

## Research Article

### Strategic Differences in Balance Recovery between Athletes and Untrained Individuals

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Received: 06-10-2014

Accepted: 09-15-2014

Published: 09-18-2014

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#### Abstract

Previous research has demonstrated superior balance control among elite athletes, compared with non-athletes, as defined by the ability to maintain static balance; while only few studies investigated dynamic postural control and balance recovery. The objectives of the current study were 1) to examine whether elite athletes demonstrate superior dynamic postural control defined by reduced center of mass (COM) and center of pressure (COP) excursion during balance recovery; and 2) identify balance recovery strategies employed by the athletes. Young males (varsity-level ice hockey players,  $n=10$ ; untrained controls,  $n=10$ ) were exposed to forward lean-and-release postural perturbations. Following the release, participants recovered balance with a single step. Two sensory conditions were investigated: eyes-open and eyes-closed. Whole-body normalized COM (nCOM) and normalized COP (nCOP) excursions were calculated and normalized to participant height. Additionally, pre-perturbation lower body and trunk angles, trunk angle excursion, and step length, velocity, and latency were calculated. Peak nCOM excursion was lower in athletes ( $1.03\pm 0.08\text{cm/cm}$ ) than in controls ( $1.41\pm 0.08\text{cm/cm}$ ); peak nCOP was not different between groups. Peak trunk angle excursion was lower in athletes ( $6.8\pm 2.02^\circ$ ) than in controls ( $14.8\pm 1.96^\circ$ ). Superior balance control among ice hockey players may be attributed to a more upright trunk position, possibly due to sport-specific training.

**Keywords:** Dynamic Balance Control; Neuromechanics; Ice Hockey; Postural Perturbation

#### Introduction

Successful balance control is underpinned by coordination of movement strategies to stabilize the whole-body center of mass (COM) within the base of support (BOS). It is known that balance control during quiet standing and during locomotion is diminished with healthy aging [1] and with certain pathology and injury, such as Parkinson's disease [2], osteoarthritis [3], and neuropathy [4], among others. Patients with confirmed balance disorders have demonstrated altered balance recovery responses, and that balance control can be improved with practice among individuals with balance impairment [5], leading to speculation that balance recovery ability may be reflective of fall risk [6]. Previous research has shown that certain athlete groups, such as gymnasts, demonstrate superior balance control [7]. However, among those athletes for whom balance is not likely a key determinant in per-

formance, such as swimmers, balance control is not different from healthy controls [8]. It is not known, however, if athletes demonstrate superior dynamic recovery when balance is disrupted.

Ice hockey is a sport in which one might expect high performance athletes to demonstrate superior dynamic balance control and balance recovery. By the nature of the sport, players are frequently exposed to postural perturbations, as they are contacted by other players or by the boards around the ice surface. Furthermore, the game is played on a slippery surface (i.e., ice) while wearing skates, which provide only a very narrow support surface. Behm, et al. [9] reported that skating speed and balance performance on a stabilometer were not related. However, skating speed is clearly not the sole determinant of performance for ice hockey players. Dynamic balance control, and balance

recovery more specifically, may be a better predictor of performance for ice hockey players, as the ability to recover and maintain balance in a dynamic sporting environment may provide a platform for the situational awareness that is required for high-level performance. The objectives of the current study were 1) to investigate whether elite level athletes, such as ice hockey players, demonstrate superior dynamic balance control than untrained individuals in a natural non-sport setting; and 2) if there are differences in balance recovery ability between athletes and untrained individuals, explore the differences in mechanisms used by the two groups in balance recovery.

## Materials and Methods

### Participants

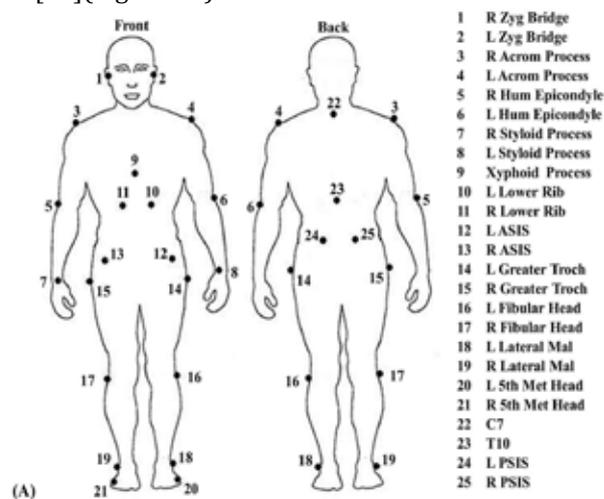
Ten university varsity-level ice hockey players (age  $23.2 \pm 1.5$ yr, height  $1.86 \pm 0.07$ m, weight  $91.4 \pm 8.37$ kg; mean  $\pm$  SD) and ten control group participants (age  $23.6 \pm 1.8$ yr, height  $1.75 \pm 0.11$ m, weight  $72.9 \pm 9.92$ kg) volunteered for this study, and provided written informed consent prior to participation. Control group participants were selected based on their self-reported lack of any involvement in organized sports or functional fitness training. A sample size calculation was based on preliminary data obtained with the first 10 participants (athletes,  $n=5$ ; non-athletes,  $n=5$ ); results indicated that a total of 20 participants (10 participants per group) would provide adequate statistical power ( $> 80\%$ ) to detect difference ( $p < 0.05$ ) between athletes and controls in the peak normalized COM excursion measure. Participants were excluded if they reported a history of neurological or musculoskeletal disorders; or had an injury, pain or surgery on their lower body and back in the six months prior to participation. The local institutional research ethics board provided ethical approval of the methods used in this study.

### Experimental Apparatus and Set-Up

Participants were barefoot for the duration of the experiment. Previous research has shown that the availability and quality of the sensory information from the soles of the feet may affect the balance recovery ability in a clinical population [4]. Thus, Semmes-Weinstein Monofilaments were used to establish an aggregate sensory index for each participant by testing the tactile sense on the plantar surface of both feet; the reliability of this test has been previously confirmed [10]. To administer the test, the monofilament was pressed against the skin with enough force to buckle the monofilament and form a U-shape. The force required to buckle each of the monofilaments is different, dependent on the stiffness of the specific filament. During the tactile sensory test participants would lay prone on a table, facing away from the researcher in such a way that they could not see their feet. The areas of interest on both feet were stimulated with the filaments in pseudo-random order,

always starting with the softest (least stiff) filament. Participants were asked to focus on the diagram of the areas that were stimulated and report which foot and what area was touched. The areas on the plantar surface of both feet tested were: calcaneus, cuboid, medial cuneiform, 5th metatarsal head, 1st metatarsal head, tip of the 5th distal phalanx, and the tip of the 1st distal phalanx. Participant received no feedback in regards to the correctness of their responses. The softest filament that the participant could accurately detect indicated the threshold of sensitivity for that area of the foot.

Participants were outfitted with a harness around their waist. The harness was attached by a tether to an electromagnet mounted to a support stand. Infrared reflective markers were placed strategically on the bony landmarks to produce a 14-segment model of whole-body COM [11] (Figure 1A).



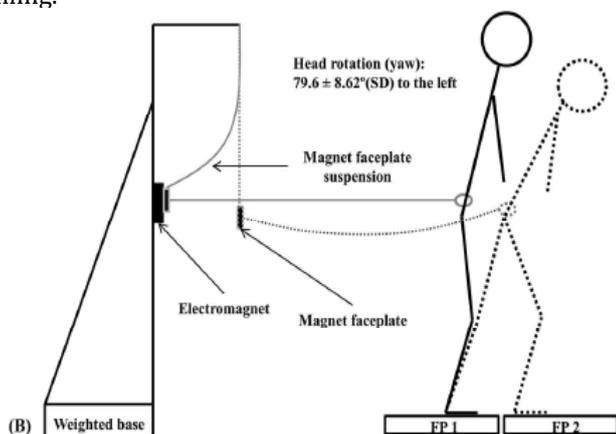
**Figure 1A.** Infrared reflective marker placement diagram for the 3D whole-body COM estimation (Adapted from Gage et al., 2004).

All trials were initiated with the participant standing on two force plates (OR6-7, AMTI, MA), with one foot on each plate. Two additional force plates were located in front of the participant; the four force plates were arranged in a 2x2 grid pattern. Force plate signals were sampled at 1000Hz, and subsequently filtered offline using a digital Butterworth 4th order low-pass filter with a 6Hz cutoff; the cutoff frequency was determined by residual analysis [12]. Net COP was calculated as the weighted average of the COP signal across all four force plates. Whole-body movement was recorded using a seven-camera motion capture system (MX40, Vicon, CO). Marker position signals were sampled at 100Hz and filtered offline using digital Butterworth 4th order low-pass filter with a 6Hz cutoff. Whole-body COM position was calculated as the weighted average of segment COM locations [11].

### Procedure

The data presented in this paper were collected as a

component of a larger study that included trials during which bilateral bipolar galvanic vestibular stimulation was provided. The data for those trials are not presented here. As such, participants maintained a posture with their head facing leftward for all trials; participants were permitted to adopt a neutral head posture between trials. The head position was not different between groups. Prior to the lean-and-release perturbation participants leaned forward away from the release device; the tether prevented the individuals from falling forward (Figure 1B). When magnet was disengaged the participant was allowed to fall forward and recover balance with a step. The lean-and-release method has been used for a number of balance recovery studies [13,14]. The lean-and-release method imposes a perturbation that is qualitatively similar to a natural experience of an unexpected loss of balance, such as a trip over an obstacle [15,16]. In the current experiment participants were instructed as follows: "When the tether is released, behave as naturally as possible. If you don't have to take a step, don't take a step. If you feel the need to take step to avoid falling, do take a step. Do what is natural to avoid falling."



**Figure 1B.** Representation of the experimental set-up, where the participant leans away from the lean-and-release device, to which they are attached by a tether. Dashed line represents the position of the participant and lean-and-release device components following the release.

The pre-perturbation lean angles were determined for each participant prior to testing by iteratively increasing and decreasing the lean angle by changing the length of the tether to find the individual's threshold for stepping. The lean angle for testing was determined as 1° greater than the threshold. Each participant completed ten trials; five with eyes open (eyes-open) and five with eyes closed (eyes-closed). Trial order was counterbalanced across the visual conditions.

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### Measures of Interest

Superior dynamic balance control was defined as a tighter control of the COM, or lower COM excursion during balance recovery following a postural perturbation. Postural responses were quantified by measuring peak changes in COM and COP position. The maximal excursion in COM was calculated via subtraction of the average COM position in the anteroposterior direction measured over the 0.5s prior to the tether release (initiation of the perturbation) in each of the trials from the peak COM position reached during the perturbation in the same trial. The maximal excursion in COP position was calculated in the same manner as the peak change in COM position. Peak COM and COP were subsequently normalized to each participant's height (nCOM, nCOP) in order to account for the height differences between the athletes and non-athletes.

Secondary kinematic measures were constructed to explore differences in mechanisms used by the two groups to control nCOM excursion during balance recovery. Pre-perturbation angles for the lower body and the trunk segment were calculated by the absolute angles with respect to vertical of the lines subtended between the lateral malleolus and greater trochanter marker, and the sacrum and c7 markers, respectively. The pre-perturbation lean angles were averaged over the 0.5s preceding the release. Peak angular excursion of the trunk segment was calculated via subtraction of the pre-perturbation trunk angle from the peak trunk angle.

Step length normalized to the participant's height, peak step velocity, and step latency were calculated. The lateral malleolus marker was used to indicate foot position during stepping. Step length was calculated as the difference between the average anterior/posterior position of the lateral malleolus marker over the 0.5s prior to perturbation and the position of the lateral malleolus at the end of the step following the perturbation. Step length was subsequently normalized to each participant's height. Step velocity was derived using the 3-point finite difference in the position of the lateral malleolus marker of the stepping foot. Peak step velocity was then calculated. Step latency was calculated as the temporal difference between the release of the magnet and the initiation of stepping foot movement, defined as the initial positive vertical acceleration of the lateral malleolus marker.

### Statistical Analyses

All statistical analyses were conducted using JMP 8.0 (SAS Institute, Cary, North Carolina). Welch's t-test was used to assess the tactile sensory index means. Two-factor 2x2 (group [athlete/control] x condition [eyes-open/eyes-closed]) mixed effects, repeated measures ANOVA, with participants nested within group, was used to test for

differences in the dependent variables between group and condition. Significance level was set at  $\alpha < 0.05$ . Contrast analyses with Tukey HSD correction and Student's t-test were performed to compare means and test interactions, as appropriate.

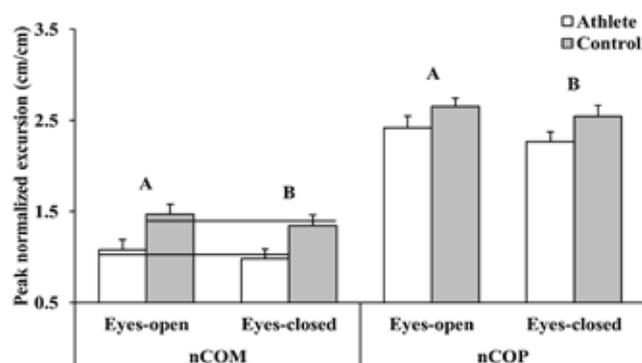
## Results and Discussions

### Results: Primary Measures

The athletes demonstrated significantly lower foot plantar sensitivity ( $t(16.36) = 2.14, p = 0.047$ ) (Table 1).

**Peak nCOM excursion:** There was no interaction effect ( $F(1,18) = 0.10; p = 0.752$ ); but there were main effects for group ( $F(1,18) = 6.29; p = 0.022$ ) and condition ( $F(1,18) = 5.39; p = 0.032$ ) observed. Athletes showed significantly smaller peak nCOM excursion than controls. Peak nCOM excursion was smaller in the eyes-closed condition than in the eyes-open condition (Table 1; Figure 2).

**Peak nCOP excursion:** There were no interaction effect ( $F(1,18) = 0.16; p = 0.690$ ) and no main effect for group ( $F(1,18) = 2.90; p = 0.106$ ); but there was a main effect for condition ( $F(1,18) = 5.99; p = 0.025$ ) observed. Peak nCOP excursion was smaller in the eyes-closed condition than in the eyes-open condition (Table 1; Figure 2).



**Figure 2.** Peak nCOM and nCOP excursion during balance recovery. Athletes demonstrated 27% lower peak nCOM excursion than controls. Peak nCOM excursion was 10% larger in the eyes-open than in the eyes-closed condition. There was no difference between groups in peak nCOP excursion. Peak nCOP excursion was 5% larger in the eyes-open than in the eyes-closed. The error bars are  $\pm$  SE. Horizontal lines indicate significant difference between group means. Letters indicate significant difference between condition means. Levels not connected by the same letter are significantly different.

Table 1

Summary of the Results Collapsed by Group and by Condition

Measure	Group			Condition		
	Athlete	Control	p-value	Eyes-open	Eyes-closed	p-value
<i>Primary</i>						
Tactile sensory index	7.30 (0.95)	6.20 (1.32)	0.047			
Peak nCOM excursion (cm/cm)	1.03 (0.08)	1.41 (0.08)	0.022	1.27 (0.09)	1.16 (0.09)	0.032
Peak nCOP excursion (cm/cm)	2.34 (0.08)	2.60 (0.08)	0.106	2.53 (0.08)	2.41 (0.08)	0.025
<i>Secondary</i>						
Lower body lean angle ( $^{\circ}$ )	10.15 (0.49)	9.61 (0.52)	0.600	10.00 (0.55)	9.76 (0.47)	0.070
Trunk lean angle ( $^{\circ}$ )	11.84 (0.63)	14.91 (1.11)	0.118	13.16 (1.00)	13.59 (0.93)	0.195
Peak trunk angle excursion ( $^{\circ}$ )	6.70 (1.09)	14.78 (1.65)	0.009	10.40 (1.59)	11.09 (1.76)	0.255
Normalized step length (cm/cm)	2.10 (0.06)	2.52 (0.10)	0.022	2.34 (0.09)	2.29 (0.11)	0.342
Peak step velocity (m/s)	2.64 (0.07)	2.83 (0.12)	0.329	2.77 (0.10)	2.70 (0.10)	0.195
Step latency (s)	0.30 (0.02)	0.32 (0.02)	0.691	0.31 (0.02)	0.30 (0.02)	0.620

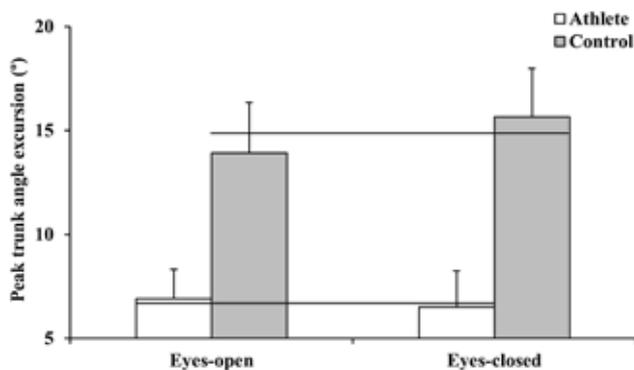
Note. The results are presented as mean (SE), the Tactile sensory index is presented as mean (SD).

## Results: Secondary Measures

Pre-perturbation lower body angle: There was no interaction effect ( $F(1,18)=0.47$ ;  $p=0.503$ ); and no effects for group ( $F(1,18)=0.29$ ;  $p=0.600$ ) or condition ( $F(1,18)=3.72$ ;  $p=0.070$ ) were observed.

Pre-perturbation trunk angle: There was no interaction effect ( $F(1,18)=0.06$ ;  $p=0.813$ ); and no effects for group ( $F(1,18)=2.70$ ;  $p=0.118$ ) or condition ( $F(1,18)=1.81$ ;  $p=0.195$ ) were observed.

Peak trunk angle excursion: There was no interaction effect ( $F(1,18)=2.70$ ;  $p=0.118$ ) or main effect for condition ( $F(1,18)=1.38$ ;  $p=0.255$ ) observed; but a main effect for group ( $F(1,18)=8.49$ ;  $p=0.009$ ) was observed. Controls showed larger peak trunk angle excursion during balance recovery (Table 1; Figure 3).

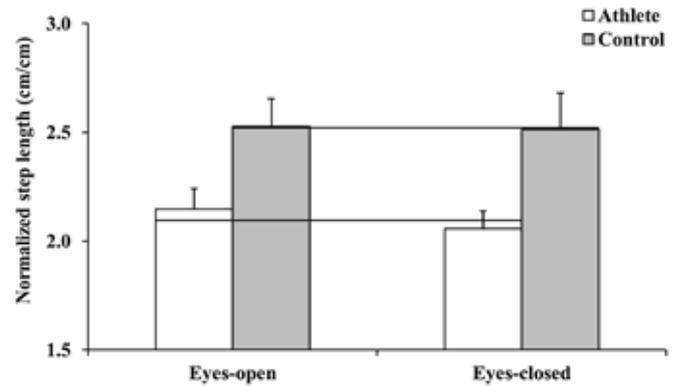


**Figure 3.** Peak trunk angle excursion during balance recovery. Athletes demonstrated 55% lower peak trunk angle excursion than controls during balance recovery. The error bars are  $\pm$  SE. Horizontal lines indicate significant difference between group means.

Normalized step length: There was no interaction effect ( $F(1,18)=0.50$ ;  $p=0.487$ ) and no main effect for condition ( $F(1,18)=0.95$ ;  $p=0.342$ ); a main effect for group ( $F(1,18)=6.32$ ;  $p=0.022$ ) was observed. Athletes showed smaller peak normalized step length during balance recovery than controls (Table 1; Figure 4).

Peak step velocity: There was no interaction effect ( $F(1,18)=1.32$ ;  $p=0.266$ ); and no main effects for group ( $F(1,18)=1.01$ ;  $p=0.329$ ) or condition ( $F(1,18)=1.81$ ;  $p=0.195$ ) were observed.

Step latency: There was no interaction effect ( $F(1,18)=2.07$ ;  $p=0.167$ ); and no main effects for group ( $F(1,18)=0.16$ ;  $p=0.691$ ) or condition ( $F(1,18)=0.25$ ;  $p=0.620$ ) were observed.



**Figure 4.** Normalized step length during stepping balance recovery. The normalized step length was found to be significantly lower in athletes than in controls; athletes' step length was 17% lower than controls' step length. The error bars are  $\pm$  SE. Horizontal lines indicate significant difference between group means.

## Discussion

The results suggest that the athletes demonstrated superior dynamic balance recovery ability in response to the perturbation than untrained individuals, indicated by reduced COM excursion during a single-step balance recovery. However, there was no difference detected between the groups in COP excursion, raising questions about how the athletes achieved lower COM excursions. Analysis of secondary measures suggests that athletes maintained the trunk substantially more erect during balance recovery than untrained individuals, indicated by reduced trunk angle excursion, which may explain the athletes' lower COM excursions.

### Discussion: Primary Measures

**Tactile Sensory Index:** Research has suggested that differences in postural control might be explained, in part, by differences in sensory information arising from the plantar surface mechanoreceptors of the feet. Impaired plantar sensitivity has been shown to negatively affect both quiet standing balance control and dynamic balance recovery following a postural perturbation [4,17]. However, in the current study, though athletes demonstrated superior balance recovery ability, they were found to have less sensitive plantar surface of the feet possibly due to observed calluses. A dermatology study conducted with ice hockey players revealed that they are at high risk of developing athlete's nodules [18], a collagen-type tissue that develops as a result of repetitive friction to the skin area [19]. In the current study the control group appeared to be largely callus free. It is unlikely that the observed superior balance recovery ability among the ice hockey players could be explained by differences in sensory information from the soles of the feet. If there were to be any contribution to differences in balance recovery ability due to differences in sensory information from the soles of the feet, it would be reasonably expected that the reduced plantar surface sensory information among the athletes should lead to

diminished balance recovery ability, not the superior balance performance actually observed.

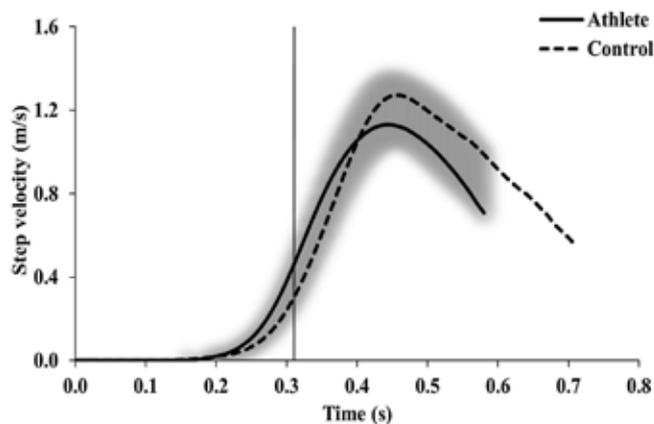
**Peak nCOM and nCOP excursions:** Peak nCOM excursion during balance recovery was significantly lower in athletes, compared with the control group. This result indicates that the athletes maintained a tighter control of their COM during perturbation, suggesting superior balance recovery ability than untrained individuals. Karamanidis and Arampatzis [20] examined the ability of endurance runners to recover balance following a forward fall with a single-step response. Experienced endurance runners demonstrated superior balance recovery ability, compared with a sedentary control group. Superior balance recovery ability was defined as a more posterior position of the COM upon recovery following the postural perturbation, which was consistent with the position of the COM among ice hockey players in the current study. In the current study, however, there was no significant difference found between groups in peak nCOP excursion, which challenges how the group difference in nCOM excursion is interpreted.

There was a significant difference found between the eyes-open and eyes-closed conditions in peak nCOM and nCOP excursions. Both athletes and controls displayed significantly smaller peak nCOM and nCOP excursions in eyes-closed condition than in the eyes-open condition. Both groups demonstrated more conservative responses to the postural perturbation when they were deprived of visual information, which is consistent with previous literature [21]. Importantly, however, there was no significant interaction between group and condition for either nCOM or nCOP excursions, which suggests that groups were not different in their responses in the sensory challenged (the lack of visual sensory information) environment. However, it remains important to distinguish how the athletes achieved smaller peak nCOM excursion, despite the lack of difference in peak nCOP excursion. The reason for lower peak nCOM excursions in athletes may be explained by differences in aspects of the response, other than nCOP excursion. Such differences might be revealed in the secondary measures calculated.

### Discussion: Secondary Measures

Further investigation of the secondary measures revealed no difference in pre-perturbation lower body lean angles between the groups, indicating that the perturbation stimulus delivered to both groups was equivalent. It has been previously suggested that superior ability of older adults, who had received neuromuscular balance recovery training, to recover their balance with a single-leg step was dependent upon the quickness of the stepping limb [5]. Therefore, a larger step velocity, or a smaller latency prior to the onset of foot movement, or both, may explain smaller peak nCOM excursion among the athletes. In other words, if the athletes were able to initiate foot movement earlier

and swing the stepping foot faster, compared with controls, they may have been able to arrest the forward translation of their COM earlier, limiting the distance that the COM translated, compared with the controls. However, both peak step velocity and movement latency were not significantly different between the groups (Figure 5). The absence of differences in peak velocity and in movement latency suggest that the athletes did not, in fact, move more quickly to arrest the movement of the COM earlier. But differences in step length during balance recovery and, to a greater extent, trunk segment angular excursions among the athletes may explain the reduced nCOM excursion, as discussed below.



**Figure 5.** Ensemble average (athlete  $n=10$ , control  $n=10$ ) of the step velocity. The time 0 indicates the release of the tether. The shaded area between the velocity curves represents the step velocity SE overlap between the athletes and controls. The vertical grey line represents average step latency across all participants ( $n=20$ ).

Oates, Frank, and Patla [22] reported that young healthy adults reduced their step length when walking on a slippery surface. The authors suggested that this strategy may have helped to minimize COM excursions during gait, and may have been proactive to enhance balance recovery in the event that a slip should occur. In the current study, the athletes displayed a significantly smaller step length than controls, suggestive of a similar proactive strategy to enhance postural stability. Given that the normalized step length demonstrated by the athletes was significantly smaller, while peak nCOP excursion was not different between groups, it appears that the ice hockey players may have utilized a larger component of their BOS in the anterior-posterior direction, allowing their COM to move closer to the anterior border of the BOS. This finding is suggestive of greater balance confidence among the athletes, though balance confidence was not measured. However, significantly smaller angular excursions of the trunk segment among the athletes most likely explain the smaller nCOM excursion.

The athletes maintained their trunk much more erect than controls during the balance recovery; prior to the onset of the perturbation, trunk segment angles were not different between the two groups, but the athletes demonstrated substantially smaller trunk angle excursion in response to the

perturbation. Given that the game of ice hockey is played on ice, which is a slippery surface, the ice hockey players may have adopted a more erect trunk posture during stepping responses to minimize COM displacement and balance disruption. A more erect trunk during recovery from a postural perturbation may represent a sport-specific strategic adaptation, developed over years of training and game play. This strategy would have the effect to maintain tighter control over the whole-body COM and to stabilize the head and visual system during movement on the ice, which may provide a strategic advantage during play. Alternatively, the superior dynamic balance control shown by the ice hockey players may have been innate, which allowed the current athletic group reach the elite level of performance. Whether the superior dynamic postural control is a sport-specific adaptation or innate ability facilitating the opportunity to become an elite level athlete remains to be investigated.

## Conclusion

It was found that ice hockey players demonstrate superior balance recovery ability when using stepping balance recovery strategy; ice hockey players were able to maintain a tighter control of their COM during stepping responses by maintaining their trunk more erect. It may also be argued that more erect trunk position provides a stable platform for the vestibular and visual systems. A more upright trunk posture may represent an acquired functional adaptation or perhaps an innate ability which enhances dynamic balance control while also providing a more stable platform for the vestibular and visual sensory systems. The literature is sparse with respect to examination of postural control and balance recovery ability and strategies in athletes, in general, and ice hockey players more specifically. This study has contributed to addressing this gap in the research.

## Acknowledgements

The authors recognize the support of the Canada Foundation of Innovation. The authors have no conflicts of interest to disclose.

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