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Effectiveness of a Computerized Cognitive Training Program for Reducing Head Impact Kinematics in Youth Ice Hockey Players

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ABSTRACT

International Journal of Exercise Science 14(1): 149-161, 2021. Cognitive training (CT) is an effective technique to improve neurological performance, but has not been investigated as a head impact primary prevention strategy. The purpose of this study was to investigate the CT's effectiveness in reducing head impact kinematics in youth ice hockey players. Twenty youth were divided into two groups: a CT and Control group. The CT group performed two 30-minute sessions of IntelliGym CT weekly for 20 weeks and the control group performed two 30-minute sessions weekly evaluating hockey videos. The dependent variables, number of head impacts, cumulative linear acceleration (CLA) and rotational acceleration (CRA) and mean linear and rotation peak acceleration, were compared with repeated measures ANOVAs, with post-hoc for main effect of time for each group, between the first and second half of the season. There were significant interactions for number of head impacts (p = 0.014) and CLA (p = 0.043) and post-hoc testing identified reductions in the second half of the season for the CT, but not control, group. There were no interactions for CRA, mean peak linear acceleration, and mean peak rotational acceleration. These preliminary results suggest CT may be an effective primary prevention strategy to reduce head impacts and cumulative linear acceleration in youth ice hockey players.

KEY WORDS: Concussion, mild traumatic brain injury, injury prevention, subconcussive impacts

INTRODUCTION

Ice hockey is a popular sport with over a million North American players annually and participation rates steadily increasing; however, concerns have been raised over hockey related concussions and repetitive head impacts (RHI) (22, 29). The nature of ice hockey includes fast skating, legal body contact (i.e., checking), and unintentional contacts with hard objects (e.g., ice, boards) resulting in considerable overall injury risk with up to ¾ of players suffering an injury during the course of a season (63). Furthermore, concussions are a common hockey injury (10 – 15%) and the concussion rate (up to 21.5 per 1,000 athlete exposures) is comparable to other collision sports (20, 21, 31). However, this may still underrepresent the true incidence rate as many concussions likely go unreported (2, 24, 36, 37). While concussions have received considerable attention and leagues have worked to update concussion diagnostic and management protocols. RHI, sometimes referred to as "subconcussive blows," are hits to the head which commonly occur in collision sports but without clinically observed neurological dysfunction (1, 9). RHIs, independent of concussion, have been speculated to be associated with later life neuropathological deficits including chronic traumatic encephalopathy (38, 44, 60). Adolescents have different physiological responses and longer recovery from concussion than adults or children. However, less is known about adolescent's response to RHI particularly when they occur during critical neurological development periods (44, 51, 60).

There is inconsistent evidence related to neuropathological effects of RHI, but a single non-concussive head impact generally does not cause cellular damage (1). Animal models have suggested that multiple RHIs may result in neuropathology including injured axonal integrity and acute neuroinflammatory response with repeated impacts over a short period of time (1, 3, 55, 57). Furthermore, earlier first exposure to RHI may be a contributing factor to later life behavioral and structural deficits (60, 61), but are not seen in collegiate athletes (10, 11). Numerous human neuroimaging studies have repeatedly identified neurological changes in American adolescent football players, but few studies exist in reference to ice hockey (6, 50, 58, 64, 65). In collegiate ice hockey players, RHI, independent of concussion, has been associated with altered white matter integrity and decreased N-acetylaspartate (33, 48). While no dose response or threshold for RHI is currently well accepted in the scientific literature, Montenigro has proposed a cumulative head impact index and suggested RHIs exceeding this threshold elevates the risk of cognitive and behavioral impairments in later life (44). Regardless of a specific threshold, the pattern of emerging evidence supports the recommendation of reducing RHI in collision sports (1).

Injury prevention models are divided into primary (preventing an injury before it occurs), secondary (reducing the effects of an injury), and tertiary (lessening long term effects) (53). In sports injury approaches, primary prevention mechanisms generally involving increasing player strength, rule changes, heightened rule enforcement, or reduced full contact practice times which have shown mixed results in reducing RHI and concussions (8, 13,17-19, 32, 34, 43, 54, 59, 62). Specific to ice hockey, delaying body checking until age 13 has reduced injury risk; however, this is doesn't protect teenage participants (4, 19, 28). While primary prevention strategies to reduce head impacts in hockey are limited, one potential approach which has received limited investigation is cognitive training (CT). CT typically refers to training core cognitive abilities with the goal of improving performance on other cognitive tasks through the concept of broad training by utilizing complex computer games (30, 56). These interventions are generally effective at improving performance on the trained task with limited translation to other tasks or overall cognitive performance (5, 56). However, some evidence supports the use of complex computer games to improve skilled performance (e.g., flight performance) when attentional control is the training program target (26). The CT goal utilized herein was to improve attention allocation weighting (e.g., strategy) during a complex computer game presenting high concurrent demands (26). This approach has successfully demonstrated transfer of skills and attentional allocation during military flight training after 20 training sessions lasting ten hours; however, it is unknown if this approach would be effective at reducing head impacts in sports (23, 26, 38).

While many questions regarding RHI impact kinematics remain unresolved, it is generally agreed that fewer RHI likely reduces potential risks (1, 44). A potential primary prevention strategy of computerized CT could be beneficial in reducing RHI. Therefore, the purpose of this study was to investigate the effectiveness of a CT program in reducing head impact kinematics in youth ice hockey players. We hypothesized that cognitive training would be effective at reducing the number and magnitude of head impacts over the course of a youth ice hockey season.

METHODS

Participants

Two youth ice hockey teams (U16 and U18) were recruited and 22 male youth ice hockey players, out of 35 potential players, agreed to participate in the study. The participants were randomly divided into the Cognitive Training (CT) group (age: 15.5 $\pm$ 0.6 years, height: 1.73 $\pm$ 0.06 m, weight: 67.8 $\pm$ 25.8 kg) and a control group (age: 16.1 $\pm$ 0.9 years, height: 1.78 $\pm$ 0.1 m, weight: 73.7 $\pm$ 9.2 kg). No anthropometric group differences were found ($p > 0.05$). The inclusion criteria was any active participant on one of the teams. Participants were excluded if they quit the team during the season (N = 2, non-injury related). All participants provided informed consent if over 18 or informed assent and parental consent if under 18 as approved by the institutional review board. The study adhered to the ethical policies set forth by the editorial board (45).

Protocol

The computerized CT was performed with the Hockey IntelliGym (Applied Cognitive Engineering, Pine Brook, NJ, USA) program. Hockey IntelliGym was developed to match perceived sport skills with training components in the game through a modified version of the Space Fortress CT protocol which has been effectively utilized across diverse populations (5, 16, 25, 26, 30). During the CT program, two five-player teams, consisting of one human player and nine artificial intelligence virtual players, compete to shoot a bomb into the opponents "home gate" which requires collaboration amongst teammates and overcoming opponents (25). This video game like environment emphasizing attentional skills, situational awareness, and attentional resources in dual task gaming environments with up to 80 parameters per game round (Figure 1).

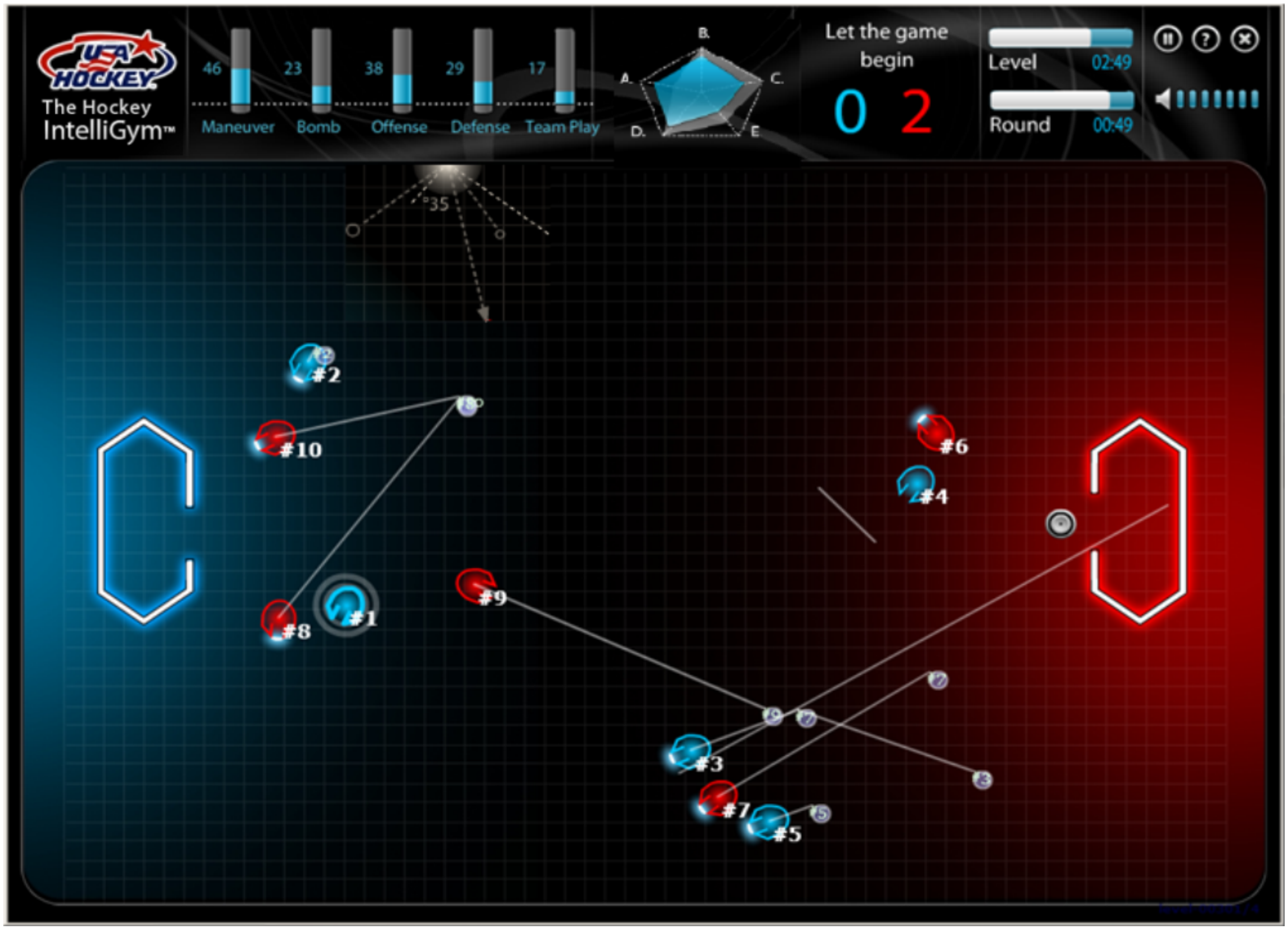

Figure 1. Exemplar screenshot of the IntelliGym program. The participant is identified as "#1" in the screenshot.

Head impact kinematics were measured utilizing the Smart Impact Monitor-G (SIM-G, Triax Technologies Inc., Norwalk, CT, USA) accelerometers. The SIM-G utilizes a high-g and low-g triaxial accelerometer to measure linear acceleration levels within a 3–150 g range and a triaxial gyro to measure angular head motion. In laboratory investigations, SIM-G was highly accurate for identifying the number of impacts (99.29 – 100%) and had average acceleration errors range from 7.9 – 20.6% which are comparable to other head impact measurement accelerometers systems (e.g., HITS: 14.1 – 29.5%, XPatch: 17.3 – 22.0%) (15). The SIM-G has been successfully utilized in clinical settings to capture real-time head impact kinematics (12). The threshold was set at 10 g's and if an impact exceeded the threshold then data from 10-ms before and 52-ms after the impact were recorded and transmitted in real-time to an access point connected via USB to a laptop computer.

Participants were randomly assigned to one of two groups: a cognitive training (CT) or a control group with similar time requirements. The CT group were instructed to perform two 30-minute training sessions per week for the 20-week long season. Participants in the control group were instructed to review two 30-minute sessions of hockey videos per week, provided by the research team, and report on specific player performance (e.g., number of shots on goal, number of passes successfully completed). All participants denied utilizing the cognitive training program outside of the study and program compliance was not tracked.

All participants wore the SIM-G accelerometers for all practices and home games. The SIM-Gs were secured to the participants head using either a headband or skullcap and positioned on the nuchal line by a certified athletic trainer prior to each event and then collected following the event (12, 35). All head impact kinematics were monitored in real time by a research team member who addressed any issues which arose during the session (e.g., player took the headband off). All practices and home game were video recorded to allow the research team to review and confirm recorded head impact, consistent with current recommendations for head impact telemetry data (49). The SIM-G system was enabled at the start of the event and terminated at the conclusion to ensure only session related impacts were recorded. Participant injuries were not tracked during the course of the season as this was not the aim of the study.

Statistical Analysis

Descriptive analysis (mean and standard deviations) of the head impacts were calculated, but analysis by position was not conducted due to limited sample size per position. Prior CT studies have suggested ten hours across 20 sessions of training are needed to demonstrate improvements (23, 26). Therefore, the season was divided into two halves (week 1 – 10 and weeks 11 – 20), which served as the independent variable. The five dependent variables of interest were: 1) number of head impacts, 2) cumulative linear acceleration (CLA), 3) mean peak linear acceleration, 4) cumulative rotational acceleration (CRA), and 5) mean peak rotational acceleration. The dependent variables of interest were compared with a 2 (group) x 2 (time) mixed design analysis of variance (ANOVA). Significant interactions were followed up with a pairwise comparison, using Tukey's procedure to examine the simple main effect of time for each group and effect sizes were reported using standard partial eta classifications.

RESULTS

There were no concussions reported by any participants during the season. Participants completed an average of 28.6 $\pm$ 6.8 practice and games over the course of the season and there was no difference between groups for sessions (CT: 29.9 $\pm$ 7.2 sessions and Control: 27.3 $\pm$ 6.4 sessions, $F = 0.725$, $p = 0.406$) completed. There was no significant interaction between group and number of sessions ($F = 1.589$, $p = 0.224$) per time period. Impact kinematics by position are provided in Table 1.

Table 1. Head Impact Kinematics by Position.

	Linear Acceleration (Mean $\pm$ SD)	Rotational Acceleration (Mean $\pm$ SD)
Defenseman (N=8)	39.8 $\pm$ 18.5 g's	4,147.4 $\pm$ 2,947.3 rad/s^2
Winger (N=7)	36.3 $\pm$ 17.5 g's	4,078.3 $\pm$ 2,808.3 rad/s^2
Center (N=3)	29.6 $\pm$ 12.6 g's	2,593.9 $\pm$ 1,325.6 rad/s^2
Goalie N=2)	31.6 $\pm$ 14.7 g's	3,365.4 $\pm$ 2,670.7 rad/s^2
Total Participants (N=20)	36.7 $\pm$ 17.6 g's	3,985.6 $\pm$ 2,807.2 rad/s^2

The position was determined by the participant's self-reported "primary" position during the season. Statistical analysis by position was not performed as the sample was underpowered.

A significant interaction was identified for number of head impacts (F = 7.494, p = 0.014, η_p^2 = 0.294). Post-hoc testing identified a significant difference between Weeks 1 – 10 and 11 – 20 for number of impacts per player in the CT group (21.8 $\pm$ 9.9 and 8.0 $\pm$ 4.2 respectively; p < 0.001), but not for the Control group (16.1 $\pm$ 6.6 and 13.8 $\pm$ 8.4 respectively; p = 0.451). There was no significant interaction between CT (Weeks 1 – 10: 33.4 + 5.7 g's and Weeks 11 – 20: 38.3 + 5.5 g's) and Control (Weeks 1 – 10: 35.1 + 6.8 g's and Weeks 11 – 20: 39.0 + 10.1 g's) for mean peak linear acceleration (F = 0.062, p = 0.806, η_p^2 = 0.003). A significant interaction for CLA was identified (F = 4.725, p = 0.043, η_p^2 =0.208). Post-hoc testing revealed a significant difference between Weeks 1 – 10 and 11 – 20 for CLA in the CT group (408.2 + 334.6 g's and: 169.1 + 178.3 g's respectively; p = 0.007), but not for the Control group (333.3 + 174.9 g's and 337.4 + 194.5 g's respectively; p = 0.959) (Figure 2). A significant reduction in the CT group (58.6%) in the second half (weeks 11 – 20) of the season was determined, but no significant change during the same time period was noted in the Control group (↑1.2%).

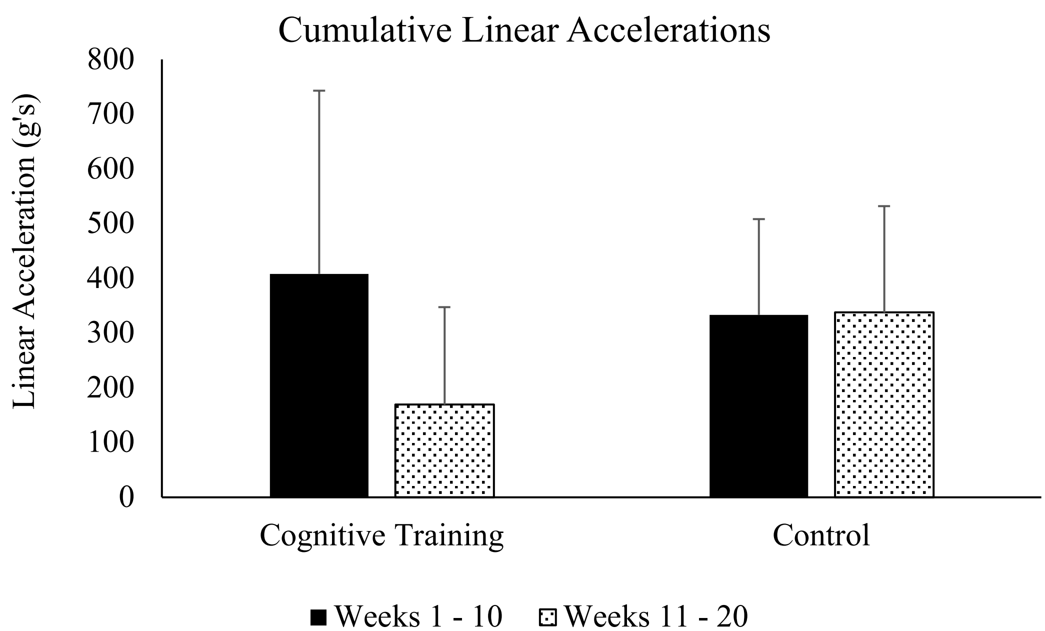

Figure 2. Cumulative Linear Acceleration.

There was no significant interaction between CT (Weeks 1 – 10: 3.9 + 1.1 krad/s^2 and Weeks 11 – 20: 2.0 + 0.8 krad/s^2) and Control (Weeks 1- 10: 4.6 + 1.7 krad/s^2 and Weeks 11 – 20: 1.5 + 0.7 krad/s^2) for mean peak rotational acceleration (F = 3.375, p = 0.083, η_p^2 = 0.158). Additionally, there was no significant interaction between CT (Weeks 1 – 10: 56.4 + 59.7 krad/s^2 and Weeks 11 – 20: 22.9 + 20.5 krad/s^2) and Control (Weeks 1- 10: 50.2 + 32.5 krad/s^2 and Weeks 11 – 20: 51.2 + 42.4 krad/s^2) for CRA (F = 3.127, p = 0.094, η_p^2 = 0.148).

DISCUSSION

This preliminary study evaluated the effectiveness of a commercially available computerized CT program on head impact kinematics in youth ice hockey players. The primary finding of this preliminary study was a reduction in the number and CLA of ice hockey head impacts, with moderate to large effect sizes, in the second half of the season following the utilization of a CT program. As there were no interactions for mean linear and rotational peak acceleration, the reduction in CLA is likely the result of the reduced number of head impacts which occurred in the second half of the season. While these results must be replicated in larger studies, this preliminary finding suggests CT could be a primary prevention method to reduce head impacts and the potential subsequent neurological burden of RHI in hockey.

Although causation has not been demonstrated, RHI is speculated to be a primary or contributing cause of later life neuropathology (38, 44, 60). Therefore, a reduction in the number and cumulative magnitude of ice hockey head impacts may potentially help mitigate the neuropathological risks. While no dose response or threshold for RHI is currently well accepted in the scientific literature, Montenigro has proposed a cumulative head impact index and suggested RHIs exceeding this threshold elevates the risk of cognitive and behavioral impairments in later life, but this was specific to football impacts (44). The ~62% reduction in head impacts during the second half of the season as well as reduction in cumulative linear acceleration herein is suggestive that CT could be beneficial in reducing the likelihood of exceeding the proposed threshold. Future studies need to investigate if these head impact kinematic reductions plateau or grow exponentially over time in order to more fully understand the potential benefits of CT.

This study was not designed to identify potential mechanisms underlying the reduction in head impact kinematics although several mechanisms can be extrapolated from the literature (26, 27, 30, 39, 46). Complex computerized CT, like the program used herein, employs a broad transfer approach which refers to transferring the effects of training tasks to other tasks which are significantly different from those that were trained (26). Indeed, programs like Space Fortress, which incorporate complex integrative CT, as opposed to isolated domain training, have demonstrated speed improvements associated with broad style transfer effects (27, 46). Furthermore, this approach focusing on attentional control has demonstrated improvements in both performance outcomes (e.g., flight performance) and underlying neurological adaptations (e.g., training induced plasticity) (26, 46). During flight performance, Gopher noted improved positive transfer of attentional strategies with pilots better able to adjust to dual-task demands and maintain performance despite elevated cognitive load (26). While the extrapolation to sports performance is not direct, Mihalik suggested that ice hockey players with increased awareness of their surroundings are better able to anticipate and prepare for an impact potentially mitigating the impact's severity (39). Herein, although there were no differences in the peak linear or rotational acceleration between groups, the CT group did have a reduced number of head impacts suggesting the possibility they were able to avoid the impact altogether. Future studies should investigate the neurological and behavioral mechanisms underlying with these improvements identified in this preliminary study.

The participants herein sustained relatively few head impacts compared to other hockey (~200) and football (500 – 700 impacts) adolescence studies (7, 42). There are several potential explanations for this lower number of impacts. First, impacts occur far more frequently in games compared to practices and herein only home games were recorded (41, 42). Secondly, the influence of media coverage of concussions and RHI may have played a role as the research team noted numerous instances of coaches instructing players on reducing or eliminating head impacts during practice. While the number of impacts was low, the mean peak linear (36.7 + 17.6 g's) and rotational (4.0 + 2.8 krad/s^2) accelerations were higher than previously reported in ice hockey (linear: 17.5 – 35.0 g's and rotational: 1.4 – 1.6 krad/s^2) (14, 39, 43). Previous hockey investigations have primarily utilized the Head Impact Telemetry System (HITS) whereas herein the SIM-G tri-axial accelerometer was utilized which has demonstrated lower acceleration related mean absolute error, root mean square errors, and a higher impact reporting accuracy than HITS (15). Furthermore, the relatively high linear peak acceleration per impact but low number of impacts identified herein could therefore be a result of reducing the "minor" head impacts thereby skewing the mean peak linear acceleration higher. Nonetheless, the overall outcome of fewer head impacts and the resulting lower cumulative acceleration in the CT group may be a positive development to improve player safety.

This finding may be particularly important as many other prevention strategies have largely been ineffective at reducing head impact kinematics (4, 39, 43). While strength training is feasible and has shown reductions in resultant accelerations in laboratory testing, cervical strength was not effective at reducing linear or rotational head impact severity in youth ice hockey players (17, 43). Rules adjustments have been attempted with inconsistent results. Eliminating body checking in younger leagues appears to reduce both overall injury and concussion risks; however, this does not benefit older players, like the U16 and U18 teams herein, in leagues which allow checking (4, 18, 19, 28). Improved rule enforcement may be beneficial strategy as illegal contact have high linear accelerations and resulting injuries, but rule enforcement cannot be controlled by the individual player (39, 40). Behavioral modification programs such as "Fair Play" (teams are awarded/penalized points based on penalty minutes) have generally been effective at reducing injury, but not concussion, risk (54, 59). While the incidence was very low, "Fair Play" has reduced the number of non-concussion head impacts (59). Finally, the inclusion of a "look-up line" (warning track near the boards) has not been assessed on concussion risk, but was not effective at improving player's head kinematics when skating near the boards (66). Thus, given the limited options for primary injury prevention, the use of CT, along with delayed body checking rules, could be an effective low-risk intervention to help reduce RHI.

This study involved 20 participants from two youth ice hockey teams and the results should be viewed as preliminary until they are confirmed in larger and more diverse studies. This study did not assess concussions and no extrapolation to concussion risk should be implied from these results. The head impact data was delimited to practices and home games due to travel logistics for the research team, thus it is unknown how head impacts during road games would have affected these results; however home games have been utilized previously in hockey analysis (52). While the SIM-G tri-axial accelerometer has been validated in laboratory settings with comparable results to other commonly utilized head impact accelerometer systems and utilized in soccer studies; there is ongoing discussion regarding accuracy and other limitations (e.g., accelerometer placement, movement, etc.) inherent across accelerometer systems (15, 47, 49). However, it is important to note that both groups herein used the same system and all events were video recorded and impacts confirmed by a member of the research team. Finally, we were not able to accurately track ice time due to camera positioning, therefore the exposure could have fluctuated over the course of the season.

The results of this preliminary study suggest that computerized CT may be an effective primary prevention strategy to reduce head impacts and cumulative linear acceleration in youth ice hockey players. Specifically, these reductions hold potential promise to reduce the long-term risks associated with repetitive head impacts. As concerns over RHI in collision sports remains high, the implementation of CT, continued rule modifications such as delayed body checking, and proper rule enforcement may serve to reduce the risk of RHI in ice hockey.

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