International Journal of EXERCISE SCIENCE

Original Research

The Effect of Shin-Torso Alignment on Muscle Activity and Joint Angles of the Lower Extremity in Collegiate Ice Hockey Players

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ABSTRACT

International Journal of Exercise Science 14(1): 552-562, 2021. Ice hockey is prevalent with injuries due to fatigue-related degradation of mechanics occurring throughout a season. The player's skating position is vital because it can impact muscle activation patterns of the lower extremity. If too much stress is placed on a muscle, it could lead to muscle fatigue and increased likelihood of injury. The purpose of this study was to measure muscle activation patterns and joint angle changes of the lower extremity in ice hockey players during three different simulated skating positions. Electromyography sensors were placed on muscles of the quadriceps, hamstrings, and low back. Additionally, electrogoniometers were placed on the hip, knee, and ankle joints. Players performed 45-second trials on a slide board in three different skating positions: forward lean (FL), shin-torso alignment (STA), and upright (UR). Muscle activation and joint angle differences were recorded and analyzed using repeated measures ANOVA with $\alpha = 0.05$. Across the three positions, significant differences ($p \leq 0.029$) were found for muscle activation in the posterior musculature: gluteus maximus and semitendinosus (FL > STA > UR). Vastus lateralis activation was significantly different ($p \leq 0.035$) (UR > STA). Across all positions, a large effect size was found for the vastus lateralis ($\eta_p^2 = 0.214$), and a medium effect size was found for the rectus femoris ($\eta_p^2 = 0.061$). Significant differences ($p \leq 0.003$) were present for hip flexion, hip extension, and ankle plantar flexion angles across trials. Greater posterior muscle activation was present during FL, and UR exhibited more anterior muscle activation. Muscle activation was more evenly distributed during STA and could result in a reduction of fatigue-related injuries.

KEY WORDS: Electromyography, biomechanics, skating technique

INTRODUCTION

Ice hockey has a high prevalence of overuse injuries that commonly occur throughout a season (13). Listola (18) reported that 69.6% of injuries throughout the course of a hockey season are due to overuse of specific muscle groups. Listola (18) found the most common overuse injuries were in the hip and groin areas, which accounted for 36.8% of all overuse injuries. Among other lower extremity injuries common in hockey are knee medial collateral ligament sprains and syndesmotic ankle sprains (13). A research study by Stull, Philippon, and LaPrade (31) used three dimensional analyses to evaluate variables of the hip associated with the sprint start in youth hockey players. The results of the study indicated that poor biomechanical form, such as externally rotating the hip joint in abduction during the push off phase of skating and internally rotating through increasing hip flexion during the recovery phase, leads to injuries from an early age (31). Therefore, a common risk factor for these overuse injuries is improper biomechanical form, illustrating the importance of proper form in the hockey stance in reducing the risk of injury.

A player's "hockey stance" was identified as a key determinant of performance in an interview completed by ten professional hockey coaches recommended by the French Federation of Ice Hockey (23). The optimal posture, as described by these coaches, is characterized by forward trunk flexion with the center of gravity forward between the skates, in essence, leaning forward. While the coaches did not provide specific measurements to define proper posture, consensus was a forward shift in the center of gravity is an important factor in acceleration. The interview was representative of a discussion on hockey posture in general, because while many have a mental image of what the stance should look like, there is little information available that provides objective parameters for optimal posture. More specifically, it is difficult to know how far of a forward lean (FL) is still efficient without knowing specific degrees or ratios to measure. A study by Upjohn, Turcotte, Pearsall, and Loh (33), observed hockey players skating on a polyethylene slat bed skating treadmill, while video analysis allowed for calculation of joint angles (JA) and stride rates. High-caliber athletes (separated by higher league of competition and years of experience) utilized a greater range of motion at the hip and knee joints during both the sagittal and frontal planes than lower-caliber athletes, contributing to a longer stride. By increasing the amount of flexion of the knee joint prior to propulsion, players have more potential for extension of their leg and are able to generate more force during extension. While the Upjohn study is valuable in providing quantified information on hockey skating position, it is still limited in its correlational nature (33). A greater range of motion of knee and hip joints was correlated with increased acceleration, but potential consequences such as muscle fatigue are still unknown. Objective information on muscle activation in different hockey positions is needed for strength and conditioning coaches creating programs, as well as for coaches and athletes in making educated adjustments to optimize sports performance.

Anecdotally, arguments have been made that aligning the angle of the torso to be parallel to the angle of the shin is optimal from a performance and injury prevention standpoint. In this properly aligned position, there should be a relatively equal distribution of muscle activation amplitude in the quadriceps and hamstrings muscle groups, and overuse of those muscles due to improper biomechanical form should be minimized. For example, leaning forward and decreasing the angle of the hip increases stress on specific muscles and conversely leaning backwards and increasing the angle of the hip will result in higher muscle activation amplitude in other muscles (26). Research by Chiu (9) found that sitting back in a squat and thus preventing the knees going past the frontal plane of the toes results in increased gluteus maximus activation during the lift to aid the quadriceps. In comparison, without this posterior shift of weight, the squat exercise will emphasize more of the quadriceps muscle group. This shows that changing the stance during a squat has an impact on the muscle activation patterns in the lower extremity.

Furthermore, McLaughlin et al. (22), showed how in the squatting position both a FL and backwards lean will make the knee flexors or the extensors dominant, respectively, thus showing that angles of the knee and hip have an impact on muscle activation amplitude. Using these concepts and applying them to a skating position that is similar to a squat, one can deduce that different musculature will be emphasized when using different biomechanical skating positions. Muscle fatigue due to too much stimulation of a particular muscle group has been found to compromise technique in a squat position (16). Therefore, we extrapolate that muscle fatigue can lead to problems in skating, such as poor biomechanical skating form and a greater risk of overuse injuries in the lower back and lower extremities. Therefore, proper shin-torso alignment (STA) may put hockey players in a more neutral biomechanical position, which balances the stress on the anterior and posterior musculature surrounding the hockey stance. Ultimately, this could also lower the risk for overuse injuries that may arise from premature muscle fatigue.

The biomechanics and angles that hockey players skate in has been previously researched, however, there is a lack of research examining patterns of muscle activation amplitude in a hockey stance (2, 5, 12). Specifically, there is no quantified information available that speaks to how altering the skating position from a FL to an upright (UR) position may affect the amplitude of muscle activity in the lower extremities. Therefore, this research provides valuable insight into skating positions, which can be used by athletic coaches and strength and conditioning professionals when teaching ice hockey skating technique and training athletes to meet the demands of the sport. The purpose of this study was to utilize surface electromyography (EMG) and electrogoniometry with ice hockey players to quantify differences in muscle activation amplitude and JA during various simulated skating positions. This study examined how three different skating positions (FL, STA, and UR) affect muscle activation amplitude in the lower body (Figure 1). It was hypothesized that there would be a more equal distribution of muscle activity, in regards to amplitude, in the lower extremity during a simulated skating stride when proper STA was used compared to FL and UR skating positions. Furthermore, we hypothesized that muscle activation amplitude would be lower for the quadriceps in the FL condition compared to UR, and the hamstrings would elicit lower activation patterns during UR compared to FL. When muscle activation patterns can be identified, hockey players will be able to adapt their techniques in order to have a more balanced distribution of muscle activity, ideally resulting in less fatigue in any particular muscle, reducing the risk of overuse injuries.

METHODS

Participants

Nineteen male NCAA Division I hockey players (21.63 ± 1.3 years, 177.53 ± 6.03 cm, and 80.82 ± 5.32 kg) were recruited for this study. All participants were free from injury and provided written informed consent prior to participation, as approved by the Institutional Review Board at The University of Alabama in Huntsville. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (25).

Protocol
This experiment analyzed quantitative data of muscle activity amplitude through the EMG sensors and JA via electrogoniometry. The EMG and JA equipment used for the study was a DataLite WS1800 system (Biometrics Ltd, Newport, United Kingdom) (4). This system outputs data which specifies no need for maximal voluntary contraction. We also did not have to account for maximal differences between participants as they served as their own control and muscle activation amplitude across the three positions was the primary outcome variable. For this study, surface EMG equipment was used to assess patterns of muscle activation amplitude of the quadriceps, hamstrings, and low back musculature. The quadriceps muscles analyzed included the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM). The hamstring muscles analyzed were the gluteus maximus (GM), biceps femoris (BF), and semitendonus (ST). The low back musculature analyzed were the erector spinae longissimus (ESL) and erector spinae iliacus (ESI). Research by Merletti et al shows that EMG is the most commonly used technique for identifying musculature activity (24), and EMG has been found to be a reliable source of data collection in the lower extremities (2, 3, 12, 20). Studies also show that surface EMG is as valid as indwelling EMG while being less intrusive (29, 34).

The concurrent collection of JA data during the simulated skating movement was to produce a more complete picture of the lower body's function. Twin-axis electrogoniometers were used to measure JA at the hip, knee, and ankle, and they provided continuous data on the angle of the joint in both the frontal and sagittal planes. Biometrics electrogoniometers have been previously used in collaboration with EMG sensors to study movement in multiple sports settings (19, 21, 27). In previous studies on reliability, the standard error of measurement of hip, knee, and ankle goniometers were found to range from 0.5° to 3.63° with the hip sensor having the larger error due to more complex motion (6, 28). Higher reliability (ICC ≥ 0.75) was reported when a standard procedure to calibrate goniometers was used prior to testing (28). Accuracy reported by Biometrics is ± 2 degrees over a range of ± 90 degrees (5). When compared to motion analysis, hip and knee validity was high ($r \geq 0.917$), but ankle validity was lower ($r \geq 0.130$), which was believed to be due to sensor shift (6). However, ankle validity tends to be higher when placed along the Achilles tendon ($r = 0.954$), and the importance of taping and pre-wrap in avoiding sensor shift was noted. A slide board (Varisport, Inc./ULTRASLIDE, Northbrook, IL, USA) was utilized for all testing procedures. The slide board was used because it allowed the participants to perform skating-like motions in an off-ice setting and has been shown to mimic movements of on-ice skating biomechanics (32).

Participants arrived at the testing laboratory in athletic clothing. With this being a repeated measures design, it was not necessary for participants to abstain from lower body exercise prior to the laboratory visit. Participants engaged in a self-directed five-minute warm-up of stationary cycling and dynamic stretching prior to commencing data collection. Participants also performed a standardized warm-up on the slide board that consisted of 45-second sets to minimize the possibility of suffering muscle cramping or soreness during the data collection (35).

The participant was then marked and prepped for data collection. Participant preparation included placement of the wireless EMG sensors on the muscle bellies of the GM, BF, ST, RF, VL, and VM of the dominant limb (4). Sensors were also placed on ipsilateral lower back musculature: ESL and ESI. Palpation of muscle bellies followed Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines (30). Electrogoniometers were then placed on the hip, knee, and ankle joints according to manufacturer guidelines. All sensors were affixed with double-sided tape and sensors were further secured with foam under-wrap and a strip of athletic tape (30).

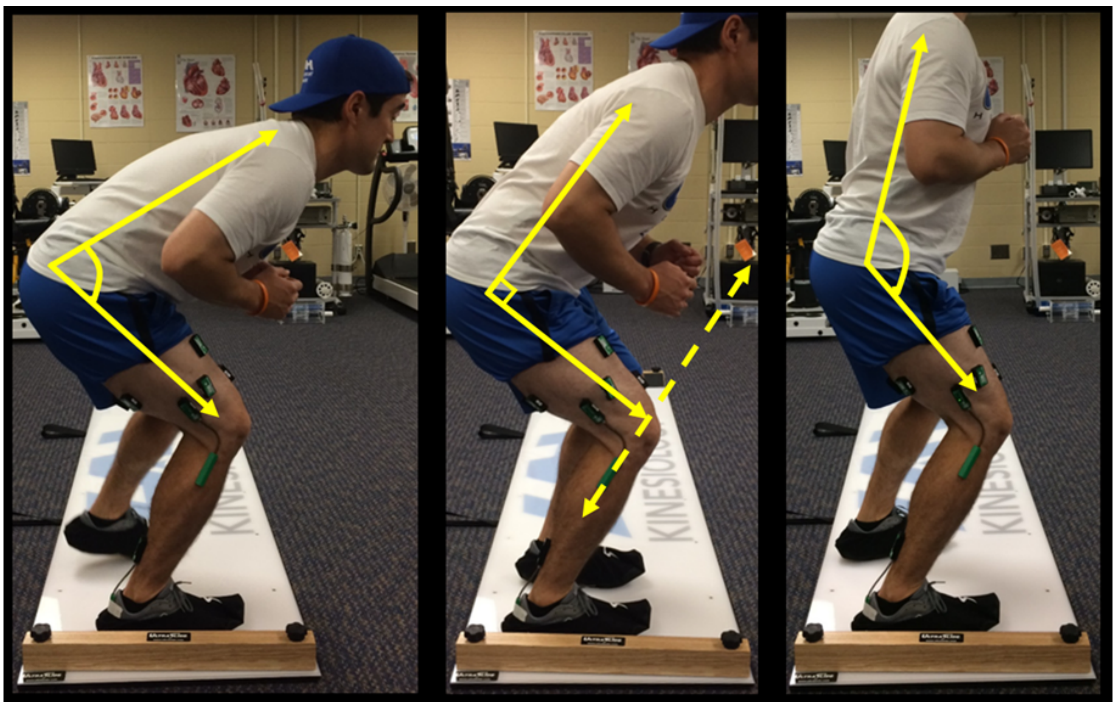

Figure 1. Three testing positions to simulate various skating strides: (left to right) Forward Lean, Shin-Torso Alignment, Upright.

Once the sensors were recording muscle activation, participants were asked to perform a 45-second trial on the slide board for familiarization with the board and comfort with the sensors. Participants were provided a two-minute rest, after which they conducted another 45-second trial in either the FL, STA, or UR position. The three positions were based on common skating techniques utilized by hockey players (23). Furthermore, anecdotal evidence suggests STA allows for a better distribution of muscle activation compared to the FL and UR, which are commonly used by forwards and defensemen, respectively. Order of trials for each participant was randomized and counterbalanced, and each subject performed all three trials with a two-minute rest between trials. The 45-second trial followed by a two-minute rest mimics standard bouts of an in-game hockey shift (10). Participants served as their own control and asked to skate at the same self-selected tempo across all trials. Proper positioning was maintained by visual analysis and verbal feedback from the research team, who were positioned to view the participant from the lateral view.

Statistical Analysis
This study utilized a within participants, repeated measures design. The middle 15 seconds of each trial was analyzed and averaged to obtain mean maximal muscle activation values in millivolts. The middle 15 seconds provided the most consistent signal for each participant, as the first 15 seconds allowed for feedback on positioning. The average angle degree for each trial was calculated from either the maximum or minimum degree found during each repetition of the 15 second window. The mean and standard deviations across trials were then calculated using the Statistical Package for Social Sciences (SPSS v24; SPS Inc. Chicago, IL, USA). Normality was assessed with a Shapiro Wilk's test. For normally distributed data sets, a repeated measure one-way analysis of variance (ANOVA) was used to compare average values, and partial eta squared (η_p^2) was used to determine effect sizes. Effect size for repeated measures ANOVA (η_p^2) was determined as 0.01 = small, 0.06 = medium, and 0.14 = large. Effect size for Friedman's ANOVA ($\bar{r}$) was determined as 0.1=small, 0.3=medium, and 0.5=large. A Friedman's ANOVA was used for non-normally distributed data, medians were reported, and the effect size was averaged with Spearman's Rho, represented as an $\bar{r}$ score for non-normally distributed values (15). Post-hoc analysis allowed for pairwise comparisons between the various positions and across muscles. Significance for all analyses was set at $p = 0.05$.

RESULTS

All participants completed each trial, and no injuries were reported during the study. Muscle activity was found to be significantly different *($p \leq 0.029$)* in GM and ST across all conditions (Table 1). These muscles exhibited significantly higher mean values during FL compared to STA, which in turn, exhibited higher mean values than UR (FL > STA > UR). Muscle activation for GM was 19.6% higher during FL compared to UR. Muscle activation for ST was 17% higher during FL compared to UR. Furthermore, significant differences were seen in the anterior musculature of the VL ($p < 0.035$), with mean values being significantly higher during UR compared to STA (UR > STA). Muscle activation for the VL was 16% higher during UR compared to FL. Large effect sizes were found for the VL ($\eta_p^2 = 0.214$) and a medium effect size was found for the RF ($\eta_p^2 = 0.061$) across all positions.

Table 1. Average values of muscle activation.

	FL		STA		UR				
	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median	*p*	ES	Trial Comparison
GM*	0.658±0.428	0.504	0.592±0.393	0.412	0.550±0.392	0.482	0.012	0.193	FL>STA>UR
BF*	1.465±1.837	0.561	0.899±1.542	0.424	0.866±1.411	0.375	0.074	0.129	
ST*	0.571±0.337	0.489	0.558±0.325	0.466	0.487±0.322	0.411	0.029	0.142	FL>STA>UR
RF	0.895±0.330	0.866	1.082±0.647	0.952	0.992±0.445	0.903	0.365	0.061	
VM*	1.439±0.776	1.206	1.325±0.511	1.204	1.509±0.753	1.356	0.607	0.015	
VL	1.297±0.515	1.190	1.385±0.775	1.172	1.506±0.963	1.301	0.035	0.214	UR>STA
ESL*	0.540±0.349	0.417	0.530±0.236	0.519	0.528±0.283	0.445	0.331	0.008	
ESI*	0.800±0.634	0.626	0.600±0.321	0.452	0.745±0.452	0.633	0.465	0.005	

* Denotes when a Friedman's ANOVA was used. FL= Forward Lean, STA = Shin Torso Alignment, UR = Upright, GM=Gluteus Maximus, BF= Biceps Femoris, ST= Semitendinosus, RF= Rectus Femoris, VM= Vastus Medialis, VL= Vastus Lateralis, ESL= Erector Spinae Longissimus, ESI = Erector Spinae Iliacus.

Although values for RF, VM, and BF were not significantly different ($p \geq 0.074$) across conditions, the trend in mean values were consistent with the hypothesis. Posterior musculature had greater average values during FL compared to STA and UR. Muscle activation for the BF was 69.2% higher for the FL compared to UR. Anterior musculature had less average activation during FL compared to UR. Muscle activation for RF was 10.8% higher during UR compared to FL and VM activation was 4.86% higher during UR compared to FL. The ESL and ESI had higher mean amplitudes during FL compared to UR with a 2.27% and 7.38% difference, respectively.

Joint angle analysis revealed hip flexion and extension were significantly different ($p \leq 0.033$) across the three positions (FL > STA > UR) (Table 2). Hip flexion was 26% higher in FL compared to UR, and hip extension was 62.2% higher in FL than compared to UR. Therefore, hip flexion was used as the primary variable to quantify position. Hip adduction, hip abduction, knee varus, and knee valgus values were not significantly different across positions ($p \geq 0.073$), as this information may be relevant in weighing potential consequences of a hockey stance, such as strain on the hip or knee area. Ankle plantarflexion was significantly different ($p < 0.001$) between the STA and UR position (UR > STA). Ankle inversion, eversion, and dorsiflexion were not found to be significantly different ($p \geq 0.084$) across the three positions.

Table 2. Average position of joint extremes in FL, STA, and UR position.

	FL		STA		UR				
	Mean±SD	Median	Mean±SD	Median	Mean±SD	Median	*p*-value	Effect Size	Trial Comparison
HF*	70.047±18.623	69.974	59.729±19.154	55.988	55.552±22.091	51.774	0.033	0.667	FL>STA>UR
HE	34.788±12.337	36.114	25.494±13.134	22.616	21.447±14.603	17.936	<0.001	0.436	FL>STA>UR
HaD*	11.826±11.993	12.686	12.357±12.523	11.724	10.519±14.362	10.956	0.510	0.055	
HaB*	22.779±18.804	19.112	23.506±16.617	20.662	21.938±6.567	16.926	0.683	-0.015	
KF	82.958±12.354	83.930	83.775±14.081	85.642	81.077±12.494	82.386	0.427	0.046	
KE	10.588±10.685	9.526	11.977±9.038	9.132	12.922±9.661	12.32	0.350	0.057	
KvaR	1.025±12.446	-3.678	2.191±11.634	-3.282	0.927±12.105	-3.472	0.073	0.135	
KvaL*	23.628±14.748	25.628	21.850±12.648	23.776	20.989±13.742	18.546	0.731	0.055	
AI	25.395±8.757	26.116	24.971±8.186	24.720	24.931±8.916	27.098	0.768	0.015	
AE	-0.574±7.957	-1.842	-1.253±7.834	-0.774	0.738±8.015	-0.126	0.084	0.136	
AD	22.061±8.326	21.318	22.542±8.307	21.398	22.959±8.540	22.886	0.121	0.111	
AP*	18.836±12.742	18.808	19.277±15.223	-5.350	15.332±16.625	-13.68	<0.001	0.143	UR>STA

* Denotes when a Friedman's ANOVA was used HF= Hip Flexion, HE= Hip Extension, HaD= Hip Adduction, HaB= Hip Abduction, KF= Knee Flexion, KE= Knee Extension, KvaR= Knee Varus, KvaL= Knee Valgus, AI= Ankle Inversion, AE= Ankle Eversion, AD= Ankle Dorisflexion, AP= Ankle Planterflexion.

DISCUSSION

The purpose of this study was to determine whether different simulated hockey skating positions would have an impact on the amplitude of lower body muscle activation and JA. We hypothesized there would be a more even distribution of muscle activation in the anterior and posterior thigh musculature during STA compared to both FL and UR skating positions. We further hypothesized the FL and UR positions would exhibit higher muscle activation in the posterior musculature and anterior musculature, respectively. The results significantly supported this hypothesis in the GM, ST, and VL. Additionally, STA resulted in a more even distribution of muscle activation amplitude across all muscles and all trials.

Elite level skaters have been shown to have a higher recruitment of the hip abductor muscles, GM, and knee extensor muscles while skating (8). The significance observed in the current study may reflect a similar pattern based on the caliber of participants, and greater engagement of GM, VM, and VL was expected. Movements on the slide board are predominantly composed of adduction and abduction and this can be seen in our results. The GM and VL are largely responsible for concentric abduction and eccentric adduction movements. Hanson et al. (14) found that soccer players recruited the GM and VL significantly during the loading phase of cutting to one side. Similarly, side-loading movements on the slide board resulted in higher activation amplitude of these lateral muscles. Extending this study to an on-ice analysis may show more significant recruitment patterns across all lower limb musculature and allow for the observation of muscle activation patterns in a more sport-specific setting.

Analysis of lower back musculature showed that more muscle activation occurred during FL, and participants experienced higher muscular activation of the lower back muscles compared to UR. During STA, participants exhibited lower activation of the ESL and ESI. Hanson et al. (14) discussed the flexion-relaxation phenomenon, which states that relaxation of the erector spinae muscles occurs in healthy individuals when the trunk is fully flexed. However, in individuals with lower back pain, EMG analysis shows activation of the erector spinae muscles. Therefore, extended time in FL, which incorporates more flexion of the trunk, may not be an optimal position for players who suffer from chronic lower back pain. Additionally, the position may lead in an increased chance of developing lower back injuries over the course of a season. While STA was investigated for its effect on lower extremity musculature, it appeared STA may also be more optimal from a lower back pain and injury-prevention perspective as well.

The analysis of JA reflected our intended methodology by showing hip flexion to be the greatest during FL and least during UR. No previous studies were found comparing hip flexion in different hockey skating positions. However, a study by Alin (1) recorded hip flexion measurements during squat exercises using the same DataLite WS1800 system (2017). The maximum values of hip flexion recorded in Alin's study ranged from 55.67 to 63.35 which is similar to the mean hip flexion of 59.729 found during STA in our study. Therefore, the degree of hip flexion in the STA skating position is comparable to that of a squat. This comparison may help provide reference for reproducing the STA stance in application. Analysis of knee JA indicated no significant differences in knee flexion during the three positions, and the differences in the amplitude of muscle activation during FL, STA, and UR appears largely dependent upon the degree of hip flexion. Previous literature by Lafontaine (17) reported a smaller range of motion at the knee during skating motion (20.5° - 55.6°) than the current study (68.155° - 72.37°). This could be a result of our data being taken during the middle portion of a 45-second trial, while Lafontaine's data was collected during the first three strides following a standing position. Lafontaine reported increased range of motion with each consecutive stride following push off, making it reasonable to expect data taken mid-session to have higher degrees of flexion (17).

Information for our study will help further the understanding of the differences that exist across varying skating positions. The choice of hockey stance results in a significantly different amount of hip flexion, and being aware of the muscle activation patterns that accompany this increase could be valuable in better understanding injury pathology. In a study of 25 NCAA sports (11), ice hockey had the highest recurrence rate of hip flexor and abductor strains. Further research is needed on the interaction between increased hip flexion and hip strains to better understand how to limit/prevent these injuries. Furthermore, future research in hockey stance and skating position should consider the impact associated with trial length and the role it may have on knee flexion.

One limitation of our study was the use of audible cues to keep help participants maintain the trial position. Future research may look to incorporate video analysis in order to help maintain more precise positioning. The lack of significance for hip adduction and hip abduction may be a result of "crosstalk" that occurs due to hip rotation (5). Because the JA sensors used in this study only measure movement in two planes, any rotation in the hip may not have been accurately captured. The use of motion capture software with JA analysis could provide more information on these planes of movement. Future research could also look to include testing different skating positions while holding a hockey stick or even adding playing equipment, as that may allow the trials to be more sport specific and provide additional information on muscle activation and JA changes.

The results of this study indicate there are differences in the amplitude of muscle activation patterns during different hockey stance skating positions. There is a greater amplitude of posterior muscle activation of the lower extremity during FL, and UR exhibits a greater amplitude of anterior thigh muscle activation. The STA skating position provides more of an equal distribution of muscle activation in the lower extremity, as well as reduced activation of lower back musculature. Extended exposure to STA during hockey could result in a reduction of fatigue-related injuries that may otherwise be present over an extended period of time, due to the utilization of improper biomechanical form. This knowledge can help hockey coaches and strength coaches prevent/limit fatigue related injuries throughout a season by adjusting biomechanical positioning and skating technique in their athletes. By achieving a more equal distribution of muscle activation in the anterior and posterior musculature of the lower extremity, there will be a lower chance of fatigue and injury throughout a hockey season.

ACKNOWLEDGEMENTS

The authors would like to thank the Research or Creative Experience for Undergraduates Staff, the Alabama Space Grant Consortium, the VP for Research and Economic Development, Provost Christine Curtis, and former President of the University Robert Altenkirch for sponsorship of this project. Also, thanks to the UAH Men's Ice Hockey team for participating in the study.

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