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Research Summary – Lower Extremity Motor Score (LEMS) – Lower Limb and Walking

Author Year Country Research Design Setting	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Sato et al. 2023 Psychometric study to evaluate the criterion validity of the trunk assessment scale for spinal cord injury (TASS) and the construct validity of the TASS and trunk control test in individuals with SCI (TCT-SCI) Rehabilitation hospital, Japan	N=30 Mean (SD) age 63.8 (10.7) years 5M, 25F Traumatic tetraplegia (n=15), traumatic paraplegia (n=5), non-traumatic tetraplegia (n=2), traumatic paraplegia (n=8) AIS A (n=6), AIS B (n=0), AIS C (n=8), AIS D (n=16) Mean (SD) time from onset to assessment 1142.0 (1720.7) days	Construct validity (Spearman coefficients) between TASS/TCT-SCI and LEMS: • TASS: r = 0.80 (0.63-0.90) • TCT-SCI: r = 0.51 (0.30-0.79)		
Sinovas-Alonso et al. 2023 Study to assess the construct validity of the	n=85, 50 heathy volunteers and 35 adults with incomplete spinal cord injury	Correlation with LEMS: *r* = .638		

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Gait Deviation Index for Spinal Cord Injury (SCI-GDI) in adult population following incomplete SCI				
Rigot et al. 2022 Study to evaluate the relationship between measures of neuromuscular impairment and limb accelerations (LA) collected during sleep among individuals with chronic SCI USA	N = 40 participants with SCI 34M, 6F Mean (SD) age: 53.7 (11.4) years Level of injury: Paraplegia (n = 28), tetraplegia (n = 12) ASIA A (n = 6), ASIA B (n = 4), ASIA C (n = 15), ASIA D (n = 15) Mean (SD) time since injury: 18.1 (11.8) years	Limb accelerations (LA) features were related to measures of impairment with models explaining 69% of the variance (R^2) in strength, and correctly classifying 81.6% (F1-score = 0.814) of the participants into spasticity categories. The most commonly selected LA features included measures of power and frequency (frequency domain), movement direction (correlation between axes), consistency		

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		between movements (relation to recent movements), and wavelet energy (signal characteristics). Rolling speed (change in angle of inclination) and movement smoothness (median crossings) were uniquely associated with strength. When LA features were included, an increase of 72% and 222% of the variance was explained for strength and sensation scores, respectively, and there was a 34% increase in spasticity classification accuracy compared to models containing only covariate features such as		

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		demographics, sleep quality, and pain.		
Lena et al. 2021 Prospective, observational study 3 Italian rehabilitation hospitals	N=140 non-traumatic SCI, 92M, 48F Mean age: 60 ± 16 years (range 15–86) Level: Cervical: 30 Thoracic: 78 Lumbar: 32 AIS A: 32 AIS B: 11 AIS C: 33 AIS D: 64	The correlations between the LEMS and the SCIM mobility subscore was significant ($r = 0.666$; $p < 0.001$). The correlations improved by considering persons with tetraplegia and paraplegia separately, dividing the assessment at admission from one at follow-up and dividing incomplete and complete lesions.	Inter-rater correlation: r = 0.986 (0.974-0.993), p = 0.001; Krippendorff's Alpha (95% CI) = 0.503 (0.431-0.535), p = 0.001 Internal consistency: Cronbach's Alpha = 0.995 (0.993-0.996)	
Ogonowska-Slodownik et al. 2019 Reliability study to determine the reliability of peak VO_2 testing for	N = 17 participants with SCI 13M, 4F Mean (SD) age: 45.7 (11.6) years Level of injury: Paraplegia (n = 9), tetraplegia (n = 8) ASIA A and B (n = 5),	LEMS influenced supported deep water, peak VO_2 (B = 0.58, P < 0.02)		

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individuals with SCI in deep water and on land; and to examine the relationship between these two testing conditions.	ASIA C (n = 4), ASIA D (n = 8) Mean (SD) time since injury: 13.7 (13.1) years			
Perez-Sanpablo et al. 2017 Observational, descriptive, transversal to evaluate the validity and reliability of spatio-temporal gait parameters measured by GaitRite in patients with SCI National Institute of Rehabilitation,	N=23 (15M/8F) Mean Age: 45.6 ± 12.6 years Mean Time since injury: 42 ± 117 months AIS D, motor subacute and chronic incomplete	Spearman correlation with LEMS: r=0.49-0.55		

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Mexico City, Mexico				
Harkema et al. 2016 Prospective multicenter observational; NRS 13-item version 6 outpatient rehabilitation centers in the Christopher and Dana Reeve Foundation NRN	N=152 (123M, 29F) Mean (SD) age: 36 (15) Median (range) time since SCI: 0.9 (0.1-45.2) years Level of Injury: 110 cervical, 42 thoracic AIS-A/B/C/D: 43/21/39/49 Physician-referred outpatients without progressive lesions above T11, capable of stepping using body weight support, with ability to wean off anti-spasticity medication Median (range) number of sessions of NRN-standardized	Pearson's r (95%CI) between LEMS and: • Modified Functional Reach: 0.81 (0.77, 0.85) • Berg Balance: 0.79 (0.74, 0.85) • 6MWT: 0.7 (0.64, 0.76) • 10MWT: 0.69 (0.63, 0.75) Pearson's r (95%CI) between LEMS and: • NRS Overall Phase: 0.70 (0.63-0.77) • NRS Summary Score: 0.80 (0.74-0.86) • NRS Body Weight Supported Treadmill Subscale: 0.72 (0.65, 0.80)		**Responsiveness** LEMS Standardized Response Means after Locomotor Training: • All individuals: 0.23 • AIS-A/B: -0.10 • AIS-C: 0.72 • AIS-D: 0.16 Median (range) number of sessions of NRN-standardized locomotor training: 70 (23-520) **Interpretability** Mean (SD) LEMS: All individuals: • Enrollment: 16 (18) • Discharge: 18 (19) AIS-A/B:

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	locomotor training: 70 (23-520)	• NRS Trunk & Leg Subscale: 0.87 (0.84, 0.91) • NRS Arm & Shoulder Subscale: 0.38 (0.25, 0.51) • NRS Arm & Shoulder + Trunk & Leg Subscales: 0.78 (0.71, 0.84)		• Enrollment: 1 (6) • Discharge: 0 (1)AIS-C: • Enrollment: 13 (11) • Discharge: 20 (16) AIS-D: • Enrollment: 39 (8) • Discharge: 40 (10) * Enrollment = pre-intervention; discharge = post-intervention; median (range) number of sessions of NRN-standardized locomotor training: 70 (23-520)
Sisto et al. 2012 Cross-sectional; NRS 11-item version	N=350 (267M, 83F) AIS-C/D: 101/249 Mean (SD) age: 42 (16)			**Interpretability:** Mean (SD) initial LEMS scores: • All patients: 31 (14)

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7 NRN outpatient rehabilitation clinics	Median (range) time since SCI: 0.9 (0.1-53.1) Incomplete SCI Presence of nonprogressive lesion above T11 No current inpatient rehabilitation No anti-spasticity medication use in the past 3 months Capable of stepping using body weight support Referred to PT by physician			• Cervical SCI: 33 (14) • High Thoracic SCI: 26 (14) • Low Thoracic SCI: 27 (15) Median (range) initial LEMS scores: • All patients: 34 (0-50) • Cervical SCI: 36 (0-50) • High Thoracic SCI: 28 (0-50) • Low Thoracic SCI: 32 (2-50)
Tester et al. 2016 Prospective; testing the Neuromuscular Recovery Scale 14-item version	N = 72 (57M, 15F) completing 20 sessions of standardized locomotor training Mean (SD) age: 36 (15) Median (range) time since SCI: 0.7 (0.1-14.7) years			**Interpretability** LEMS Smallest Real Difference (SRD): 1.3

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6 outpatient sites in the Christopher and Dana Reeve Foundation NeuroRecovery Network	N=45 longer than 6 months 44 cervical, 28 thoracic AIS-A/B/C/D: 17/10/20/25			
Scivoletto et al. 2013 Analysis of prospectively collected data Studying the ISNCSCI N=600 SCI unit of a rehab hospital in central Italy	N = 600 (440M) Mean age 50.35±18.8 Mean time from lesion 51.6±36.8 days Mean time in rehab 123.6±86.3 days 334 traumatic, 266 nontraumatic Lesion level: cervical 192, thoracic 289, 110 lumbar 233 AIS-A, 67 B, 158 C, 142 D			**Interpretability** LEMS: Admission mean =13.8, SD=16.8, Discharge mean = 20.2, SD=19.7 MCID=3.66, ES-based estimate for small change=3.36, substantial change = 8.4 **Mean (SD) LEMS scores Admission to Discharge:** Cervical B = 0(0) to 11.5(16.6) Cervical C = 19.4(11.8) to 37.3(12.7) Cervical D = 39.2(9.2) to 44.8(6.5)

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				Thoracic A = 0(0) to 0.76(3.1) Thoracic B = 0(0) to 10.3(12.4) Thoracic C = 14.6(8.6) to 27.4(12.3) Thoracic D = 34.6(7.2) to 40.8(5.8) Lumbar A = 6.6(9.6) to 11.9(12.8) Lumbar B = 6.9(9.4) to 14.4(11.3) Lumbar C = 16.3(7.9) to 28.7(9.4) Lumbar D = 36.6(7.6) to 41.6(9.4) **MID by Injury Level and Severity:** Cervical B = 2.35 Cervical C = 2.45 Cervical D = 1.5 Thoracic A = 0.44 Thoracic B = 1.75 Thoracic C = 2.12 Thoracic D = 1.31 Lumbar A = 2.26 Lumbar B = 2.08 Lumbar C = 1.73

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				Lumbar D = 1.71 Effect size-based estimate for small/large changes in LEMS scores: Cervical B = 0/0 Cervical C = 2.36/5.9 Cervical D = 1.84/4.6 Thoracic A/B = 0/0 Thoracic C = 1.72/4.3 Thoracic D = 1.44/3.6 Lumbar A = 1.92/4.8 Lumbar B = 1.88/4.7 Lumbar C = 1.58/3.95 Lumbar D = 1.52/3.8
Burns et al. 2011 Cross-sectional validation of WISCI II Canada	Patients who are able to ambulate >= 10m N = 76 (79%M) Mean age: 43.3±13.8 Mean post-injury time: 6.32±5.99 years 45% paraplegia, 55% tetraplegia	Spearman correlations between LEMS (N=76) and: • Self-selected WISCI level: 0.704 ($p<0.0001$) • Self-selected WISCI Speed: 0.509 ($p<0.05$)		

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	AIS-A/B/C/D: 3%/1%/8%/88%	• Max WISCI level: 0.717 ($p<0.0001$) • Max WISCI speed: 0.572 ($p<0.0001$) More details of paraplegic/tetraplegic values available in article.		
Ditunno et al. 2008 Prospective cohort study to demonstrate validation for the formulation of hierarchical rankings Prospective Cohort in Denmark, Germany, Italy and the USA.	N = 150 (USA = 112; Europe = 38) AIS A: Tetra = 18, Para = 41 AIS B: Tetra = 12, Para = 7 AIS C: Tetra = 22, Para = 10 AIS D: Tetra = 32, Para = 8	WISCI II Total Spearman correlation w/ Lower Extremity Motor Score (LEMS) ($p<0.001$): • Initial = 0.47 • Final = 0.91 • Improvement = 0.59 • Final for those who progressed = 0.71		

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Marino et al. 2008 Inter-rater and intra-rater reliability study. Inpatients and outpatients from the Kessler Institute for Rehabilitation.	N = 16 patients with SCI (2 inpatient, 14 outpatient) 10 men, 6 women, age range from 18-65 years N = 16 examiners (8 physicians, 8 physical therapists) > 2 years of experience in field of SCI		**Inter-rater reliability:** • All patients: ICC = n/a • Complete: ICC = n/A • Incomplete: ICC = 0.98	
Ditunno et al. 2007 Single-blinded, parallel-group, multicenter randomized clinical trial 6 regional SCI inpatient rehab. USA	N = 146 (114M, 32F) Mean age = 32 years (range 16 – 69 years) Incomplete spinal cord injury patients who had a Functional Independence Measure locomotor score for walking of < 4 on entry.	WISCI Spearman correlation w/ LEMS (P < 0.001): • At 3 months: = 0.85 • At 6 months: = 0.85 • At 12 months: r = 0.88 WISCI @ 12 months Spearman correlation w/ LEMS: • Baseline: 0.73 • At 3 months: 0.81		

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		• At 6 months: 0.86		
Graves et al. 2006 Retrospective medical record analysis USA	N = 6,116 AIS motor scores 80% male 48% paraplegia	Separate UE/LE motor scores more accurately represented motor function than a single combined score: P<.0001 (82% in 1D model and 87% of variance in 2-D model)		

van Hedel et al. 2006
 	
Longitudinal study
 	
European Multicenter Study of Human Spinal Cord Injury
	N = 22 (18M, 4F)
	
	Mean age = 45.5 years (range 17 – 78 years)
	
	Incomplete spinal cord injury patients who were able to stand or walk within the first month after SCI.
		Spearman correlation of ASIA LEMS with other measures at various post-injury time:
		• WISCI II:
		  ○ Within 1 month: 0.49 (P=0.02)
		  ○ After 3 months: 0.50 (P=0.02)
		  ○ After 6 months:		

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		0.38 (P=0.08) o After 12 months: 0.32 (P=0.15) • 6 Minute Walk Test: o Within 1 month: 0.54 (P=0.01) o After 3 months: 0.34 (P=0.12) o After 6 months: 0.49 (P=0.02) o After 12 months: 0.55 (P<0.01) • 10 Meter Walk Test: o Within 1 month: -0.45 (P=0.04) o After 3 months: -		

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		0.30 (P=0.18) o After 6 months: -0.40 (P=0.06) o After 12 months (P=0.07)		
Morganti et al. 2005 Retrospective analysis A large rehabilitation hospital in the center of Italy.	N = 284 patients (184M, 100F) Mean age: 50.4±19.3 years Mean (SD) time since SCI at admission to spinal unit: 56.9(43.9) days Concurrent validity sample: N=76 "Traumatic or non-traumatic SCLs admitted between 1997-2001. Non-	"The initial ASIA [impairment] grade was predictive of mobility outcome in WISCI" Correlation between ASIA LEMS and WISCI: • For all patients (N=200): 0.58 (P<0.001) • For WISCI levels 1-19 only (N=63): 0.57 (P<0.001) • For patients aged <50		

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	traumatic etiology was present in the majority of the patients (177/284): inflammatory (40), vascular (36), neoplastic (39), degenerative (62); traumatic lesions (107/284): car accident (38), motorcycle accident (15), sport accident (7), act of violence (6), suicide attempts (6), and accidental falls (31)."	(N=35): 0.50 (P<0.01) • For patients aged >= 50 (N=28): 0.64 (P<0.01) • For traumatic SCI patients (N=37): 0.49 (P<0.01) • For non-traumatic SCI patients (N=26): 0.58 (P<0.01)		
Marino & Graves 2004 Secondary analysis of prospectively collected data Model Spinal Cord Injury Systems centers.	N = 4338 (3443M, 895F) People with traumatic SCI discharged between Jan. 1994 and Mar. 2003 Median age: 33 (IQR= 22~46) Median time from injury to rehab	• R^2 =0.59 for total ASIA motor score in predicting total FIM motor. • R^2 = 0.71 for separate UE/LE ASIA scores in predicting total FIM motor. • R^2=0.44 for predicting FIM UE		**Interpretability:** Normative data (N=4338): • Median ASIA Motor at discharge: 50 (IQR= 31~70) • Median Upper Extremity Motor Score at

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USA	admission: 15 (IQR= 9~28) days Median time in rehab: 46 (IQR= 29~73) days AIS-A/B/C/D: 2049/511/655/1123 Neurologic category: Complete tetraplegia: 854 Incomplete tetraplegia: 1464 Complete paraplegia: 1195 Incomplete paraplegia: 825	score with total ASIA motor score • R^2=0.72 for predicting FIM LE score with separate UE/LE ASIA scores • R^2=0.60 for predicting FIM LE score with total ASIA motor score • R^2=0.65 for predicting FIM UE score with separate UE/LE ASIA scores		discharge: 44 (IQR= 23~50) • Median Lower Extremity Motor Score at discharge: 0 (IQR= 0~30) **Floor and ceiling effect:** • UEMS: 42% of participants at ceiling (50) • LEMS: 53% of participants at floor (0)
Field-Fote et al. 2001 Methodological study testing reliability, validity, and sensitivity of the	N=22 (5F, 17M) Age: 32±13 Incomplete SCI 14 Cervical, 5 Thoracic, 3 Lumbar Ability to independently maintain stance on	Correlation between % change in gait score and in change lower extremity motor scores (LEMS): r=0.58		

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<table>
<tr><th>Author Year
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Setting</th><th>Demographics and Injury Characteristics of Sample</th><th>Validity</th><th>Reliability</th><th>Responsiveness
Interpretability</th></tr>
<tr><td>Spinal Cord Injury Functional Ambulation Inventory (SCI-FAI)

University of Miami, USA</td><td>the weight-bearing limb and ability to take at least 8 steps.

Sensitivity:
N=19 (6 female, 13 male)
Age: 31.7±9.4
13 tetraplegia, 6 paraplegia</td><td></td><td></td><td></td></tr>
<tr><td>Curt et al. 1998

Correlation study on a prospective cohort

SCI center, university hospital.

Switzerland</td><td>N = 70

Acute=36
M/F = 31/5

Median age = 40.5y (17-77)

Chronic=34
M/F = 26/8

Median age = 32y (18-73)
Level of Injury SCI : C2-T1</td><td>LE (lower extremity)
ASIA MS correlated with nonstandardized ambulatory capacity = 0.79 (acute), 0.78 (chronic)</td><td></td><td>Interpretability
ASIA scores – mean (SD) – of acute and chronic patient groups with cervical SCI

Please see Table 5 below</td></tr>
<tr><td></td><td>Table 5
<table>
<tr><th>ASIA scores</th><th>Acute SCI – Initial Examination</th><th>Acute SCI - Increment after 6 months</th><th>Chronic SCI</th></tr>
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		Motor (total)	39 (30.4)	18.4 (19.1)	44.8 (27.3)
		Upper limb	23.6 (15)	8.1 (7.7)	28.4 (13.2)
		Lower limb	15.4 (19.9)	10.3 (14.4)	14.4 (17.2)
		Light touch	65.2 (33.4)	8 (16.8)	60.4 (34.9)
		Pin prick	53.3 (36.2)	12.1 (21.4)	49.3 (34.9)
Marino et al. 1993 Cross-sectional SCI centre	N=22 (all male) Avg. age = 33 years (range 10 to 63 years) Inpatients traumatic quadriplegia C4-C7 injury		Best FIM predictive model was using separate ASIA upper extremity motor score (UEMS) and lower extremity motor score (LEMS) (model 3). • ASIA UEMS and FIM motor score: t=91.0 (P<.001) • ASIA LEMS and FIM motor score: t=33.2 (P<.001) Use of separate ASIA UEMS and LEMS improved prediction of motor FIM scores (R^2 = .71) over that of total ASIA motor scores (R^2 = .59)		

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		ASIA UEMS and FIM upper cord score: t=101.7 (P<.001) ASIA LEMS and FIM upper cord score: t=8.4 (P<.001) R^2 = .72 ASIA UEMS and FIM lower cord score: t=73.0 (P<.001) ASIA LEMS and FIM lower cord score: t=41.0 (P<.001) R^2 = .75		