(138) = -100.19,\ p \leq .001,\ \alpha = 0.05$. The mediolateral arm swing had significantly higher angular velocity in glenohumeral abduction and adduction.

The two-tailed paired *t*-test revealed a statistically significant difference between elbow flexion/extension range of motion between the mediolateral ($\bar{x} = 102.71,\ s = 15.78$) and the anteroposterior ($\bar{x} = 82.25,\ s = 7.32$) arm swing techniques, $t(138) = 23.37,\ p \leq .001,\ \alpha = 0.05$. This indicates that the mediolateral arm swing had a significantly larger range of motion through elbow flexion and extension than the anteroposterior arm swing.

The two-tailed paired *t*-test revealed a statistically significant difference between the elbow flexion/extension angular velocities of the mediolateral ($\bar{x} = 102.71,\ s = 15.68$) and anteroposterior ($\bar{x} = 82.55,\ s = 7.41$) arm swing techniques, $t(138) = -14.27,\ p \leq .001,\ \alpha = 0.05$. The mediolateral arm swing had significantly higher angular velocity in elbow flexion and extension.

Discussion

Kinematic analysis of the video taken during testing showed that the subjects used significantly different movement patterns to perform each arm swing technique. The mediolateral technique had significantly more frontal plane range of motion and the anteroposterior technique had significantly more sagittal plane range of motion. These results were expected based on the arm swing training provided prior to data collection.

The range of motion at the elbow through flexion and extension was also shown to be significantly different between the two techniques with the mediolateral technique using a greater range of elbow motion as compared to the anteroposterior technique. During the training session athletes were instructed specifically on glenohumeral movements and allowed to freely move the elbows in a way that felt natural to them. It is known that trained athletes who use their arms during skill performance have shown the ability to use their arms more effectively than unskilled individuals (Shetty & Etnyre, 1989). In the present study, the mean reported number of years participating in structured competitive hockey was 12.17 years ($s = 2.49$). Based on the work of Shetty and Etnyre (1989), it was expected that these athletes would select a skilled movement pattern that is effective for performance.

The angular velocities of glenohumeral flexion/extension, abduction/adduction and elbow flexion/extension were all significantly different between the two arm swing techniques. The subjects performed the arm swing trials to the beat of a metronome set to 1 Hz. Successful adherence to the cadence was monitored during the testing session using the video records to ensure uniformity of arm swing velocities. The mediolateral arm swing had higher glenohumeral abduction/adduction and elbow flexion/extension angular velocities while the anteroposterior arm swing had higher glenohumeral flexion/extension angular velocity.

The results of this study confirm that the mediolateral arm swing produces lower peak sagittal plane and higher peak frontal plane GRFs than the anteroposterior arm swing technique. The mediolateral arm swing occurs primarily in the frontal plane. As the hip extends and abducts during the propulsive phase, the shoulder of the same side of the body flexes and adducts. When the right leg begins the recovery phase by flexing and adducting at the hip, the right shoulder extends and abducts in the (Havam, 2007) opposite direction. This technique of arm swing is widely used by speed skaters during high velocity skating (US Speedskating, 2010).

It was hypothesised at the onset of the study that the mediolateral arm swing technique would produce greater frontal plane and lesser sagittal plane GRFs than the anteroposterior arm swing. Statistical analysis of the data collected for this study confirmed this result with the mediolateral arm swing producing 37% greater frontal plane and 33% less sagittal plane GRFs than the anteroposterior arm swing.

Consistent with Newton's third law of action and reaction, the mediolateral arm swing produces a higher proportion of GRFs in the frontal plane as compared with the anteroposterior technique. The anteroposterior arm swing is advocated by many hockey and skating coaches (Glantz, 2010; Nauman, 2009; Rhoads, 2010; Stamm, 2000) and is performed using primarily glenohumeral flexion and extension. Hockey skating coaches often tend to favour this technique on the incorrect basis that it helps to create and maintain forward momentum of the skater (Glantz, 2010; Nauman, 2009). It is believed by some coaches that any motion of the arms that is not directed forward and backward is wasted energy and will negatively affect skating velocity (Rhoads, 2010). The arms alone are not able to generate momentum for the skater without transferring the force that is created against the ground surface (Dapena, 1988). This suggests that the momentum that is generated by the arms should be produced in the same direction as the momentum created by the propulsion of the legs.

Studies of the action of the arms generally conclude that the use of an arm swing can contribute to performance by various mechanisms (Arellano & Kram, 2011; Bhowmick & Bhattacharyya, 1988; Cheng, Wang, Chen, Wu, & Chiu, 2008; Feltner, Fraschetti, & Crisp, 1999; Hara, Shibayama, Arakawa, & Fukashiro, 2008; Hara et al., 2006; Harman et al., 1990; Lees et al., 2006; Miller et al., 2009; Ortega, Fehlman, & Farley, 2008; Shetty & Etnyre, 1989; Umberger, 2008). To date, the only study located that focused specifically on the direction of the arm swing was done by Hara et al. in 2008 which examined the effect of arm swing direction in the sagittal plane on horizontal forward and backward jumping. The results of this study showed that the arm swing should occur in the same direction as the jump, that is, the arms swing forward when the direction of travel is forward and the arms swing backward if the jump is to travel backward.

The resultant magnitude of the GRFs is similar between the two arm swings, though the direction of the resultant is significantly different. In order for the forces created by the arm swing to contribute maximally to the forward velocity of a skater, they should be directed along the line of push of the propulsive leg. The GRFs produced by the anteroposterior arm swing are directed more posteriorly than the mediolateral technique because the upswing of the arm occurs in the sagittal plane. Due to the nature of blade to ice contact, a portion of the GRFs will be lost to a sliding motion and will not contribute to forward propulsion. It is recommended that skaters push off with the propulsive leg at an angle of 45° to the sagittal plane (Alexander, Hayward, & Taylor, 2010). The mediolateral arm swing generates GRFs that are directed very close to the recommended 45 degree angle of push and thus may contribute more efficiently to forward velocity production. Mike Bracko, hockey researcher and director of Calgary's Institute for Hockey Research has been quoted as saying 'fast skaters move their arms side to side as opposed to slow skaters who move their arms back and forth' (McMurray, 2010).

Conclusions

Both the anteroposterior and mediolateral arm swing techniques produce resultant GRFs of similar magnitudes but the plane of motion of the arm movement closely reflects the plane of GRFs produced. The mediolateral arm swing technique uses a movement pattern that closely opposes the action of the legs using abduction and adduction of both the glenohumeral and hip joints. This acts to counterbalance the rotation produced about the longitudinal axis of the body. The GRFs produced by the mediolateral arm swing closely match in direction with the angle of push of the leg against the ice which may lead to a greater contribution to skating velocity. Ice hockey skaters should perform the mediolateral arm swing to maximise the effective GRFs produced with each stride, producing a higher impulse and skater velocity with each full skating stride.

Disclosure statement

No potential conflict of interest was reported by the authors.

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