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Characterizing inter-limb synchronization after incomplete spinal cord injury: A cross-sectional study

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ABSTRACT

Background: Individuals with incomplete spinal cord injury (iSCI) demonstrate greater postural sway and increased dependency on vision to maintain balance compared to able-bodied individuals. Research on standing balance after iSCI has focused on the joint contribution of the lower limbs; however, inter-limb synchrony in quiet standing is a sensitive measure of individual limb contributions to standing balance control in other neurological populations. It is unknown if and how reduced inter-limb synchrony contributes to the poor standing balance of individuals with iSCI.
Research question: How does an iSCI affect inter-limb synchrony and weight-bearing symmetry in standing?
Methods: Eighteen individuals with non-progressive motor iSCI and 15 age- and sex-matched able-bodied individuals (M-AB) were included in the study. Participants stood in a standardized position on two adjacent force plates in eyes open and closed conditions for 70 s per condition. Net centre-of-pressure (COP) root mean square (RMS), net COP velocity, COP inter-limb synchrony (i.e. cross-correlation between left and right COP), and weight-bearing asymmetry (i.e. vertical force from each limb over total vertical force) were calculated. Muscle strength of the lower limbs was assessed with manual muscle testing.
Results: Individuals with iSCI demonstrated reduced inter-limb synchrony when standing with eyes open and eyes closed, but did not differ to M-AB with respect to weight-bearing asymmetry. They also produced greater net COP RMS and velocity when compared to M-AB. Muscle strength of the two lower limbs demonstrated an overall asymmetry in individuals with iSCI.
Significance: Individuals with iSCI demonstrated impaired balance control as evidenced by reduced inter-limb synchrony and greater COP RMS and velocity compared to M-AB individuals. This increased understanding of how balance control is impaired following iSCI may inform balance assessment and intervention for this population. Future work examining the association between inter-limb synchrony and the occurrence of falls in iSCI is warranted.

1. Introduction

After incomplete spinal cord injury (iSCI), sensory and motor impairments below the site of injury are common. These sensorimotor impairments influence balance control and coordination between the lower extremities, resulting in poor balance control and a high occurrence of falls [1]. For example, in those with chronic incomplete injuries, lower limb muscle strength is reduced compared to able-bodied individuals, often with notable asymmetries between limbs [2], and reduced lower limb strength is linked to the future occurrence of falls [3]. Among individuals with iSCI who ambulate, falls commonly occur when walking, changing positions, or standing [4]. To reduce the occurrence of falls, balance control during standing and walking is often a focus of rehabilitation after iSCI; however, there is a paucity of knowledge concerning what balance interventions are most beneficial for those living with iSCI [5]. A thorough understanding of how balance

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control is impaired following iSCI is needed to identify and design effective iSCI-specific interventions.

Numerous impairments in standing balance control manifest after iSCI. When standing, individuals with iSCI show greater postural sway [5], decreased stability limits [6], and reduced trunk-leg movement coordination [7], with deficits increasing when vision is removed [5]. While research to date on standing balance control after iSCI has focused on the joint contribution of the two lower limbs, individual limb contributions to standing balance control are known to be critical for individuals with other neurological conditions, such as stroke [8]. For efficient static balance control, equal force production from the two feet is required [9]. Despite studies demonstrating sitting weight-bearing asymmetry [10] and walking step asymmetry after SCI [11], it is unknown whether weight-bearing asymmetry contributes to poor balance control in standing in individuals with an iSCI.

Inter-limb synchronization, which analyzes the spatial and temporal relationship between the left and right limb centre-of-pressure (COP), has been a sensitive measure of individual limb contributions to standing balance control in able-bodied individuals [9,12] and individuals with stroke [8,13–15]. Inter-limb synchronization also provides insight into the inter-limb coordination of the lower extremities, with a strong in-phase and anti-phase relationship found in able-bodied individuals in the anteroposterior (AP) and mediolateral (ML) directions, respectively [9]. This focus on individual limb contributions differs to common posturographic net measures of balance, such as postural sway metrics in the AP and ML directions, which reflect ankle and hip motion control [16]. Although net measures of balance identify the contribution of both limbs, they lack specificity on individual limb contributions.

Inter-limb synchrony is reduced in individuals with traumatic brain injury [17] and stroke [8,13–15]. This biomarker of standing balance control has clinical relevance as reduced inter-limb synchronization is associated with an increased rate of falls among individuals who have experienced a stroke [13,18]. Understanding individual limb contributions during standing will contribute to the knowledge of balance control following iSCI, possibly lending to more effective balance interventions and a reduction in the occurrence of falls.

The purpose of this study was to characterize inter-limb synchronization in standing in individuals with iSCI in comparison to able-bodied controls. Additionally, measures of weight-bearing symmetry and net measures of balance in standing were evaluated. It was hypothesized that individuals with iSCI would demonstrate the following in comparison to able-bodied controls: 1) reduced inter-limb synchronization, and in turn 2) unequal weight-bearing symmetry, as well as 3) poorer balance control as evidenced by greater net COP root mean square (RMS) and velocity, in line with previous research [5,6].

2. Methods

2.1. Participants

Individuals with iSCI were recruited through posted flyers, rehabilitation therapy staff, and a central recruitment database as a part of a larger study [19]. Participants were included in the study if they were > 18 years old; more than one year post-injury; had a traumatic or non-traumatic, non-progressive motor iSCI (i.e. self-reported American Spinal Injury Association Impairment Scale (AIS) rating C or D, meaning there was some preservation of sensory and motor function below the level of spinal injury); were able to stand independently without mobility aids or physical assistance for 30 s; and demonstrated a moderate level of trunk control (i.e. score ≥ 2 on the Berg Balance Scale Reaching Forward task [20]). Age- (within +/- 3 years) and sex-matched able-bodied individuals (M-AB) were recruited from the university and local community. The study was approved by the Research Ethics Board at the University Health Network.

2.2. Data collection and procedures

Posturographic (force plate) measures were collected in individuals with iSCI and M-AB controls. Ground reaction forces and moments were collected using dual force plates (AccuSway-Dual, AMTI, Watertown Massachusetts) and sampled at 2000 Hz. Participants donned a safety harness attached to the ceiling and placed one foot on each force plate. The harness did not support any body weight, but would have prevented the participants from hitting the floor during a fall. Participants stood in a standardized position, with the heels spaced 17 cm apart, 14 degrees between the feet and the arms crossed on the chest [21]. Participants stood under two conditions, eyes open (EO) and eyes closed (EC), for 70 s per condition. The eyes closed condition was included since individuals with iSCI show an increased reliance on vision for balance control, such that impairments in balance control are more pronounced when vision is removed [5]. Participants were also asked to report the number of falls, defined as "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level" [22], within the past three months.

2.3. Lower extremity manual muscle testing

Muscle strength of the lower limbs was measured in the participants with iSCI. Manual muscle testing of 12 lower extremity muscle groups was performed by a physical therapist. Muscle groups tested included muscles from the hip (flexors, extensors, abductors, adductors, external rotators, internal rotators), knee (flexors, extensors) and ankle (dorsiflexors, plantarflexors, inverters, evertors). Participants were tested in standardized positions in supine, side-lying and sitting. Muscle strength was graded on a scale from 0 to 5; a score of 0 and 5 indicated the absence of a muscle contraction and full muscular strength, respectively, with a maximum score of 60 for each limb [23]. Manual muscle testing is valid and reliable for measuring strength in individuals with iSCI [24].

2.4. Data analysis

Ground reaction forces and moments were low-pass filtered using a zero-lag, 4th ordered, Butterworth filter with a 10 Hz cut off frequency prior to processing. The first 5 s of data from the COP signal were removed from all files and the next 60 s of data were used to calculate all COP measures. The RMS of the net COP displacement and average velocity of net COP were calculated. The individual limb COP was calculated to then compute the inter-limb synchrony, which used the cross-correlation function between the left and right mean-removed AP and ML COP waveforms. Inter-limb synchrony is defined by the cross-correlation coefficients at zero phase-lag ($R_{xy}(0)$) [15]. The peak cross-correlation function within a ±1 s window from time zero ($R_{xy}(\tau_{peak})$) and the timing of the peak (τ_{peak}) were also calculated to account for potential time lag in COP fluctuations between limbs. The magnitude of the coefficient, ranging from −1.0 to 1.0, illustrates the strength of correlation of the COP time series. The timing of the peak identifies whether COP oscillations in one leg were leading the other.

Weight-bearing symmetry was calculated using the stance load symmetry ratio of the average vertical force applied onto one force plate, relative to the sum of the average vertical forces applied onto both force plates over the 60 s. This was determined for both the left and right sides. Absolute stance load symmetry was defined as the stance load symmetry ratio of the less-loaded limb. All data were processed using MATLAB R2017b (MathWorks, Natick, USA).

2.5. Statistical analyses

Statistical analyses were performed using SPSS v26.0 (IBM SPSS Statistics, Armonk, USA). Independent *t*-tests were conducted to test whether there were significant differences in the demographic variables (i.e. age, mass) between iSCI and M-AB controls. To test whether there were significant asymmetries in lower extremity strength, as measured with manual muscle testing, a paired *t*-test was conducted between the limb that produced the higher muscle strength score to the limb that produced the lower muscle strength score.

To test the hypothesis that inter-limb synchrony would be reduced in individuals with iSCI when compared to M-AB controls and higher in the EC condition, a 2 × 2 analysis of variance (ANOVA) was conducted to assess the effect of Group and Condition on $R_{xy}(0)$, $R_{xy}(\tau_{peak})$, and absolute τ_{peak}. Because the $R_{xy}(0)$ values are bounded by values of -1 and 1, a Fisher transform was applied. To test the hypothesis that weight-bearing asymmetry would be evident in individuals with iSCI, a 2 × 2 mixed ANOVA was used to assess the main effect of Group and Condition on absolute stance load symmetry between participants with iSCI and M-AB controls. Data were log-transformed if the values were not normally distributed. In cases where the assumption of sphericity was not met, Greenhouse-Geisser values were reported. Statistical significance was set at $p < 0.05$.

To test the hypotheses that net measures of balance (net AP and ML COP RMS and velocity) would be greater in the participants with iSCI when compared to M-AB controls and when vision was omitted, a series of 2 × 2 mixed ANOVA were conducted to assess the main effect of Group (iSCI, M-AB) and Condition (EO, EC).

2.6. Secondary analyses

As associations between net measures of balance and measures of inter-limb synchronization have been found in individuals with weight-bearing asymmetries [8,17], exploratory analyses were conducted to test relationships between inter-limb synchrony and postural sway (variability and velocity) and inter-limb synchrony and absolute stance load symmetry in individuals with iSCI. Spearman correlations were conducted between $R_{xy}(0)$ and COP RMS and absolute stance load symmetry.

3. Results

3.1. Demographic characteristics

Demographic information for individuals with iSCI is listed in Table 1. Of the 21 individuals with iSCI that were recruited, 18 individuals (4 M, 14 F) were included in the analyses; three participants were excluded from the analysis as they were unable to stand in the eyes closed condition for 70 s. Fifteen M-AB controls (4 M, 11 F) were included in the analyses. There were no significant differences found in age (t_{31} = .153, p = 0.88) between the participants with iSCI [56.9 ± 15.0 years (range: 32–88)] and M-AB controls [56.2 ± 12.4 years (range: 31–84)]; however, individuals with iSCI (69.1 ± 17.9 kg) were significantly heavier than M-AB controls (56.5 ± 11.1 kg; t_{31} = 2.37, p = 0.024). See Supplementary Material for a summary of the statistical comparisons between the group with iSCI and M-AB controls. The mean time post-injury for individuals with iSCI was 6.1 ± 8.8 years (range: 1–38.6). Six individuals with iSCI experienced one or more falls in the last three months prior to the assessment.

3.2. Lower extremity manual muscle testing

When lower extremity muscle strength scores were compared between limbs (grouped by higher and lower extremity scores), paired *t*-tests demonstrated that there was a significant difference between the limb that produced the higher muscle strength score (46.1 ± 5.1) and the limb that produced the lower strength score (41.8 ± 6.8; t_{17}= -6.89, p < 0.0001).

3.3. Inter-limb synchrony

Inter-limb synchrony was reduced in individuals with iSCI when compared to M-AB control in both the AP and ML direction. A significant Group effect was found in the 2 × 2 ANOVA for AP $R_{xy}(0)$ ($F_{1,31}$ = 10.32, p = 0.003, partial η^2 = .25) and ML $R_{xy}(0)$ ($F_{1,31}$ = 9.87, p = 0.004, partial η^2 = .24), where individuals with iSCI produced lower $R_{xy}(0)$ in both directions (Fig. 3A–B). There were no significant Condition main effects.

Similarly, peak inter-limb synchrony was reduced in individuals with iSCI when compared to M-AB controls in both the AP and ML directions. The 2 × 2 ANOVA demonstrated a significant Group effect for AP $R_{xy}(\tau_{peak})$ ($F_{1,31}$ = 10.15, p = 0.003, partial η^2 = .25) and ML $R_{xy}(\tau_{peak})$ ($F_{1,31}$ = 9.40, p = 0.004, partial η^2 = .23), where individuals with iSCI produced lower $R_{xy}(\tau_{peak})$ in both directions (Fig. 3C–D). There were no significant Condition main effects. A significant Condition effect ($F_{1,31}$ = 5.10, p = 0.031, partial η^2 = .14) and Group effect ($F_{1,31}$ = 6.65, p = 0.015, partial η^2 = .18) were found for ML absolute τ_{peak}, where individuals with iSCI produced greater phase lag compared to M-AB and EO produced a greater phase lag than EC (Fig. 1E–F, see Supplementary Material for plots of representative participants). No significant main effects of Condition and Group were found for AP absolute τ_{peak}

Table 1
Participant demographics for individuals with incomplete spinal cord injury (iSCI) including, sex, age, level of injury, time since injury, mobility aid, lower extremity manual muscle testing (LE MMT) score for the left and right limb, and number of falls in the last three months prior to the assessment.

iSCI Participant	Sex	Age (yrs)	*Level of Injury	Time Since Injury (yrs)	Type of Mobility Aid‡	LE MMT L (/60)	LE MMT R (/60)	No. Falls
1	F	61	C3	1	4 W W	40.5	43.0	1
2	F	54	T10	1	none	40.5	36.0	0
3	F	32	C4	3.5	none	45.0	47.0	0
4	M	70	T1	1.8	4 W W	54.5	50.0	0
5	M	60	C5	3.2	none	57.0	58.0	0
6	F	43	T6	3.9	Cane	51.5	51.0	0
7	F	87	T4	2.6	Cane (outdoor only)	48.0	46.0	1
8	F	57	C2	2.9	Cane	47.5	41.5	0
9	F	59	C1	1.1	4 W W	39.0	43.0	0
10	F	55	C5	9.1	Cane	48.5	45.5	1
11	F	38	T4	1.3	4 W W	40.5	34.0	1
12	F	54	C4	13.4	Cane	36.5	42.0	0
13	F	56	L5	1.2	none	32.5	40.0	0
14	F	69	C5	4.8	none	32.0	40.0	0
15	M	88	C6	5.3	none	44.0	42.0	0
16	F	38	T11	6.8	none	45.5	45.5	1
17	M	51	C3	7.9	4 W W	47.5	43.0	0
18	F	53	C4	38.6	Walking pole (outdoor only)	39.0	48.0	1

F and M correspond to female and male; Level of injury: C – cervical, T– thoracic, L – lumbar; Type of mobility aid: 4 W W - 4-wheel walker. *Neurological level of injury. ‡Highest level of mobility aid is reported.

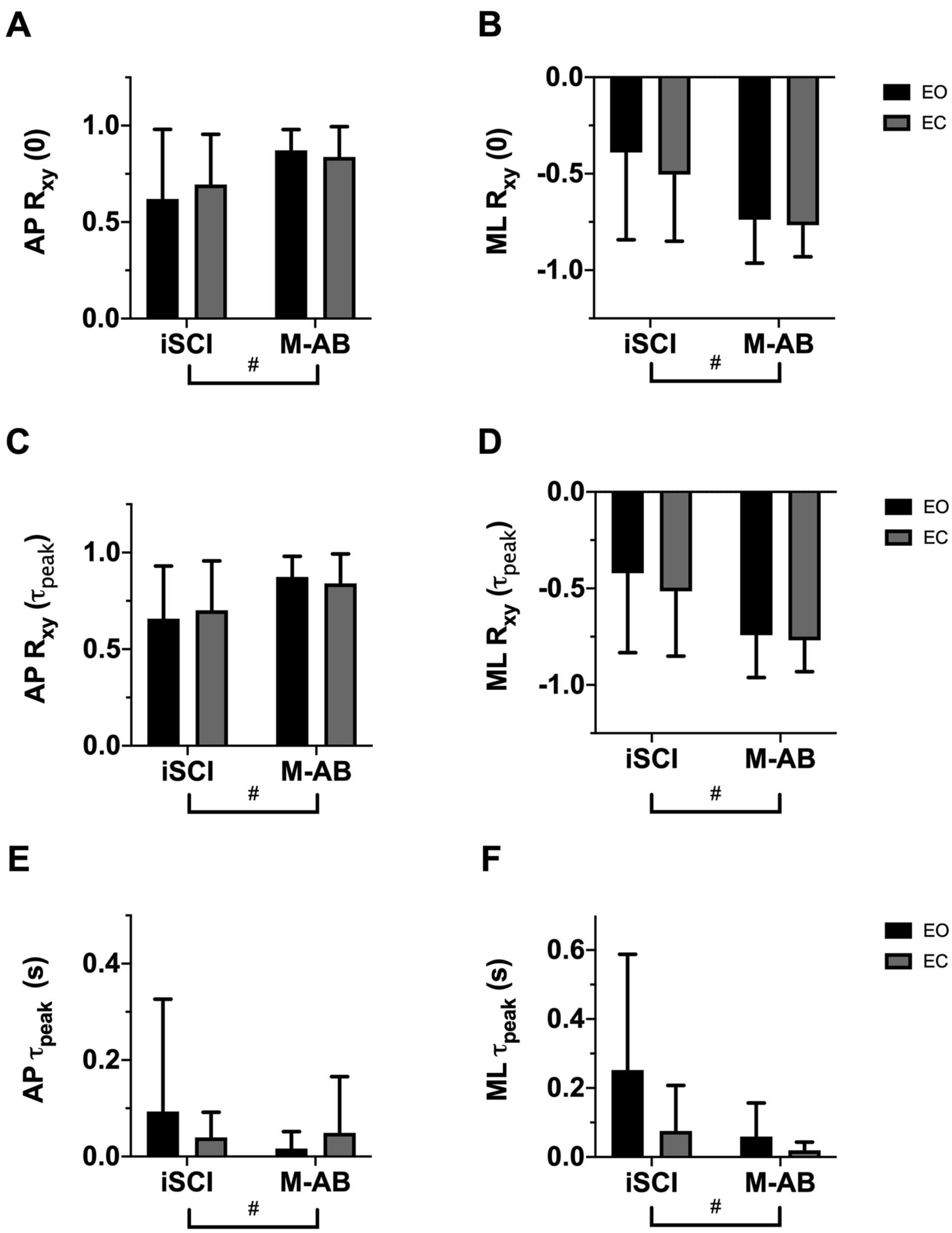

Fig. 1. AP (**A**) and ML (**B**) inter-limb synchrony at zero phase-lag ($R_{xy}(0)$), AP (**C**) and ML (**D**) peak inter-limb synchrony ($R_{xy}(\tau_{peak})$), and AP (**E**) and ML (**F**) absolute phase lag (τ_{peak}) group means and standard deviations for individuals with iSCI and M-AB controls in EO (black) and EC (grey) conditions. A significant Group effect was found for AP and ML $R_{xy}(0)$ and $R_{xy}(\tau_{peak})$. A significant Condition and Group effect was found for ML absolute τ_{peak}. Significant Group effects are depicted by the pound symbol (#).

3.4. Weight-bearing symmetry

There was no significant difference in weight-bearing symmetry, as indicated by absolute stance load symmetry, between individuals with iSCI and M-AB ($p = 0.098$, Fig. 2).

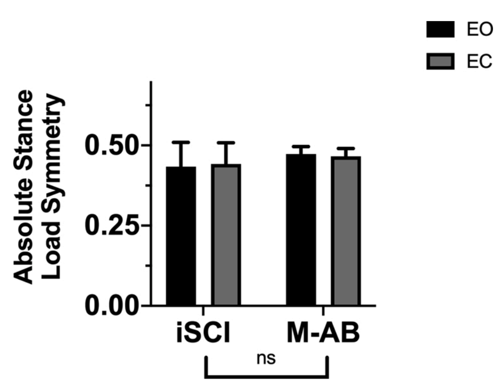

Fig. 2. Absolute stance load symmetry ratio (depicting the less loaded limb) group mean and standard deviation for individuals with iSCI and M-AB controls in EO (black) and EC (grey) conditions. Absolute stance load symmetry did not demonstrate significant weight-bearing asymmetries between individuals with iSCI and M-AB ($p = 0.098$).

3.5. Net measures of balance

For AP COP RMS, the 2 × 2 ANOVA demonstrated a significant Group × Condition interaction effect ($F_{1,31} = 4.27$, $p = 0.047$, partial $\eta^2 = .12$). Post-hoc *t*-test demonstrated greater AP COP RMS in individuals with iSCI compared to M-AB controls in EC ($t_{1,31} = 2.99$, $p = 0.005$). No differences were found between the groups in EO for AP COP RMS ($p > 0.025$). For ML COP RMS, the 2 × 2 ANOVA demonstrated a significant Condition effect ($F_{1,31} = 7.56$, $p = 0.010$, partial $\eta^2 = .20$) and Group effect ($F_{1,31} = 33.51$, $p < 0.0001$, partial $\eta^2 = .52$), where EC had greater ML COP RMS over the EO condition, and individuals with iSCI produced greater ML COP RMS than M-AB controls (Fig. 3A and B).

AP COP and ML COP velocity demonstrated greater velocity when

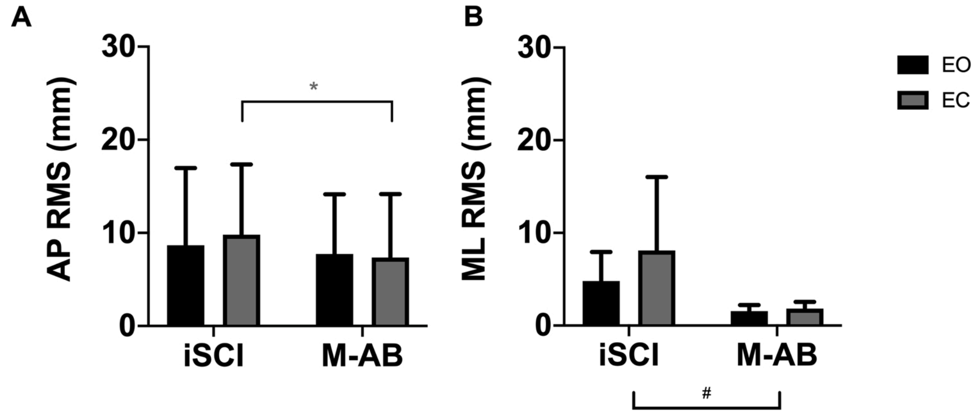

Fig. 3. AP (**A**) and ML (**B**) COP RMS group means and standard deviations for individuals with iSCI and M-AB controls in EO (black) and EC (grey) conditions. A significant Group × Condition interaction effect was found for AP RMS. Asterisks denotes significant post-hoc *t*-test are between iSCI and M-AB control for EC. A significant Condition and Group main effect were found for ML RMS; significant Group effects are depicted by the pound symbol (#).

vision was omitted and in individuals with iSCI. The 2 × 2 ANOVAs demonstrated a significant Condition effect for AP COP velocity ($F_{1,31}$ = 45.1, $p < 0.0001$, partial $\eta^2 = .59$) and ML COP velocity ($F_{1,31}$ = 17.91, $p < 0.0001$, partial $\eta^2 = .37$), where EC was greater than EO. A significant Group effect was also found for AP COP velocity ($F_{1,31}$ = 13.36, p = 0.001, partial $\eta^2 = .30$) and ML COP velocity ($F_{1,31}$ = 19.0, $p < 0.0001$, partial $\eta^2 = .39$), where individuals with iSCI produced greater COP velocity compared to that of M-AB controls (Fig. 4A and B).

3.6. Secondary analysis

Spearman correlations between ML COP RMS and ML $R_{xy}(0)$ in EC conditions demonstrated a significant association (p = 0.016), while all other correlations in either directions or conditions did not demonstrate any significant associations ($p > 0.05$). Absolute stance load symmetry and AP $R_{xy}(0)$ in EO demonstrated a significant association (p = 0.032), while the other conditions did not demonstrate any significant associations ($p > 0.05$; see Table 2).

Table 2
Relationship between inter-limb synchronization $R_{xy}(0)$ and standing balance measures (COP RMS, COP velocity, absolute stance load symmetry) for eyes open (EO) and eyes closed (EC). Spearman correlation coefficients and the associated p-values are shown in parenthesis. Statistically significant correlations and p-values are highlighted in bold font.

	AP $R_{xy}(0)$	ML $R_{xy}(0)$
AP COP		
RMS – EO	0.364 (0.137)	−0.278 (0.265)
RMS – EC	0.257 (0.303)	0.011 (0.964)
Velocity – EO	0.181 (0.473)	−0.096 (0.705)
Velocity – EC	0.175 (0.484)	0.106 (0.675)
ML COP		
RMS – EO	−0.205 (0.414)	0.387 (0.113)
RMS – EC	−0.292 (0.240)	**0.558 (0.016)**
Velocity – EO	−0.022 (0.932)	0.199 (0.639)
Velocity – EC	−0.265 (0.287)	0.354 (0.150)
Absolute stance load symmetry		
EO	**0.507 (0.032)**	−0.358 (0.145)
EC	0.309 (0.213)	−0.197 (0.433)

4. Discussion

The current study characterized inter-limb synchronization in standing balance in individuals with iSCI and compared their performance to age- and sex-matched able-bodied controls. As hypothesized, individuals with iSCI demonstrated reduced inter-limb synchrony in both the AP and ML directions, but inter-limb synchrony did not change with the removal of vision for either group. Contrary to our hypothesis, individuals with iSCI did not demonstrate weight-bearing asymmetry, but did have asymmetry in lower limb muscle strength. As hypothesized, individuals with iSCI demonstrated poorer balance control as found with greater COP RMS and velocity in both the AP and ML directions when compared to able-bodied controls. There were few associations found

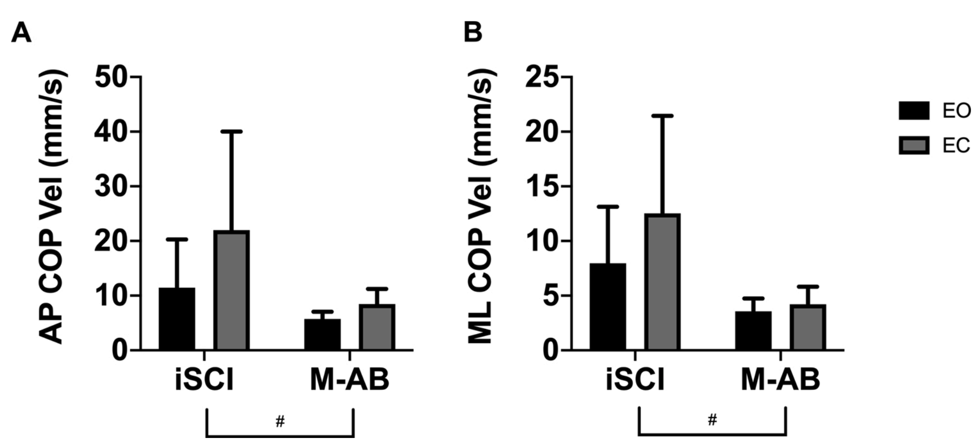

Fig. 4. AP (**A**) and ML (**B**) COP velocity group means and standard deviations for individuals with iSCI and M-AB controls in EO (black) and EC (grey) conditions. Significant Group main effects and Condition main effects were found for both AP and ML COP velocity; significant Group effects are depicted by the pound symbol (#).

between the postural measures. Overall, the findings indicate that individuals with iSCI demonstrate poor standing balance control, characterized by reduced inter-limb synchrony, gross motor asymmetry, and greater postural sway.

The findings reported here support previous literature that has also evaluated standing balance in individuals with iSCI [5,6,25,26]. The current study found similar AP and ML COP RMS and COP velocity to that of Lemay et al. [5,6] which included participants of similar ages and a similar sample size to the current study. However, it is important to note the current sample's time post-injury is greater. Lemay et al. included individuals with iSCI at 0.84 ± 0.59 and 0.87 ± 0.62 years post-injury with a traumatic injury and AIS D [5,6]. COP RMS in the ML direction, but not the AP direction, was significantly greater in our participants with iSCI compared to the M-AB controls. Since balance control in the ML direction is believed to require increased contributions from supraspinal neural centers, such as visual and vestibular feedback, than control in the AP direction [27], it is not surprising that those with iSCI showed poorer performance compared to their able-bodied peers. Maintaining balance control in the ML direction is challenging for the iSCI population, and its performance can distinguish those who will and will not experience future falls [3].

Inter-limb synchrony in individuals with iSCI has not been analyzed in previous studies. Consistent with previous study in individuals with stroke [8,13,15,18] and traumatic brain injury [17], we found that individuals with iSCI had reduced inter-limb synchrony in both the AP and ML directions when standing. Inter-limb synchrony plays a role in preparing for instability, and hence, provides insight into one's anticipatory balance control [28]. While our findings suggest an impairment in anticipatory balance control after iSCI, prior research in this area found minimal deficits [29]. Individuals with AIS D iSCI were able to appropriately modulate the amplitude and timing of lower limb muscles in anticipation of surface perturbations in standing [29].

Interestingly, we found that inter-limb synchrony was unaffected by condition (i.e. eyes open versus eyes closed), suggesting the influence of vision on inter-limb synchrony is minimal. It has been previously reported that individuals with iSCI show an increased reliance on visual inputs to maintain standing balance, as evidenced by poorer performance on measures of postural sway when eyes are closed [5,30]. However, other biomarkers of standing balance control, related to trunk-leg movement coordination, were recently reported to be unaffected by the removal of vision in individuals with iSCI [7]. Altogether, these findings provide insight into the characteristics of standing balance control that are and are not influenced by visual inputs.

Greater inter-limb synchrony has been associated with lower weight-bearing asymmetry in individuals with stroke [8]. In individuals with iSCI, we found that the small strength asymmetry observed between the lower extremities did not translate to upright standing weight-bearing asymmetry, yet reduced inter-limb synchrony was observed. Despite individuals with iSCI demonstrating no weight-bearing asymmetries when compared to able-bodied individuals, there was a moderate positive association between AP inter-limb synchrony and absolute stance load symmetry suggesting the greater inter-limb synchrony one has, the less weight-bearing asymmetry. Our findings suggest that the contributors to inter-limb synchrony include more than an imbalance in motor impairment between the lower limbs, such as somatosensory asymmetries and/or spasticity [31].

AP and ML COP RMS has also been associated with inter-limb synchrony in both individuals with stroke and traumatic brain injury [8,15,17]; however, apart from the one association, there were no other associations found in individuals with iSCI. The lack of associations may have been attributed to a lower sample size in the current study than that of previous studies, which included 45–82 participants [8,15,17].

Though this study provides novel findings, there were a few limitations. The participants that were included in this study resulted from a convenience sample. In turn, the ambulation ability and level of injury within an AIS C or D was variable and the range of years post-injury of the population was large, thus increasing the heterogeneity of the sample. The large range of injury chronicity (i.e. 1–38 years) may have affected the study findings, as the time course of recovery of balance control after iSCI is unknown. When compared to other iSCI postural studies, the sample size was comparable; however, when compared to other neurologically impaired populations there was a reduced sample size. Further, the proportion of females in the sample was large and did not represent the Canadian iSCI population. Somatosensory information plays a role in balance control and this was not measured in the current study. Lastly, participants donned a safety harness that did not provide physical support, but may have reduced their anxiety or fear of falling during the study activities. Situational anxiety is known to affect postural control [32]; hence, use of a safety harness may have affected the findings.

5. Conclusions

Individuals with iSCI demonstrated greater postural sway and greater postural sway velocity in the AP and ML directions when compared to able-bodied controls. AP COP RMS was sensitive to detect greater postural instability as a function of vision loss. Individuals with iSCI demonstrated reduced inter-limb synchrony, but no weight-bearing asymmetry.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2021.02.007.

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