THE RELATIONSHIP BETWEEN TRUNK ROTATION AND SHOT SPEED WHEN PERFORMING ICE HOCKEY WRIST SHOTS

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Abstract

There has been minimal work examining the kinematics of ice hockey wrist shots. The objective was to determine if puck and blade speed were related to trunk rotation during ice hockey wrist shots in elite and recreational players. Elite (n=10) and recreational (n=10) ice hockey players completed wrist shots while skating and from a stationary position on real ice. A 14 camera motion capture system collected kinematic data for the trunk, pelvis, stick, and puck. Dependent variables included peak puck and blade speeds. Independent variables included peak trunk rotation angles, trunk rotation range of motion (ROM), and group (elite vs. recreational). Hierarchical linear models compared relationships between dependent and independent variables for both skating and stationary wrist shots. Greater peak trunk rotation away from the net was related to faster puck and blade speeds for skating ($p<0.01$) and stationary ($p=0.02$ to 0.04) wrist shots. This relationship was stronger in the recreational group for skating wrist shots ($p<0.01$). Greater trunk rotation ROM was related ($p=0.01$) to faster puck and blade speeds for the skating wrist shots only. Coaches should encourage players to increase trunk rotation away from the net during wrist shots, especially in recreational players.

Keywords: ice hockey, motion capture, wrist shot, shooting, trunk, joint angle

Introduction

Ice hockey is a popular sport with more than 1.7 million registered players worldwide according to the International Ice Hockey Federation (IIHF, 2019). Shooting is an essential skill and the two most common shot types are wrist and slap shots. In comparison to slap shots, wrist shots have a faster release with greater accuracy, although the puck speed produced is lower (Lomond, Turcotte, & Pearsall, 2007; Wu et al., 2003). In the 2018-2019 National Hockey League (NHL) season, wrist shots accounted for 55.1% of shots on net and 51.7% of goals scored (NHL, 2020). Thus, ice hockey players must develop an effective wrist shot if they are to consistently score.

In order to have an effective wrist shot, players must maximise shooting speed and accuracy. Previous studies have examined which factors predict wrist and slap shot speed and accuracy including stick properties, player characteristics, and shot technique (Lomond et al., 2007; Michaud-Paquette, Pearsall, & Turcotte, 2009; Wu et al., 2003). Much of the focus has been on properties of the stick. Decreased stick stiffness is related to increased shooting speed during wrist and slap shots (Gilenstam, Henriksson-Larsén, & Thorsen, 2009; Pearsall, Montgomery, Rothsching, & Turcotte, 1999; Worobets, Fairbairn, & Stefanyshyn, 2006). However, the size of this difference appears to be small and contradictory results have been found (Kays & Smith, 2017; Wu et al., 2003). In terms of player characteristics, larger and stronger players have faster wrist and slap shots (Wu et al., 2003). A few studies have examined how wrist shot technique affects performance and they were conducted on synthetic ice. In one study, elite players achieved higher puck speeds from wrist shots, partially because they produced greater stick bending, than recreational players (Wu et al., 2003). Studies examining wrist shot accuracy found that both stick (e.g. blade orientation) and player (e.g. upper extremity angles) kinematics predicted shooting accuracy, although which factors were significant depended on the target location (Michaud-Paquette, Magee, Pearsall, & Turcotte, 2011; Michaud-Paquette et al., 2009). These studies highlight that additional research is required to assess optimal player kinematics that will maximise wrist shot speed.

In contrast to ice hockey, body kinematics have been studied more extensively in other sports. One often evaluated measure in golf is the X-factor, which represents the difference in trunk versus pelvis axial rotation about the superior-inferior axis at the top of the backswing (Brown et al., 2011; Joyce, 2017; Sorbie, Gu, Baker, & Ugbolue, 2018). Previous research has determined that X-factor relates to clubhead and ball speed in golfers (Brown et al., 2011; Joyce, 2017). Another study has examined wrist shots in floorball players, which perhaps shares the most similarity with the ice hockey wrist shot. Faster wrist shot speeds were related to greater trunk ROM in floorball players (Lazzeri, Kayser, & Armand, 2016). Thus, findings from other sports support that trunk kinematics may affect ice hockey wrist shots.

In summary, there are few studies examining wrist shot kinematics in ice hockey players. Research is required to determine which joint kinematics relate to higher wrist shot speeds. This includes trunk kinematics, which have been shown to relate to performance in other sports. Additionally, elite players produce greater shot speeds than recreational players (Lomond et al., 2007; Wu et al., 2003). The relationship between trunk rotation and shot speed might vary depending on skill level. As evidence, differences in stick kinematics have been observed between elite and recreational players during wrist shots (Wu et al., 2003). Comparing body kinematics between skill levels would elucidate potential movement-to performance factors, which could be used by coaches to teach optimal wrist shot performance. Therefore, the objective was to determine if puck and blade speed were related to trunk rotation during ice hockey wrist shots taken on ice in elite and recreational players from both a stationary position and while skating. The secondary objective was to compare trunk rotation during wrist shots between elite and recreational players. It was hypothesised that increased trunk rotation would be related to in increased puck and blade speed in elite and recreational players.

Materials and Methods

Participants

This cross-sectional study recruited elite (n=10; 7 left-handed shooters) and recreational (n=10; 5 left-handed shooters) male ice hockey players between October to December 2016 in Montreal, Canada. All participants actively played hockey during the current and previous season. Exclusion criteria included if participants reported any current injury that limited their participation in ice hockey or if they reported current pain in any body part. Participants were classified as elite if they played in either major junior (Canadian Hockey League) and/or the Canadian Interuniversity Sport men's hockey league. Recreational participants played in any level lower than the aforementioned leagues. Participant demographics are provided in Table 1. Written informed consent was obtained from all participants. The study was conducted with the formal approval of the university ethics board.

A formal sample size calculation was not performed. Data collection was limited by the cost and technical difficulty of collecting on an ice surface.

Data Collection

Data were collected on an indoor ice surface (McConnell Arena, Montreal, Canada). Weight and height were measured from participants using a digital scale and tape measure, respectively. All participants used the same skate (Vapor 1X, sizes 7 to 11, Bauer Inc., Blainville, Canada) and stick (Nexus 1N, 87 flex with P92 blade pattern, Bauer Inc., Blainville, Canada) models to control for potential effects from this equipment. This was not their normal equipment. Skates were sharpened to a 3/8 inch (9.53 mm) hallow. Stick lengths were 58, 60, and 62 inches and the length was selected based on participant preference. Participants wore a tight fitted suit (Opti-track, Corvalllis, USA) and hockey gloves.

Participants performed wrist shot testing on real ice. Motion data were recorded with a 14 camera Vicon motion capture system (Vicon Motion Systems Ltd., Oxford, United Kingdom) which included four Vantage V5, two T40S and eight T10S cameras. Data from all cameras were sampled at 240 Hz and all the cameras were synchronized. Reflective markers (14 mm) were placed on the pelvis and trunk according to previous guidelines (Leardini, Biagi, Merlo, Belvedere, & Benedetti, 2011) including: right and left anterior superior iliac spine, right and left posterior superior iliac spine, jugular notch, xiphoid process, spinous process of the seventh cervical vertebrae, and midpoint between the inferior spines of the scapula. The stick blade was tracked with three reflective markers placed on the proximal, middle, and distal ends. Locations were chosen to ensure markers were not occluded while the puck was on the stick blade. A reflective marker was placed on the centre of the puck on one of its flat surfaces and stabilised with a screw.

Testing on ice consisted of a three minute warm-up. Participants were instructed to skate around and shoot in order to acclimatise to the equipment. A participant was provided additional warm-up time if they requested it. Next, they completed a static standing trial as an anatomic calibration and to determine joint centres. Ten skating wrist shot trials were then performed. Participants were instructed to skate while carrying the puck and then release the puck approximately 9 m from the net. This distance replicates the slot, which is a high scoring area in front of the net. They had approximately 9 m to skate and release the shot, allowing them at least two full skating strides. Four pylons marked this release area. Participants were instructed to complete the skating wrist shot as hard as possible and aim for a target hung in the middle of the net. They were provided with no further instructions on shooting technique. Shots were included in analyses even if they did not strike the target. Next, participants completed five stationary wrist shots, which were taken approximately 9 m from the net. Instructions were similar, but participants started from a stationary position. More trials were taken for the skating wrist shots since it more closely represents typical wrist shots during game situations. Additional stationary wrist shots were not taken due to limitations in testing times and to prevent fatigue. Participants were provided with a one minute rest between shooting trials to minimise fatigue. Images of the data collection setup are provided in the Supplemental.

Data Processing

Confirmation of correct marker assignment and gap filling were completed using Vicon Nexus (Version 2.1.1, Vicon Motion Systems Ltd., Oxford, United Kingdom). The remaining data processing was completed in Visual3D (Version 5.01, C-Motion Inc., Germantown, USA). Reflective markers were filtered with a 4^{th} order, recursive, low-pass Butterworth filter with a cut-off frequency of 25 Hz. Trunk (based in the thorax) and pelvis coordinate systems were constructed as previously described (Leardini et al., 2011). Trunk relative to pelvis angles were determined using an Euler sequence of YXZ (lateral bending, flexion/extension, axial rotation). This angle and sequence has been recommended for calculating X-factor in golfers (Brown, Selbie, & Wallace, 2013; Joyce, Burnett, & Ball, 2010). The axial rotation was multiplied by -1 for left-handed shooters to ensure that axial rotation towards the net was positive for all shooters. Thus, left axial rotation was positive for right-handed shooters and right axial rotation was positive for left-handed shooters. The angle measured during the static standing trial was removed from shooting trials to account for offset due to reflective marker placement.

Two shooting events were identified. The starting event occurred when the puck was furthest behind the pelvis in the anterior-posterior direction. Puck release occurred when the puck was off the stick blade. This was identified as the first instance when the distance between reflective markers on the puck and middle of the stick blade was greater than 9 cm. Automatic detection algorithms were created to identify these events, and an investigator checked all events.

Variables

The two dependent variables were peak puck speed and peak blade speed in the direction of puck primary progression (i.e. towards the net). These were taken from the derivative of the puck and stick blade marker positions and peak values were identified anywhere during the shooting task.

The primary independent variables were player group (elite vs. recreational) and two measures identified from trunk angles: peak trunk axial rotation away from the net and trunk axial rotation range of motion (ROM; i.e. difference between peak axial rotation away and towards the net). These angle measures were identified between the shooting events and were taken from each trial from the non-time normalised waveforms.

Other control variables were accounted for in analyses. This included demographic factors: age and body mass index. One investigator identified the skate that remained on the ice during shooting trials through observation. This was classified as either the lead skate (e.g. left skate for right-handed shooters) or trail skate (e.g. right skate for right-handed shooters). The number of trials was recorded to account for potential fatigue. Skating speed at puck release was determined by taking the derivative of the reflective markers placed on the posterior superior iliac spines in the direction of primary progression (i.e. towards the net). The identification of the above listed discrete variables were performed in Matlab (version R2018a, MathWorks Inc., Natick, USA).

Statistical Analysis

Although ten and five trials were collected for the skating and stationary wrist shots respectively, not all trials could be analysed due to marker dropout. Descriptive statistics summarised the number of available trials. Independent t-tests compared demographic variables between elite and recreational groups. Two-way analysis of variance (ANOVA) compared puck speed, blade speed, skating speed, peak trunk rotation, and trunk rotation ROM between wrist shot types (skating, stationary) and groups (elite, recreational). For the ANOVAs, ensemble averages from the multiple trials were determined for each participant for the skating and stationary wrist shots prior to entering the data into these analyses.

To compare trunk axial rotation between groups throughout the entire shot, Statistical Parameter Mapping (SPM) was conducted (Pataky, Vanrenterghem, & Robinson, 2016). Firstly, trunk axial rotation waveforms were time normalised to 100% of the shot cycle (start to puck release) using cubic spline interpolation and ensemble averages were created for each participant for each shot type. Two sample, t-test SPM compared trunk axial rotation waveforms between elite and recreational groups for both skating and stationary wrist shots using the spm1D toolbox in Matlab (version R2018a, MathWorks Inc., Natick, USA) (Pataky, 2012, 2020). The time node was each 1% of the shot cycle and statistical significant was set at $p<0.05$.

Hierarchical linear models were constructed to address the primary objective. Separate analyses were conducted for skating and stationary shots. Dependent variables were puck and blade speed and separate models were run for these variables. Individual shooting trial data were

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entered into the models, opposed to ensemble averages, and data were clustered with-in participants. This allowed for more accurate partitioning of between and within participant variability (Tirrell, Rademaker, & Lieber, 2018). The first step of the model construction was entering the intercept and control variables including age, body mass index, shooting trial number, shooting skate (i.e. skate that remained on the ice), and skating speed. Next, group (elite vs. recreational) was entered, which was followed by peak trunk rotation. Potential interactions between peak trunk rotation and group were explored and only retained in the final model if it was statistically significant. Analyses were repeated with trunk rotation ROM replacing peak trunk rotation. These variables were not entered together because of concerns of multicollinearity. In total, eight hierarchical linear models were constructed that varied shot type (skating or stationary), dependent variable (puck or blade speed), and independent variable (peak trunk rotation or trunk rotation ROM). Shooting skate (0=lead, 1=trail) and group (recreational=0; elite=1) were entered as categorical variables and remaining variables were entered as continuous. Different stages of model development were assessed with -2 log-likelihood (*-2LL*) and critical values for the chi-square statistic. The regression coefficients (i.e. slope) with 95% confidence intervals were reported. Statistical significance was set at p=0.05. For the models, the covariance structure was variance components, full maximum-likelihood was chosen, and degrees of freedoms were calculated with the Kenward-Roger method, (Singer & Willett, 2003; Wang, Xie, & Fisher, 2011). The following diagnostics were examined to ensure statistical assumptions were met: linearity, normality, homoscedasticity, multicollinearity, and influential cases. Statistical analyses were performed with SPSS version 24 (IBM Corp., Armonk, USA).

Results

There were no statistically significant differences in age, height, mass, and body mass index between elite and recreational groups (Table 1). Eight of ten elite participants shot from their lead leg. Six of ten recreational participants shot from their lead legs. For the skating wrist shots, there were 183 available trials (minimum=5 trials per participant, maximum=10 trials per participant). For stationary wrist shots, there were 96 available trials (minimum=4 trials per participant, maximum=5 trials per participant). Additionally, two of these 96 trials did not have available data for peak trunk rotation and trunk ROM.

ANOVA Results

ANOVA results for puck speed found statistically significant main effects for shot type (skating vs. stationary) and group (elite vs. recreational), while the interaction was non-significant (Table 2). Skating wrist shots and elite participants produced faster puck speeds. Similar results were found for blade speed (Table 2). For peak trunk rotation, there was a statistically significant shot type main effect, while the group main effect and interaction were non-significant (Table 2). The skating wrist shot resulted in greater magnitudes of peak trunk rotation away from the net (negative values) than stationary wrist shots. Similar results were found for trunk ROM, although stationary wrist shots had greater trunk rotation ROM than skating wrist shots (Table 2).

Statistical Parameter Mapping

SPM scalar statistics remained within the critical threshold for all analyses (Figure 1). Thus, there were no significant differences in the trunk axial rotation waveforms between elite and recreational groups for both skating and stationary wrist shots (Figure 1).

Hierarchical linear models- Skating Wrist Shots

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Regression coefficients for all hierarchical linear models are provided in Table 3. For skating wrist shots with puck speed as the dependent variable, the model was significantly improved by adding group (-*2LL* change=10.10, p<0.01), peak trunk rotation (-*2LL* change=16.60, p<0.01), and the interaction between these variables (-*2LL* change=9.01, p<0.01). The elite group was associated with faster puck speeds. Greater peak trunk rotation away from the net (more negative values) was associated with faster puck speeds, although this relationship was stronger in the recreational group (Figure 2). An additional 5 degrees of rotation away from the net would increase puck speed by 0.71 m/s (b=-0.14) in the recreational group if all other factors were kept constant. Similar results were found when blade speed was the dependent variable instead of puck speed (group: -*2LL* change=12.47, p<0.01; peak trunk rotation: -*2LL* change=18.86, p<0.01; interaction: -*2LL* change=8.82, p<0.01).

Analyses were repeated with trunk rotation ROM as an independent variable instead of peak trunk rotation. For skating wrist shots with puck speed as the dependent variable, the model was significantly improved by adding group (-*2LL* change=10.10, p<0.01) and trunk rotation ROM (-*2LL* change=6.17, p=0.01). The interaction between these variables did not significantly improve the model (-*2LL* change=2.68, p=0.10). The elite group was associated with faster puck speeds. Greater trunk rotation ROM was associated with faster puck speeds and an additional 5 degrees of ROM would increase puck speed by 0.23 m/s (b=0.05) if all other factors were kept constant. When blade speed was the dependent variable, group (-*2LL* change=12.47, p<0.01), trunk rotation ROM (-*2LL* change=15.92, p<0.01) and their interaction (-*2LL* change=4.63, p=0.03) significantly contributed to the model. The elite group was associated with faster blade speeds. Greater trunk rotation ROM was related to faster blade speeds and this relationship was stronger in the recreational group (Figure 2). An additional 5 degrees of ROM would increase puck speed by 0.33 m/s (b=0.07) in the recreational group.

Hierarchical linear models- Stationary Wrist Shots

For stationary wrist shots with puck speed as the dependent variable, the model was significantly improved by adding group (-*2LL* change=6.31, p=0.01) and peak trunk rotation (-*2LL* change=5.88, p=0.02). The interaction between these variable did not significantly improve the model (-*2LL* change=0.02, p=0.89). The elite group was associated with faster puck speeds. Greater peak trunk rotation away from the net (more negative values) was associated with faster puck speeds (Figure 3). An additional 5 degrees of rotation away from the net would increase puck speed by 0.40 m/s (b=-0.08) if all other factors were kept constant. Similar results were found when blade speed was the dependent variable instead of puck speed (Figure 3; group: -*2LL* change=11.77, p<0.01; peak trunk rotation: -*2LL* change=4.34, p=0.04; interaction: -*2LL* change=0.15, p=0.70).

Stationary wrist shot analyses were repeated with trunk rotation ROM as an independent variable. When puck speed was the dependent variable, the model was significantly improved by adding group (-*2LL* change=6.31, p=0.01), but not by adding trunk rotation ROM (-*2LL* change=0.05, p=0.83) or their interaction (-*2LL* change<0.01, p=0.98). The elite group was associated with faster puck speeds. Similar results were found when blade speed was the dependent variable (group: -*2LL* change=11.77, p<0.01; trunk rotation ROM: -*2LL* change=1.17, p=0.28; interaction: -*2LL* change=0.18, p=0.67).

Discussion

The main finding was that higher peak trunk rotation angles away from the net were related to faster puck and blade speeds during skating and stationary wrist shots, especially in recreational players. This was in support of our hypothesis. However, total trunk rotation ROM showed weaker relationships with puck and blade speed during stationary wrist shots. Trunk axial rotation did not significantly differ between elite and recreational players. Coaches should focus on encouraging trunk rotation away from the net at the beginning of both skating and stationary wrist shots to improve shot performance.

Higher peak trunk rotation angles away from the net were related to faster puck and blade speeds. Other ice hockey studies are not available for comparison. However, X-factor during a golf swing is a similar measure of trunk rotation, and likewise is related to ball and clubhead speed (Brown et al., 2011; Joyce, 2017). Additionally, higher trunk ROM is related to faster wrist shot speeds in floorball players (Lazzeri et al., 2016). The stretch-shortening cycle has been proposed as an explanation for these findings in golf research. Specifically, trunk muscles are stretched when rotating away from the target and this energy is released when trunk axial rotation changes direction (Lamb & Pataky, 2018). The size of the relationship between peak trunk rotation and puck speed should also be considered. As an example using the regression coefficients in Table 3, the recreational player that produced the slowest puck speed for a skating wrist shot would have his predicted peak puck speed increase by 3.53 m/s if his peak trunk rotation during this shot changed from 14.18 degrees (measured value) to -10.80 degrees (recreational group mean). This assumes that all other factors are kept constant. Thus, axial trunk rotation away from the net should be encouraged in recreational players.

Relationships between puck speed and peak trunk rotation were generally stronger in the recreational compared to the elite group. The lower amount of variability in the elite group likely explains this finding. Figure 2 and 3 demonstrate that puck/blade speeds and peak trunk rotation data were more clustered in the elite group trials. Thus, most elite participants had adequate amounts of peak trunk rotation and other factors likely affected puck/blade speeds such as muscular strength, stick bending, or upper/lower extremity kinematics. Perhaps the recreational participants that had low peak trunk rotation angle magnitudes could not produce greater angles due to an inability to maintain balance during shooting, an inability to coordinate body segments, or insufficient trunk muscle activation. These hypotheses should be investigated in future studies. Another interesting finding is that relationships between puck/blade speeds with trunk rotation ROM appeared weaker than relationships between puck/blade speeds with peak trunk rotation. One potential explanation is again the stretch-shortening cycle. Trunk axial rotation away from the net would increase trunk muscle stretching adding passive tension. This passive tension is released as players rotate towards the net during the shot release and this passive tension might contribute to higher shot speeds. Increasing trunk ROM would not necessarily increase this passive tension if the added ROM is due to increased trunk axial rotation towards the net during puck release and follow through. Regardless, increased trunk rotation away from the net at the beginning of the shot should be encouraged and not necessarily total trunk ROM. These above findings have implications for coaching and training. When teaching wrist shots to players, the focus is often on developing proper upper and lower extremity mechanics. In addition, coaches and trainers should encourage increased trunk rotation, especially in recreational and developing players, and strengthening of the trunk rotators should be considered. However, research is needed to determine if such interventions would be effective at improving puck and blade speed.

Secondary findings include higher puck and blade speeds in the elite group. This is consistent with previous research (Lomond et al., 2007; Wu et al., 2003). Furthermore, skating

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wrist shots produced greater puck and blade speeds than stationary wrist shots. Momentum added to the stick during skating and greater peak trunk rotation magnitudes partially account for this finding. Finally, peak trunk rotation, trunk rotation ROM, and trunk axial rotation waveforms were not statistically significantly different between elite and recreational groups for both skating and stationary wrist shots. However, standard deviations for these variables (Table 2) again generally demonstrate greater variability in the recreational group. Thus, only specific recreational or developing players would require encouragement to increase trunk rotation away from the net.

Several study limitations exist. The sample size was small due to limitations of on ice time availability and the technical difficulty of setting up the data collection. Due to the study design, current results cannot assume causation between peak trunk rotation and puck/blade speed. Other important factors were not considered that could relate to puck/blade speed including stick bending and upper/lower extremity kinematics. However, the objective was to examine trunk angles, which have been studied infrequently in ice hockey shooting research, but often in other sports such as golf. Finally, only males were included and results cannot be generalised to females.

In conclusion, higher puck and blade speeds were related to higher peak trunk rotation angles away from the net during wrist shots. This was especially true in recreational players and thus increasing trunk rotation should be encouraged in this group. Future studies should examine joint kinematics in other ice hockey players (e.g. females, developing players) and during different shot types (e.g. slap, snap). Measuring shooting kinematics in different population will further out understanding of movement-to performance factors. In turn, this will help in developing coaching strategies.

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Disclosure of Interest

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Data Availability Statement

Data are not available for this study.

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Table 1. Mean ± standard deviation values for demographic variables.

Variable	Elite	Recreational	p values*
Age (y)	26±5	26±5	0.87
Height (m)	1.82±0.04	1.81±0.05	0.58
Mass (kg)	86.70±5.44	85.75±8.74	0.78
Body mass index (kg/m^2)	26.27±2.07	26.31±3.10	0.97

*p vales from independent t-tests

Table 2. Mean ± standard deviation values for the shooting variables and the ANOVA results.

Variable		Elite	Recreational	ANOVA p values		
				Group Effect	Shot Type Effect	Interaction
Puck Speed (m/s)	Skating	31.35±0.84	28.31±2.92	<0.01	<0.01	0.63
	Stationary	29.22±1.39	26.38±3.04			
Blade Speed (m/s)	Skating	24.87±0.70	22.20±2.20	<0.01	<0.01	0.90
	Stationary	22.89±1.19	20.17±1.91			
Skating Speed (m/s)	Skating	2.78±0.36	3.07±0.60	0.24	<0.01	0.40
	Stationary	1.12±0.40	1.23±0.33			
Peak Trunk Rotation (degrees)*	Skating	-18.96±12.40	-10.80±14.75	0.25	<0.01	0.23
	Stationary	0.05±6.21	1.16±7.21			
Trunk Rotation ROM (degrees)	Skating	23.28±4.79	24.29±3.43	0.77	<0.01	0.76
	Stationary	29.53±5.19	29.66±6.99			

Note: ROM, range of motion. ANOVA, analysis of variance.
*Negative values represent axial rotation away from the net and positive values indicate axial rotation towards the net.

Table 3: Regression coefficients (i.e. slope) estimates (95% confidence intervals) for the independent variables in the hierarchical linear models.

Model	Independent Variable	Skating Wrist Shot- Dependent Variable		Stationary Wrist Shot- Dependent Variable	
		Peak Puck Speed	Blade Speed	Peak Puck Speed	Blade Speed
Peak Trunk Rotation Models	Group	4.53 (2.52, 6.55)	3.48 (2.08, 4.88)	2.37 (0.75, 3.98)	2.44 (1.31, 3.57)
	Peak Trunk Rotation	-0.14 (-0.19, -0.09)	-0.09 (-0.12, -0.06)	-0.08 (-0.15, -0.02)	-0.06 (-0.12, -0.01)
	Interaction*	0.12 (0.04, 0.20)	0.08 (0.03, 0.13)	-	-
Trunk Rotation ROM Models	Group	2.75 (1.18, 4.31)	3.48 (1.95, 5.00)	2.36 (0.53, 4.20)	2.45 (1.23, 3.66)
	Trunk Rotation ROM	0.05 (0.01, 0.08)	0.07 (0.04, 0.10)	-0.01 (-0.07, 0.06)	0.03 (-0.02, 0.08)
	Interaction*	-	-0.05 (-0.09, 0.00)	-	-

Note: ROM, range of motion.
*Interactions were only retained in the final model if they significantly contributed to the model.

Robbins SM, Renaud PJ, MacInnis N, Pearsall DJ (2021). The relationship between trunk rotation and shot speed when performing ice hockey wrist shots. Journal of Sports Sciences, 39(9), 1001-1009. doi: 10.1080/02640414.2020.1853336.

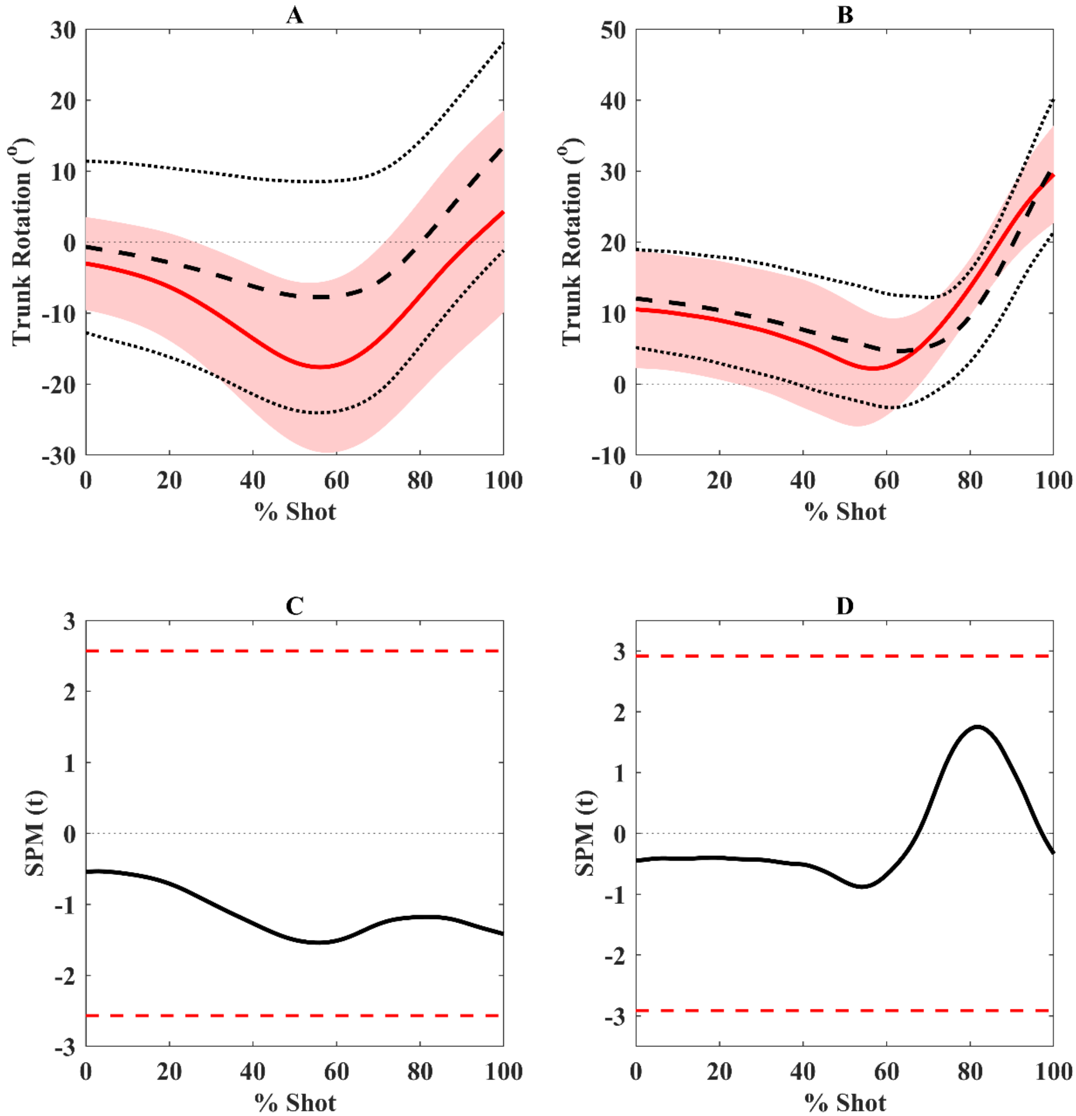

Figure 1. Ensemble group means for axial trunk rotation for A) skating and B) stationary wrist shots for the elite (red, solid lines) and recreational (black, dashed lines) groups normalised to the shooting cycle (0%=puck furthest behind pelvis, 100%=release). The pink shaded area represents one standard deviation for the elite group and the dotted lines represent one standard deviation for the recreational groups. Positive values represent axial trunk rotation towards the net and negative values represent axial trunk rotation away from the net. Associated Statistical Parameter Mapping (SPM) plots for C) skating and D) stationary wrist shots are also provided. The scaler statistics (SPM(t); black, solid lines) remain within the critical threshold (red, dashed lines), indicating no significant difference between elite and recreational groups. Figures will appear as grey-scale in print editions. Colour figures are available online.

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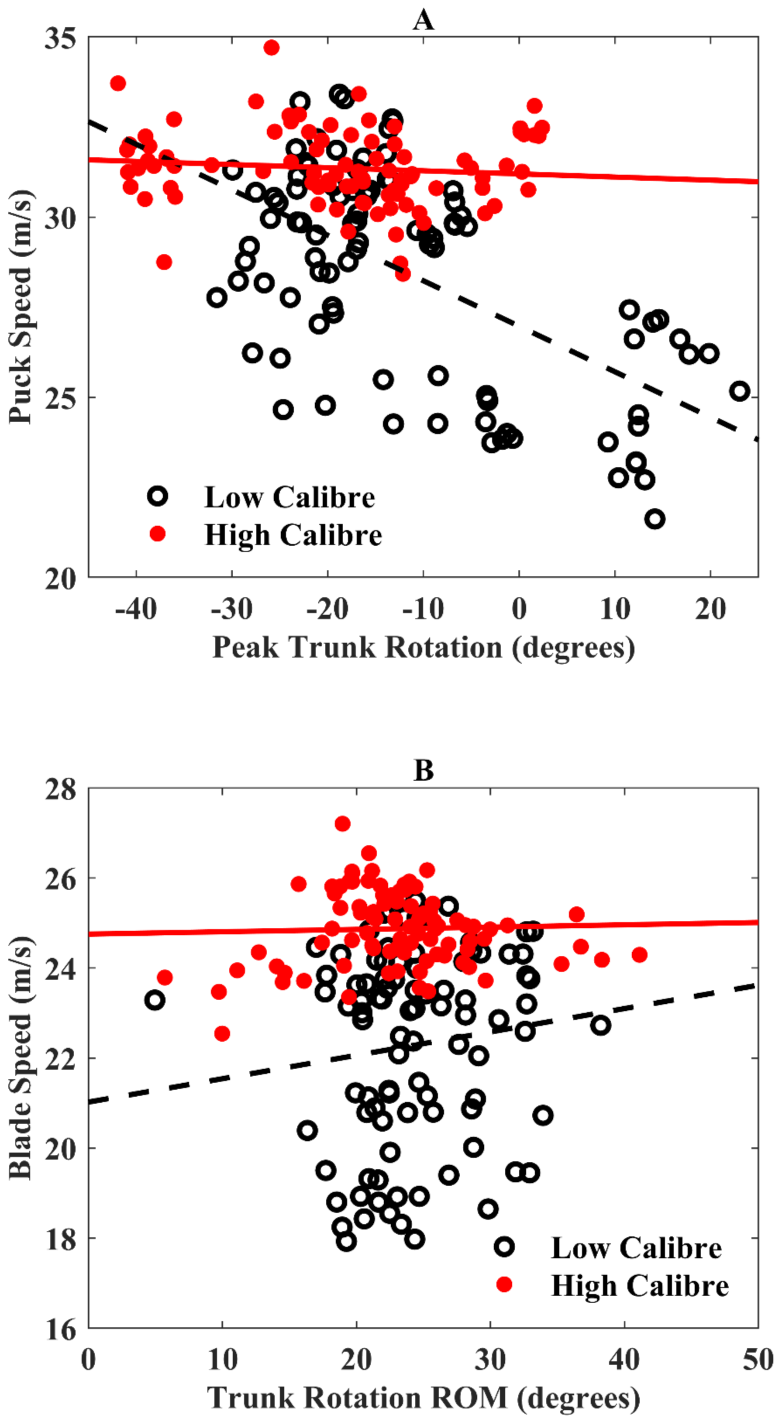

Figure 2. Skating wrist shot scatter plots of A) puck speed with peak trunk rotation and B) blade speed with trunk rotation range of motion (ROM). Elite participants are represented by red, filled dots and recreational participants by black, unfilled dots. The lines of best fit for the elite (red, solid) and recreational (back, dashed) groups are represented. Figures will appear as grey-scale in print editions. Colour figures are available online.

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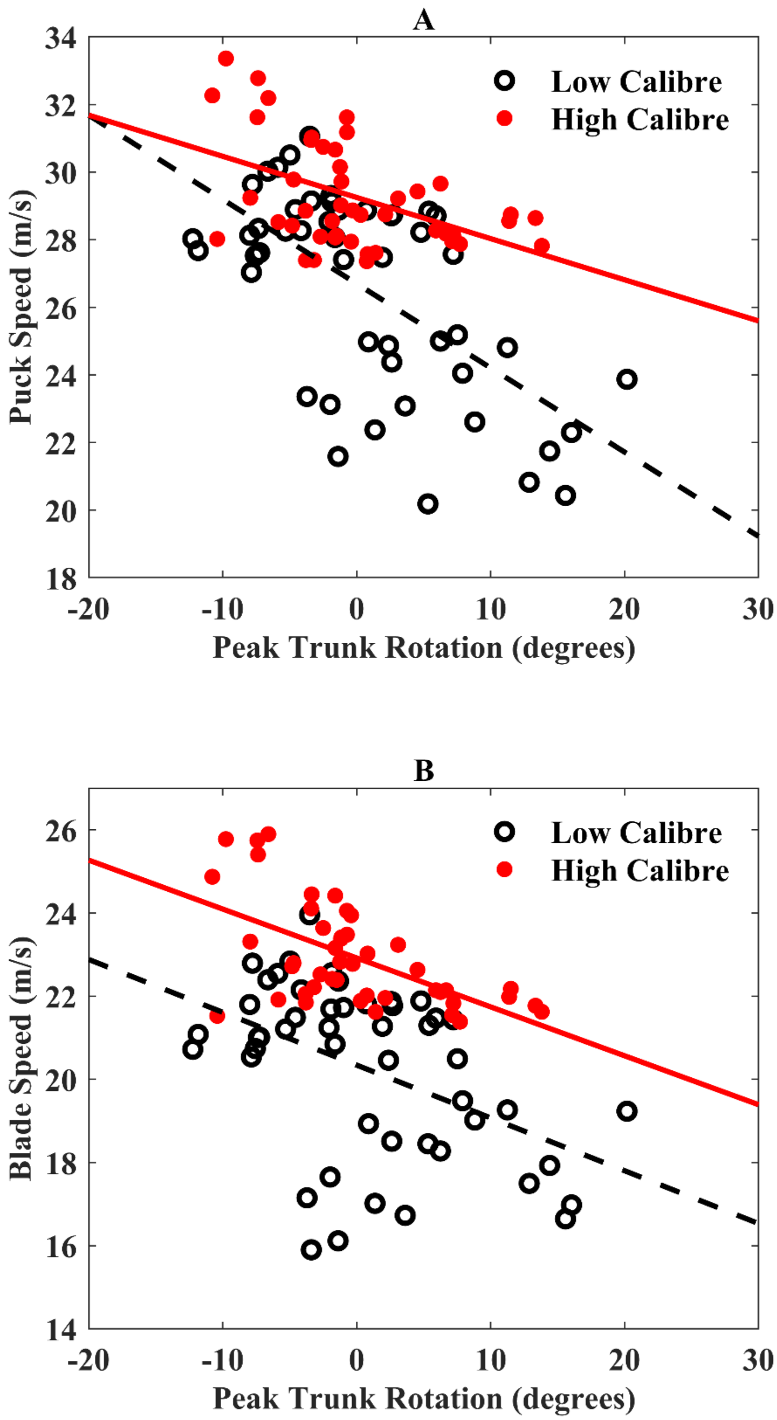

Figure 3. Stationary wrist shot scatter plots of A) puck speed with peak trunk rotation and B) blade speed with peak trunk rotation. Elite participants are represented by red, filled dots and recreational participants by black, unfilled dots. The lines of best fit for the elite (red, solid) and recreational (back, dashed) groups are represented. Figures will appear as grey-scale in print editions. Colour figures are available online.

Robbins SM, Renaud PJ, MacInnis N, Pearsall DJ (2021). The relationship between trunk rotation and shot speed when performing ice hockey wrist shots. Journal of Sports Sciences, 39(9), 1001-1009. doi: 10.1080/02640414.2020.1853336.