JOURNAL OF NEUROTRAUMA 38:1783–1790 (July 1, 2021)

DOI: 10.1089/neu.2020.7397

Unexpected Findings from a Pilot Study on Vision Training as a Potential Intervention to Reduce Subconcussive Head Impacts during a Collegiate Ice Hockey Season

Daniel G. Antonoff,[1] Jordan Goss,[1] Taylor L. Langevin,[1] Christina Renodin,[1] Lee Spahr,[1] Jane McDevitt,[2] Dianne Langford,[3] and John M. Rosene[1]

Abstract

Player-to-player contact is the most frequent head impact mechanism in collegiate ice hockey. Training with three-dimensional multiple-object tracking (3D-MOT) could potentially reduce the quantity and severity of head impacts by enhancing player anticipation of these impacts. The purpose of this study was to evaluate the efficacy of 3D-MOT training to reduce the numbers of head impacts sustained by National Collegiate Athletic Association Division III men's and women's ice hockey players. Collegiate men's and women's ice hockey players ($N=33$; men = 17, women = 16) were randomly assigned to a 3D-MOT group ($n=17$) or a control (C) group ($n=16$). Head impacts were monitored during practices and games, and 3D-MOT training occurred twice per week for 12 weeks throughout one regular season. 3D-MOT forwards sustained head impacts with greater mean peak linear acceleration (3D-MOT = 41.33 ± 28.54 g; C = 38.03 ± 24.30 g) and mean peak rotational velocity (3D-MOT = 13.59 ± 8.18 rad·sec^{-1}; C = 12.47 ± 7.69 rad·sec^{-1}) in games, and greater mean peak rotational velocity in practices versus C forwards (3D-MOT = 11.96 ± 6.77 rad·sec^{-1}; C = 10.22 ± 6.95 rad·sec^{-1}). Conversely, 3D-MOT defensemen sustained head impacts with a mean peak rotational velocity less than that of C defensemen (3D-MOT = 11.54 ± 6.76 rad·sec^{-1}; C = 13.65 ± 8.43 rad·sec^{-1}). There was no significant difference for all other parameters analyzed between 3D-MOT and C groups. Player position may play an important role in future interventions to reduce head impacts in collegiate ice hockey.

Keywords: concussion; ice hockey; subconcussive; vision

Introduction

The incidence of concussions in collegiate ice hockey players has been reported as 0.76/1000 athlete exposures (AE) for men and 0.72/1000 AEs for women.[1] These differences have been attributed to force of impact and rotational acceleration of the head,[2,3] rule differences (checking in men's ice hockey vs. no checking in women's ice hockey), anticipation of contact, and differences in neck strength.[4-6] Concussions are of concern in collegiate ice hockey with 415 reported concussions in men's and women's ice hockey between 2009/10 and 2014/15 (Divisions I and III combined)[1]; however, the frequency of repetitive subconcussive head impacts in collegiate ice hockey is also troubling. Wilcox and colleagues reported 1965 head impacts for men, and 2532 for women throughout three ice hockey seasons of home games, while Brainard and colleagues reported 15,281 head impacts for men, and 12,897 head impacts for women over two seasons of practices and games.[2,3] The higher incidence of repetitive subconcussive head impacts in collegiate ice hockey compared with concussion incidence are noteworthy due to the potential for increased susceptibility to future concussive events or poor long-term outcomes, such as development of chronic traumatic encephalopathy.[7–11] The potential for repeated subconcussive head impacts and the incidence of concussions in ice hockey highlight the need to develop interventions that assist in preventing the occurrence of these potentially injurious events.

The use of vision training has been proposed as a modality to reduce the incidence of subconcussive and concussive head impacts in sport. By enhancing both foveal and peripheral vision, athletes may better prepare for contact and/or avoid contact altogether, thereby lowering the risk of injury.[12,13] Three-dimensional multiple-object tracking (3D-MOT) has been shown to improve foveal and peripheral vision, working memory, and visual information processing speed in university aged students.[14] Further,

[1]Department of Exercise and Sport Performance, University of New England, Biddeford, Maine, USA.
[2]Department of Health and Rehabilitation Sciences, [3]Department of Neuroscience, Temple University, Philadelphia, Pennsylvania, USA.

collegiate athletes have shown greater learning abilities than age matched non-athletes when training with 3D-MOT.[15] Ultimately, training with 3D-MOT may increase spatial awareness during competition, which may aid athletes in avoiding injury-causing situations during play.[16]

The most frequent subconcussive and concussive head impact mechanism in men's and women's collegiate ice hockey is player-player contact.[2,5,6,17] Through enhanced spatial awareness as can be obtained with 3D-MOT training, the ability for players to avoid or reduce the incident of player–player contact may in turn reduce the incidence of subconcussive and concussive head impacts. The purpose of this pilot investigation was to examine the utilization of in-season 3D-MOT training in reducing the quantity and magnitude of head impacts in National Collegiate Athletic Association (NCAA) Division III men's and women's ice hockey players. Comparisons between practices and games, as well as positional differences (forwards and defensemen) were examined. We hypothesized that in-season 3D-MOT training would decrease quantity and magnitude of head impacts among male and female Division III ice hockey players during practices and games. In addition, when examining differences in quantity and magnitude of head impacts by position, forwards and defensemen, 3D-MOT training would result in fewer and lower magnitude head impacts versus control (C).

Methods

Subjects

Members of collegiate men's and women's varsity ice hockey teams ($N=33$; men = 17, women = 16, mean age = 20.52 ± 1.77 years) were recruited for a season-long study. All participants were either forwards or defensemen. Prior to beginning the study, subjects provided informed consent and proper Institutional Review Board approval was attained. Using a random number generator, subjects from both teams were randomly assigned to a 3D-MOT group (3D-MOT = 17) or a non-3D-MOT, control group (C = 16). Table 1 presents the demographic data for 3D-MOT and C groups.

Head impact monitoring

The ice hockey helmets (Bauer RE-AKT, Bauer Hockey, Inc., Exeter, NH) were fit according to manufactures' guidelines. To account for helmet movement being associated with movement of the head, all head impacts were confirmed either live or upon video review. In cases where there was a recorded head impact as a result of helmet movement but no contact to the head, that head impact was deleted from analysis. Only head impacts where there was confirmation of a direct blow to the head and/or the head made direct contact with an object (boards, ice, stick, puck, another player) were included in the analysis.

Table 1. Baseline Demographic Characteristics of Subjects

	3D-MOT (n = *17*)	*Control* (n = *16*)
Sex (males/females)	9/8	8/8
[a]Mean age (years)	20.65 ± 1.69	20.38 ± 1.89
[a]Mean height (cm)	171.45 ± 12.67	174.70 ± 8.53
[a]Mean weight (kg)	72.63 ± 12.03	78.51 ± 10.88
[b]Player position (F/D)	12/5	9/7

[a]Data for age, height, and weight are presented as mean ± standard deviation.

[b]F = forwards, D = defense

3D-MOT, three-dimensional multiple-object tracking.

Players were individually assigned head impact monitors (GFT; GForce Tracker Inc., Richmond Hill, ON, Canada) attached to the back of the outside of the helmet. The GFT contained a triaxial accelerometer and a triaxial gyroscope, allowing for the measurement of linear acceleration (g) and rotational velocity (rad.sec^{-1}). This unit has been tested on the outside back location of the Bauer RE-AKT ice hockey helmet and was demonstrated to be an effective tool to measure linear acceleration and rotational velocity.[18] All GFTs were calibrated per manufacturer's guidelines when secured to the helmet.

Head impact data was viewed in real time and was also stored on the GFT. GFT data were subsequently uploaded onto a computer every other day when charging the units. A reportable AE was defined as one student-athlete participating in one collegiate practice or game in which the student-athlete was exposed to the risk of injury, regardless of playing time.

3D-MOT

Three-dimensional multiple-object tracking was performed with NeuroTracker (CogniSens Inc., Montreal, Quebec, Canada), using a modification of the Athletic Performance training protocol, as recommended by the manufacturer. Baseline 3D-MOT testing was performed using three Core sessions and one Sustained Attention session in the NeuroTracker program. The sessions consisted of 20 trials, each lasting between 6 and 8 sec where the subject was presented with eight yellow spheres, or balls, in a 3D box on a television monitor. At the center of the visual field, a fixation spot was displayed and subjects were instructed to focus on the fixation spot while tracking four target balls. The four target balls were illuminated, informing the subject which balls to track during that trial, and then turned back to their original yellow color before the start of each trial. All eight balls moved in a linear, random manner around the screen for 6 to 8 sec. When the trial concluded, the balls were numbered 1-8 and the subject identified the four target balls that were marked for tracking at the beginning of the trial. During the Core sessions, the movement speed of the balls increased for the next trial with correct identification of all four target balls; incorrect identification of the four balls resulted in a decrease in movement speed for the next trial. At the end of 20 trials, a speed threshold was calculated.[14]

The three Core sessions and the one Sustained Attention session were considered the first week of training for the subjects in the 3D-MOT group. Training occurred twice per week for 12 weeks and included a progression from sitting to standing to stickhandling, with players using their own stick and gloves. Players in the 3D-MOT group performed the training 173 cm away from a 165.1 cm television monitor (XBR65X930D, Sony Inc.) with the lights off, while wearing active 3D glasses (TDG-BT500A, Sony Inc.). The 3D-MOT protocol is presented in Table 2.

Confirmation of head impacts

All head impacts were confirmed via video analysis. Both men's and women's ice hockey home games and practices were recorded (Handycam DCR-SR45 Hybrid HDD, Sony Inc.) from the highest possible viewing location. Away games were filmed from the best viewing location for that arena, such that the zone of game play (offensive, defensive, or neutral zone) was clearly visible in the camera field.

A minimum threshold of 20 g for peak linear acceleration (PLA) was used.[2] A head impact was defined as a direct blow to the head from an external force, such as another player, the boards, a stick, or the puck, or the head hitting the ice during falls. A head impact was verified if there was a clear live view of the player at the time of the head impact event and/or the head impact event was clearly identified on film.

Table 2. Training Protocol for 3D-MOT Subjects

Training position	*Sitting*							*Standing*			*Standing + stick handling*		
Week	1	2	3	4	5	6	7	8	9	10	10	11	12
Session 1	CORE x3	DYN	OVR	SLT	DTB	OVR	CORE	CORE	OVR	OVR		DYN	DYN
Session 2	SA	CORE	CORE	CORE	CORE	CORE		OVR	OVR		CORE	DYN	DYN

Session types: Sustained Attention (SA), Core, Dynamic (DYN), Overload (OVR), Selective (SLT), and Distribute (DTB)
Shaded boxes indicate that no training occurred in that time slot, note that Week 10 was split between standing and standing and stick handling
3D-MOT, three-dimensional multiple-object tracking.

Statistical analysis

Independent samples t-tests compared quantity of head impacts, mean PLA, and mean peak rotational velocities (PRV) between 3D-MOT and C players for practices and games. We used 2×2 independent groups analyses of variance compared the mean PLA and mean PRV of impacts between player positions (forward and defense) of 3D-MOT and C players. To examine the effect of time relative to changes in PLA and PRV between groups throughout the season, we performed a general linear mixed-model analysis with the between-subjects factor of Neurotracker training versus no Neurotracker training, and the within-subjects factor of four average time-points over 8 weeks. Although the overall vision training program was 12 weeks, we only analyzed the Core scores for the seated portion of the training program. For Weeks 9-12, players were standing and then stick handling for training (standing Weeks 9-10; stick handling Weeks 11-12). Due to quantity of head impacts each week from the variable practice and game schedules, and also because some players had no impacts in a particular week, we averaged head impacts in 2-week increments to analyze the effect of time, thereby resulting in four average time-points over the 8 weeks. All statistical analyses were performed using SPSS software version 25. The level of significance was set at $p < 0.05$.

Results

Quantity and magnitude of head impacts

Head impact data was recorded for 43 games and 96 practices during the regular season. Players in the 3D-MOT group sustained a total of 230 and 903 head impacts in practices and games, respectively. Players in the C group sustained a total of 154 and 655 head impacts in practices and games, respectively. Ice time was recorded for all games. Players in the 3D-MOT group had a mean ice time of 1045 ± 272 sec per player, the C group had a mean ice time of 1004 ± 296 sec per player. There was no significant difference in the mean ice time between groups ($p = 0.683$).

There was no significant difference in the quantity of head impacts sustained per player between 3D-MOT and C groups in practices (3D-MOT $= 0.28 \pm 0.18$ head impacts per player-per practice; C $= 0.20 \pm 0.17$ head impacts per player-per practice; $p = 0.195$). In games, there was no significant difference in number of head impacts sustained per player between the 3D-MOT and C groups (3D-MOT $= 2.32 \pm 1.17$ head impacts per player-per game; C $= 1.71 \pm 1.39$ head impacts per player-per game; $p = 0.178$).

For PLA, there was no significant difference between 3D-MOT and C groups in practices and games (Practice: 3D-MOT $= 39.04 \pm 27.32$ g; C $= 37.60 \pm 23.39$ g; $p = .591$; Games: 3D-MOT $= 41.34 \pm 29.06$ g; C $= 39.47 \pm 26.44$ g; $p = 0.194$). For PRV, there was no significant difference between 3D-MOT and C groups in practices (3D-MOT $= 11.85 \pm 6.60$ rad.sec^{-1}; C $= 11.29 \pm 7.04$ rad.sec^{-1}; $p = 0.427$). Likewise, in games, there was no significant difference in mean PRV of head impacts between 3D-MOT and C groups (3D-MOT $= 13.18 \pm 7.95$ rad.sec^{-1}; C $= 12.98 \pm 8.03$ rad.sec^{-1}; $p = 0.627$).

Player position

We also examined quantity, PLA, and PRV of head impacts by player position: forwards ($n = 21$; 10 male, 11 female) and defensemen ($n = 12$; 7 male, 5 female). Forwards in the 3D-MOT group ($n = 12$) had a mean of 0.31 ± 0.19 head impacts per player-per practice, while forwards in the C group ($n = 9$) had a mean of 0.21 ± 0.20 head impacts per player per practice. In games, forwards in the 3D-MOT group had a mean of 2.61 ± 1.12 head impacts per player per game, while forwards in the C group had a mean of 1.81 ± 1.52 head impacts per player-per game. Defensemen in the 3D-MOT group ($n = 5$) had a mean of 0.20 ± 0.15 head impacts per player-per practice, while defensemen in the C group ($n = 7$) had a mean of 0.18 ± 0.13 head impacts per player per practice. In games defensemen in the 3D-MOT group had a mean of 1.61 ± 1.07 head impacts per player per game, while defensemen in the C group had a mean of 1.58 ± 1.31 head impacts per player per game. There were no significant differences between 3D-MOT and C groups for quantity of head impacts per player for practices and games by position ($p > 0.05$).

There was a significant difference between the mean PLA of head impacts for 3D-MOT forwards and C forwards in games ($p = 0.045$; 3D-MOT $= 41.33 \pm 28.54$ g; C $= 38.03 \pm 24.30$ g), but not in practices ($p = 0.139$; 3D-MOT $= 38.12 \pm 25.06$ g; C $= 33.62 \pm 21.07$ g) with the 3D-MOT forwards having greater PLA versus C. There was a significant difference between the mean PRV of head impacts for 3D-MOT forwards and C forwards in practices ($p = 0.047$; 3D-MOT $= 11.96 \pm 6.77$ rad.sec^{-1}; C $= 10.22 \pm 6.95$ rad.sec^{-1}) and in games ($p = 0.029$; 3D-MOT $= 13.59 \pm 8.18$ rad.sec^{-1}; C $= 12.47 \pm 7.69$ rad.sec^{-1}) with the 3D-MOT forwards having greater PRV versus C (Fig. 1 and Fig. 2).

There was no significant difference between the mean PLA of head impacts for defensemen in the 3D-MOT group and defensemen in the C group in practices ($p = 0.848$; 3D-MOT $= 42.55 \pm 34.67$ g; C $= 43.66 \pm 25.54$ g) or in games ($p = 0.993$; 3D-MOT $= 41.35 \pm 31.15$ g; C $= 41.37 \pm 28.95$ g). There was a significant difference between the mean PRV of head impacts for 3D-MOT defensemen and C defensemen in games ($p = 0.003$) (3D-MOT $= 11.54 \pm 6.76$ rad.sec^{-1}; C $= 13.65 \pm 8.43$ rad.sec^{-1}), but not in practices ($p = 0.244$) (3D-MOT $= 11.45 \pm 5.96$ rad.sec^{-1}; C $= 12.92 \pm 6.92$ rad.sec^{-1}) with C defensemen having greater PRV versus 3D-MOT (Fig. 3 and Fig. 4).

Vision and time

For vision (Core) scores, there was a significant difference in Core scores from Weeks 1-2 compared with Weeks 7-8 ($p = 0.005$;

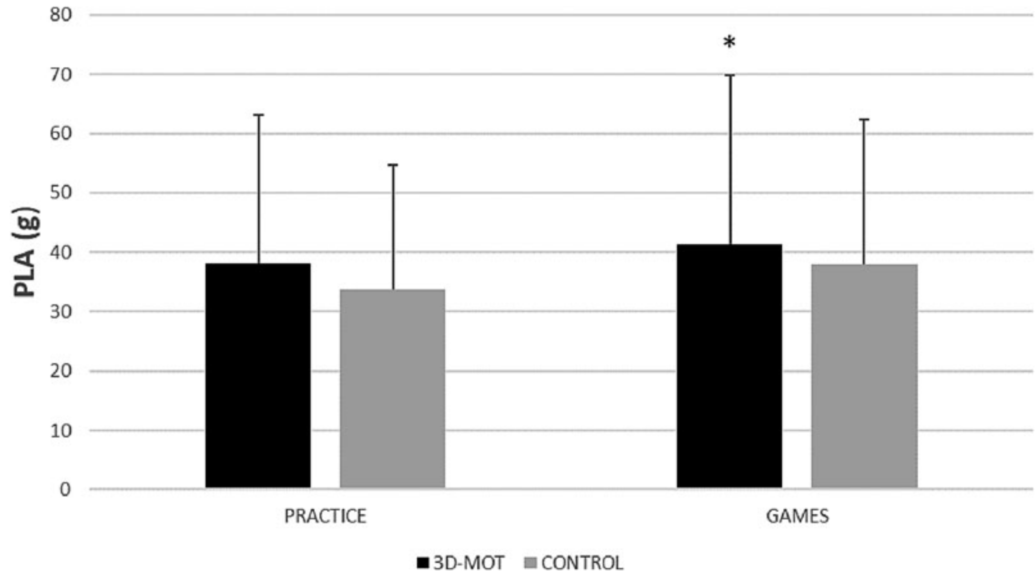

FIG. 1. Peak linear acceleration (PLA) for forwards between three-dimensional multiple-object tracking (3D-MOT) and Control (C) groups in practices and games. *3D-MOT forwards had higher PLA versus C in games.

Weeks 1-2 = 1.56 ± 0.54; Weeks 7-8 = 1.74 ± 0.36). The Core score associated with the Neurotracker program is the score that tracks progress. An increase in Core score is associated with an increase in foveal and peripheral vision tracking ability (or perceptual, cognitive ability). There was no significant difference in PLA throughout the season for the 3D-MOT group ($p = 0.469$; Weeks 1-2 = 40.46 ± 10.75 g; Weeks 3-4 = 37.74 ± 12.33 g; Weeks 5-6 = 40.78 ± 14.02 g; Weeks 7-8 = 35.66 ± 11.82 g). There was no significant difference in PLA throughout the season between groups ($p = 0.312$; Weeks 1-2: 3D-MOT = 40.46 ± 10.75 g, C = 41.31 ± 16.79 g; Weeks 3-4: 3D-MOT = 37.74 ± 12.33 g, C = 38.90 ± 11.56 g; Weeks 5-6: 3D-MOT = 40.78 ± 14.02 g, C = 39.28 ± 15.11g; Weeks 7-8: 3D-MOT = 35.66 ± 11.82 g, C = 35.50 ± 10.47). For PRV, there was no significant difference throughout the season for the 3D-MOT group ($p = 0.695$; Weeks 1-2 = 13.18 ± 4.30; Weeks 3-4 = 12.34 ± 3.12; Weeks 5-6 = 12.40 ± 3.28; Weeks 7-8 = 11.42 ± 2.71). There was no significant difference in PRV throughout the season between groups ($p = 0.139$; Weeks 1-2: 3D-MOT = 13.18 ± 4.30, C = 13.18 ± 5.35; Weeks 3-4: 3D-MOT = 12.34 ± 3.12, C = 10.51 ± 3.43; Weeks 5-6: 3D-MOT = 12.40 ± 3.28, C = 11.68 ± 4.72; Weeks 7-8: 3D-MOT = 11.42 ± 2.71, C = 13.00 ± 5.21; Fig. 5A-D).

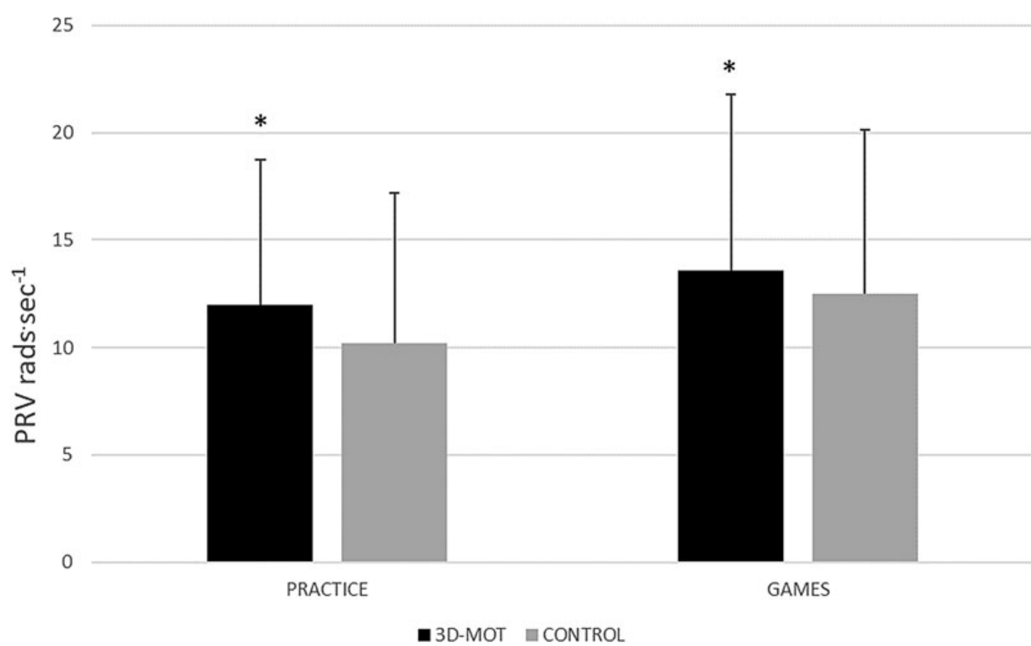

FIG. 2. Peak rotational velocity (PRV) for forwards between three-dimensional multiple-object tracking (3D-MOT) and Control (C) groups in practices and games. *3D-MOT forwards had higher PRV versus C in both practices and games.

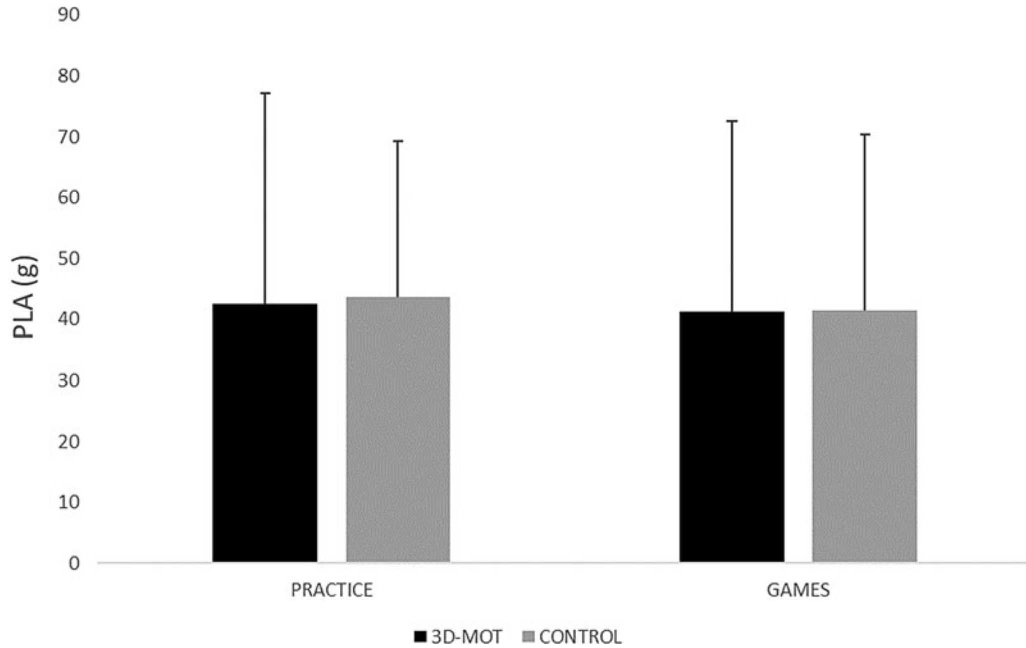

FIG. 3. Peak linear acceleration (PLA) for defensemen between three-dimensional multiple-object tracking (3D-MOT) and Control (C) groups in practices and games. There were no significant differences between mean PLA between groups in practices and games.

Discussion

This is the first investigation to examine if 3D-MOT training can be a useful tool in reducing the quantity and severity of head impacts in NCAA Division III men's and women's ice hockey players. The use of 3D-MOT may improve skill to enhance decision-making capabilities, by training players to track multiple objects in the foveal and peripheral visual fields, thereby increasing spatial awareness. Spatial awareness requires the uptake and processing of real time data in the visual field, contributing to athletic movement.[19] In ice hockey, increased spatial awareness during game play enhances decision making processes affecting puck and body movement, thereby affecting performance.[20] Utilizing 3D-MOT may enhance spatial awareness and decision-making capabilities assisting athletes in collision avoidance leading to a reduction in head impacts.[16] Contrary to our hypothesis, we found no significant difference in the quantity of head impacts sustained between players training with 3D-MOT and C players in both practice and game settings.

We also examined head impact differences by position, forwards and defensemen, between 3D-MOT and C groups. Previous studies in ice hockey have not reported positional differences in head

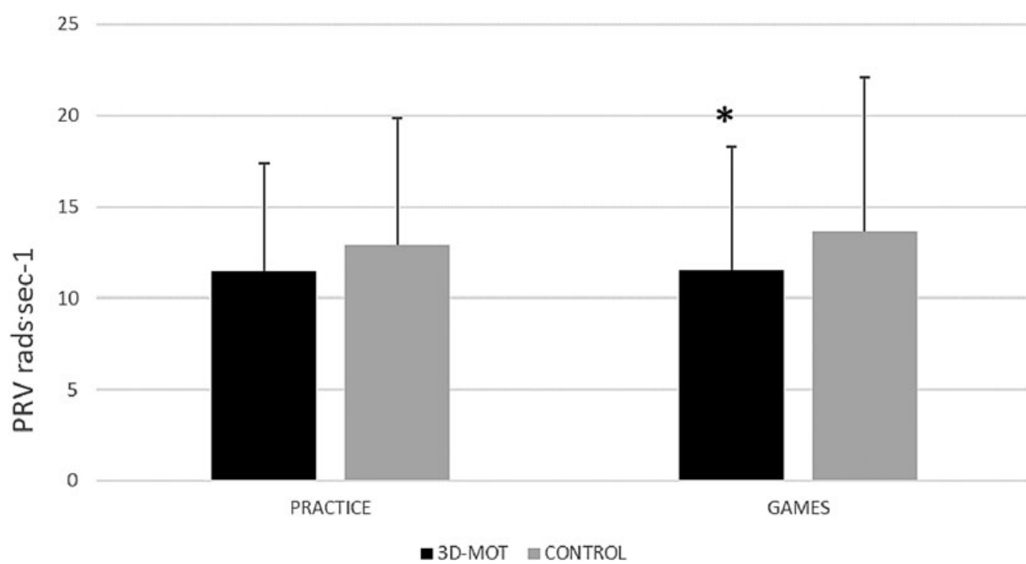

FIG. 4. Peak rotational velocity (PRV) for defensemen between three-dimensional multiple-object tracking (3D-MOT) and Control (C) groups in practices and games. *3D-MOT defensemen had lower PRV versus C in games.

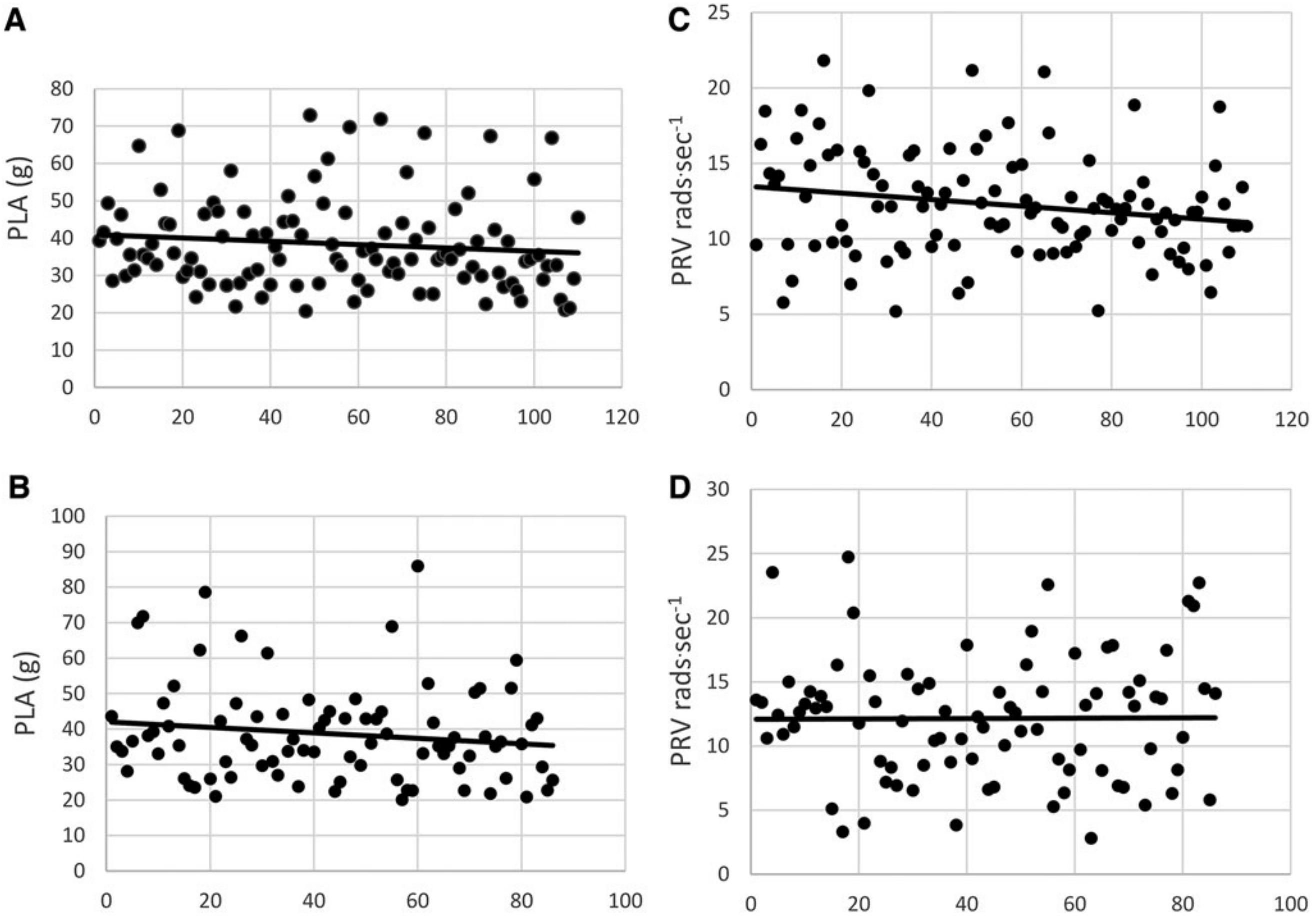

FIG. 5. Peak linear acceleration (PLA) and peak rotational velocities (PRV) throughout the season for three-dimensional multiple-object tracking (3D-MOT; **A** and **C**) and Control (C) groups (**B** and **D**). There were no significant differences in PLA and PRV throughout the season or between groups.

impact quantity and severity.[21] Wilcox and colleagues reported no significant differences in the quantity or linear acceleration of head impacts between collegiate ice hockey forwards and defensemen,[22] and Mihalik and colleagues[21] reported similar findings in youth ice hockey players. In our investigation, forwards in the 3D-MOT group sustained head impacts with a greater mean PLA and greater mean PRV in games, as well as a greater mean PRV in practices compared with the C group. Conversely, defensemen in the C group sustained head impacts with greater mean PRV than defensemen in the 3D-MOT group in games. The PRV result is particularly meaningful due to the injury causing effects of rotational forces on the head, causing greater strain on brain tissue versus linear force.[23,24]

The positional requirements of forwards and defensemen in ice hockey may partly explain the differences between 3D-MOT and C groups. For example, forwards have a greater need for puck possession versus defensemen. Generally, forwards are responsible for competing with opposing players to retrieve the puck in the offensive zone and maintain possession, which may increase head impact exposure. It is also possible that forwards who engage in 3D-MOT training may experience increased confidence in addition to improvements in vision. Romeas and colleagues reported that collegiate soccer players had improved confidence in decision-making accuracy proportional to on-field statistical improvements after training with 3D-MOT[13] compared with active and passive C subjects. Clark and colleagues reported that vision training increased on-field awareness in DI football players.[25] While we did not evaluate confidence levels of participants, the potential for increased confidence and on-ice awareness may have contributed to a more aggressive style of play by 3D-MOT forwards, subsequently increasing head impact exposure.

Conversely, defensemen are predominantly positioned in space, constantly scanning the ice for opposing players, and move into position for puck support. Additionally, defensemen are tasked with retrieving the puck in the defensive zone and controlling its clearance, thereby requiring awareness of opposing players and teammates. The positional requirements of defensemen demonstrate the importance of enhanced vision, particularly in the periphery, thereby improving on-ice spatial awareness. Due to the positional requirements of forwards and defensemen, 3D-MOT training may not be an effective tool to reduce head impact exposure in collegiate ice hockey forwards, but may be effective for defensemen.

Concussive/sub-concussive head impact risk is higher in contact, collision, and combat sports versus non-contact sports, due in part to the increased frequency of head impacts.[26] While training with 3D-MOT may aid athletes in reducing exposure to injury-causing collisions,[16] our findings suggest that player position may be an important factor to consider with future interventions attempting to reduce head impact exposure in collegiate ice hockey. Further study is required to examine the potential for vision training as an intervention to assist in the reduction of subconcussive and/or concussive head impacts, however position specific interventions may be required in variable athletic settings. In conjunction with examining vision training programs to decrease head impact exposure, measures of confidence and personality are warranted. Poltavski and Biberdorf[20] suggested that impulsivity of players may help explain potential negative consequences of vision training programs. We recommend that future studies assess personality traits of players to examine if more aggressive personality traits, such as impulsivity, result in negative consequences regardless of enhanced visual acuity.

When studying collegiate level athletes during a regular season, there are implicit limitations due in part to class schedules, school breaks, and other demands place on collegiate athletes. Players participated in 3D-MOT training during the regular season, which included a 3-week break for the winter holidays. During this 3-week period, 3D-MOT players did not participate in training and resumed training following the break for the remainder of the regular season. Losses of perceptual cognitive gains during 1- to 2-month gaps in training have been reported to be negligible.[16] However, further research is needed to examine whether the effects of 3D-MOT training persist over time,[14] and it is unclear whether this gap in training played a significant role in the results of this study. In addition, all collegiate ice hockey players, excluding goalies, that agreed to participate in the study were included (Participation rates: men = 74%; women = 94%). Therefore, the sample size was limited to those who volunteered from a sample of two NCAA Division III ice hockey teams during a single season. The competitive and aggressive nature of collegiate ice hockey provides an opportunity for further research evaluating vision training programs such as 3D-MOT, as an intervention to reduce head impact exposure.

Acknowledgments

We thank the players, coaches, and athletic trainers of the men's and women's University of New England ice hockey teams for their participation and cooperation with this study. We would also like to thank Dr. Wallace Marsh, Director, Academic Affairs and Assessment, University of New England, School of Pharmacy for his assistance with the statistical analysis.

Funding Information

This study was supported by the Peter Morgane Research Fellowship, University of New England College of Osteopathic Medicine.

Author Disclosure Statement

No competing financial interests exist.

References

1. Rosene, J.M., Raksnis, B., Silva, B., Woefel, T., Visich, P.S., Dompier, T.P., and Kerr, Z.Y. (2017). Comparison of concussion rates between NCAA Division I and Division III men's and women's ice hockey players. Am. J. Sports Med. 45, 2622–2629.
2. Wilcox, B.J., Machan, J.T., Beckwith, J.G., Greenwald, R.M., Burmeister, E., and Crisco, J.J. (2014). Head-impact mechanisms in men's and women's collegiate ice hockey. J. Athl. Train. 49, 514–520.
3. Brainard, L.L., Beckwith, J.G., Chu, J.J., Crisco, J.J., McAllister, T.W., Duhaime, A.C., Maerlender, A.C., and Greenwald, R.M. (2012). Gender differences in head impacts sustained by collegiate ice hockey players. Med. Sci. Sports Exerc. 44, 297–304.
4. Agel, J.H.E. (2010). A 7-year review of men's and women's ice hockey injuries in the NCAA. Can. J. Surg. 53, 319–323.
5. Agel, J., Dick, R., Nelson, B., Marshall, S.W., and Dompier, T.P. (2007). Descriptive epidemiology of collegiate women's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 2000–2001 through 2003–2004. J. Athl. Train. 42, 249–254.
6. Agel, J., Dompier, T.P., Dick, R., and Marshall, S.W. (2007). Descriptive epidemiology of collegiate men's ice hockey injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. J. Athl. Train. 42, 241–248.
7. Bailes, J.E., Petraglia, A.L., Omalu, B.I., Nauman, E., and Talavage, T. (2013). Role of subconcussion in repetitive mild traumatic brain injury. J. Neurosurg. 119, 1235–1245.
8. McKee, A.C., Cantu, R.C., Nowinski, C.J., Hedley-Whyte, E.T., Gavett, B.E., Budson, A.E., Santini, V.E., Lee, H., Kubilus, C.A., and Stern, R.A. (2009). Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. J. Neuropathol. Exp. Neurol. 68, 709–735.
9. Naunheim, R.S., Standeven, J., Richter, C., Lewis, and L.M. (2000). Comparison of impact data in hockey, football, and soccer. J. Trauma 48, 938–941.
10. Breedlove, E.L., Robinson, M., Talavage, T.M., Morigaki, K.E., Yoruk, U., O'Keefe, K., King, J., Leverenz, L.J., Gilger, J.W., and Nauman, E.A. (2012). Biomechanical correlates of symptomatic and asymptomatic neurophysiological impairment in high school football. J. Biomech. 45, 1265–1272.
11. Tagge, C.A., Fisher, A.M., Minaeva, O.V., Gaudreau-Balderrama, A., Moncaster, J.A., Zhang, X.L., Wojnarowicz, M.W., Casey, N., Lu, H., Kokiko-Cochran, O.N., Saman, S., Ericssoon, M., Onos, K.D., Veksler, R., Senatorov, V.V., Kondo, A., Zhou, X.Z., Miry, O., Vose, L.R., Gopaul, R.K., Upreti C., Nowinski, C.J., Cantu, R.C., Alvarez, V.E., Hildebrandt, A.M., Franz, E.S., Konrad, J., Hamilton, J.A., Hua, N., Tripodis, Y., Anderson, A.T., Howell, G.R., Kaufer, D., Hall, G.F., Lu, K.P, Ransohoff, R.M., Cleveland, R.O., Kowall, N.W., Stein, R.D., Lamb, B.T., Huber, B.R., Moss, W.C., Friedman, A., Stanton, P.K., Mckee, A.C., and Goldstein, L.E. (2018). Concussion, microvascular injury, and early tauopathy in young athletes after impact head injury and an impact concussion mouse model. Brain 141, 422–458.
12. Knudson, D. and Kluka, D. (1997). The impact of vision and vision training on sport performance. JOPERD. 68, 17–27.
13. Romeas, T., Guldner, A., and Faubert, J. (2015). 3D-Multiple object tracking training task improves passing decision-making accuracy in soccer players. Psych. Sport Exerc. 22, 1–9.
14. Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Bérubé, S., Scheffer, O., Beauregard, M., and Faubert, J. (2016). Enhancing cognitive function using perceptual-cognitive training. Clin. EEG Neurosci. 47, 37–47.
15. Faubert J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. Sci. Rep. 3, 1154.
16. Faubert, J. and Sidebottom, L. (2012). Perceptual-cognitive training of athletes. Clin. J. Sport Psychol. 6, 85–102.
17. Hutchison, M.G. (2011). Concussions in the National Hockey League (NHL): The Video Analysis Project. [doctoral thesis]. Toronto, CN: University of Toronto.
18. Allison, M.A., Kang. Y.S., Maltese, M.R., Bolte, J.H. 4th, and Arbogast, K.B. (2015). Measurement of hybrid III head impact kinematics using an accelerometer and gyroscope system in ice hockey helmets. Ann. Biomed. Eng. 43,1896–1906.
19. Kiefer, A.W., DiCesare, C., Nalepka, P., Barber Foss, K., Thomas, S., and Myer, G.D. (2018). Less efficient oculomotor performance is associated with increased incidence of head impacts in high school ice hockey. J. Sci. Med. Sport 21, 4–9.
20. Poltavski, D. and Biberdorf, D. (2015). The role of visual perception measures used in sports vision programmes in predicting actual game performance in Division I collegiate hockey players. J. Sports Sci. 33, 597–608.

21. Mihalik, J.P., Guskiewicz, K.M., Jeffries, J.A., Greenwald, R.M., and Marshall, S.W. (2008). Characteristics of head impacts sustained by youth ice hockey players. Proc. Inst. Mech. Eng. P 222, 45–52.
22. Wilcox, B.J., Beckwith, J.G., Greenwald, R.M., Chu, J.J., McAllister, T.W., Flashman, L.A., Maerlender, A.C., Duhaime, A.C., and Crisco, J.J. (2014). Head impact exposure in male and female collegiate ice hockey players. J Biomech. 47, 109–114.
23. Post, A. and Hoshizaki, T.B. (2012). Mechanisms of brain impact injuries and their prediction: A review. Trauma 14, 327–349.
24. Zhang, J., Yoganandan, N., Pintar, F.A., and Gennarelli, T.A. (2006). Role of translational and rotational accelerations on brain strain in lateral head impact. Biomed. Sci. Instrum. 42, 501–506.
25. Clark, J.F., Graman, P., Ellis, J.K., Mangine, R.E., Rauch, J.T., Bixenmann, B., Hasselfeld, K.A., Divine, J.G., Colosimo, A.J., and Myer, G.D. (2015). An exploratory study of the potential effects of vision training on concussion incidence in football. Opt. Vis. Perf. 3, 116–125.
26. Patton, D.A. (2016). A review of instrumented equipment to investigate head impacts in sport. Appl. Bionics Biomech. 1–16.

Address correspondence to:
John M. Rosene, DPE, LAT, ATC, CSCS, ACSM EP-C
Department of Exercise and Sport Performance
University of New England
11 Hills Beach Road
Biddeford, ME 04005
USA

E-mail: jrosene@une.edu