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Research Summary – Graded Redefined Assessment of Strength, Sensibility and Prehension (GRASSP) – Upper Limb

Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Voss et al. 2023 Psychometric study to assess the psychometric properties of remote version of the GRASSP (r-GRASSP) Shirley Ryan Ability Lab, IL, USA; Hines VA Hospital, IL, USA; and Kessler Institute for Rehabilitation, NJ, USA	Participants with tetraplegia (n = 61): Mean age: 49 ± 15 yr Gender: males = 43, females: 18 Level of injury: C1-T1 Mean time since injury: 0.6 ± 43.3 yrs AIS scale: A=6, B=7, C=12, D=35.	**Concurrent validity:** Overall, the r-GRASSP demonstrated excellent concurrent validity with the GRASSP. Table 1.	**Inter-rater reliability:** Comparison r-GRASSP total scores for Examiner 1 vs. Examiner 2 demonstrated high inter-rater reliability, with ICC = 0.99 for both the right and left sides (95% CI [0.98, 0.99] for both sides) Table 2.	

Table 1. Intraclass Correlation and 95% Confidence Interval Comparing the GRASSP and Remote GRASSP (Validity) for Both the Left and Right Hand.

Scale	ICC_left	CI_left	ICC_right	CI_right
Total	0.96	(0.94–0.97)	0.96	(0.94–0.98)
Strength	0.96	(0.93–0.97)	0.95	(0.92–0.97)

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Interpretability</th></tr>
<tr><td></td><td colspan="4">
<table>
<tr><td>Sensibility</td><td>0.59</td><td>(0.41–0.73)</td><td>0.68</td><td>(0.47–0.8)</td></tr>
<tr><td>Prehension ability</td><td>0.94</td><td>(0.91–0.96)</td><td>0.95</td><td>(0.92–0.97)</td></tr>
<tr><td>Prehension performance</td><td>0.92</td><td>(0.82–0.96)</td><td>0.93</td><td>(0.88–0.96)</td></tr>
</table>

Table 2. Intraclass Correlation and 95% Confidence Interval Comparing the Remote GRASSP Examiner 1 and Remote GRASSP Examiner 2 (Reliability) for Both the Left and Right Hand.
<table>
<tr><th>Scale</th><th>ICC_left</th><th>CI_left</th><th>ICC_right</th><th>CI_right</th></tr>
<tr><td>Total</td><td>0.99</td><td>(0.98–0.99)</td><td>0.99</td><td>(0.98–0.99)</td></tr>
<tr><td>Strength</td><td>0.99</td><td>(0.99-1)</td><td>0.99</td><td>(0.99–0.99)</td></tr>
<tr><td>Sensibility</td><td>1.00</td><td>(0.99-1)</td><td>1.00</td><td>(1-1)</td></tr>
<tr><td>Prehension ability</td><td>0.95</td><td>(0.92–0.97)</td><td>0.97</td><td>(0.95–0.98)</td></tr>
<tr><td>Prehension performance</td><td>0.95</td><td>(0.92–0.97)</td><td>0.94</td><td>(0.9–0.96)</td></tr>
</table>
</td></tr>
<tr><td>Kalsi-Ryan et al. 2022

Multi-centre, observational, longitudinal cohort study to</td><td>Acute cervical SCI (n = 147):
Mean age: 49.3 ± 23.8 yr. Gender: males = 99, females = 28.
Level of injury: C1=6, C2=12, C3=20, C4=41, C5=29, C6=11, C7=3,</td><td></td><td></td><td>MCID:
Tables 1 and 2 define the MCID values for all subtests of the GRASSP v1 at six months.</td></tr>
</table>

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establish the MCID of all subtests of the GRASSP v1 for cervical SCI 7 sites in Canada (London Health Sciences [2 sites], ON; Hamilton Health Sciences [2 sites], ON; St. Michael's Hospital, ON; Toronto Western Hospital, ON; and Toronto Rehabilitation Institute, ON) and 5 sites in Europe (Klinik Hohe Warte Bayreuth, D; Unfallklinik Murnau, D; Orthopädische	C8=2, T1=3 Mean time since injury: NR. AIS scale: A=29, B=17, C=26, D=55.			

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Universitätsklinik Heidelberg, D; Balgrist University Hospital Zurich, CH; and Swiss Paraplegic Center, CH)				

Table 1. Minimum Clinically Important Difference Values for the Graded Redefined Assessment of Strength, Sensation, and Prehension Version Subtests, Spinal Cord Independence Measure, and the Upper Extremity Motor Score Using the Anchor Based Approach for Patients Reporting "Better" or "Much Better" Functional Outcome from Their One Month to Six Month Follow-Up Post-Injury

	Better (n = 58) Mean (95% CI)	**Much Better (n = 30) Mean (95% CI)**
GRASSP v1 Strength	13 (4.1-16.7)	19 (11.4-26.6)
GRASSP v1 Sensation	0 (-7.7-7.7)	0 (-7.6-7.6)
GRASSP v1 PA	2 (-3.9-7.9)	3 (-2.5-8.5)
GRASSP v1 PP	23 (14.8-31.2)	30 (20.8-39.2)

CI, confidence interval; GRASSP v1, Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1; PA, prehension ability; PP, prehension performance.

Table 2. Minimum Clinically Important Difference Values for the Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1 Subtests, Spinal Cord Independence Measure, and the Upper Extremity Motor Score Using the Anchor Based Approach for Patients

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<tr><td></td><td colspan="4">Dichotomized Based on Their Initial American Spinal Injury Association Classification into “A+B” and “C+D”
<table>
<tr><th></th><th>ASIA A + B (n = 369
Mean (95% CI)</th><th>ASIA C + D (n = 52)
Mean (95% CI)</th></tr>
<tr><td>GRASSP v1 Strength</td><td>12 (6.3-17.7)</td><td>17 (11.4-26.6)</td></tr>
<tr><td>GRASSP v1 Sensation</td><td>0 (-5.5-5.5)</td><td>0 (-6.3-6.3)</td></tr>
<tr><td>GRASSP v1 PA</td><td>2 (-3.5-7.5)</td><td>1 (-5.0-6.0)</td></tr>
<tr><td>GRASSP v1 PP</td><td>6 (-2.3-14.3)</td><td>12 (2-22)</td></tr>
</table>
CI, confidence interval; GRASSP v1, Graded Redefined Assessment of Strength, Sensation, and Prehension Version 1, PA, prehension ability; PP, prehension performance.</td></tr>
<tr><td>Kalsi-Ryan et al. 2020

Observational and cross-sectional study to develop and validate GRASSP-Myelopathy

Toronto Western Hospital, Canada</td><td>- Degenerative cervical myelopathy (DCM) (n = 148).
Mean age: 56.89 ± 10.67 yr; Gender: males = 84, females = 64; Level of injury: cervical = 148; Mean duration of symptoms = 45.5 ± 60.4 months; Severity: Mild (modified Japanese</td><td>Concurrent validity: All GRASSP-M subtests showed a positive, moderate correlation with the upper limb motor, upper limb sensory, and total upper limb mJOA scores. Dexterity time showed a negative, moderate correlation with these scores. All correlations were significant except for the correlation between</td><td>The ICC – Cronbach’s alpha for inter-rater reliability was 0.869 (95% CI: 0.759-0.928) in the dominant hand and 0.862 (95% CI: 0.748-0.925) in the non-dominant hand.

The ICC – Cronbach’s alpha for intra-rater reliability was 0.868 (95% CI: 0.727- 0.936) in the dominant hand and 0.790 (95%</td><td>Discriminative Qualities of GRASSP-M Domains:
Table 3.</td></tr>
</table>

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	Orthopaedic Association [mJOA] 15.85 ± 0.748) (n = 75), moderate (mJOA 13.20 ± 0.782) (n = 41), and severe (mJOA 9.94 ± 1.110) (n = 32). - Healthy participants (n = 21). Mean age: 53.67 ± 16.81 yr; Gender: males = 11, females = 10.	dexterity time in the dominant hand and the mJOA upper limb sensation score. Table 1. **Known groups' validity:** The prehension/dexterity score was the most discriminative subtest of the GRASSP-M, followed by the strength subscore. Table 2.	CI: 0.565-0.899) in the non-dominant hand.	

Table 1. Concurrent validity:

Subtest		**UL mJOA**	**UL motor mJOA**	**Sensation mJOA**
GRASSP-M strength	**Dominant**	0.431*	0.373*	0.323*
	Non-dominant	0.406*	0.384*	0.251*
GRASSP-M sensation	**Dominant**	0.412*	0.374*	0.280*
	Non-dominant	0.488*	0.448*	0.323*
GRASSP-M prehension/dexterity	**Dominant**	0.502*	0.511*	0.250*
	Non-dominant	0.533	0.524	0.301
GRASSP-M prehension/dexterity time	**Dominant**	-0.407*	−0.455*	−0.138*
	Non-dominant	-0.439*	− 0.469*	− 0.186*

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	*Indicates statistical significance (P ≤ 0.05) Table 2. Discriminative Qualities of GRASSP-M Domains:			

Subtest		**P-value**		
		Mild vs moderate	**Moderate vs severe**	**Mild vs severe**
GRASSP-M strength	**Dominant**	0.019	0.028	0.001
	Non-dominant	0.028	0.079	0.001
GRASSP-M sensation	**Dominant**	0.883	0.001	0.001
	Non-dominant	0.567	0.000	0.000
GRASSP-M prehension/dexterity	**Dominant**	0.000	0.004	0.000
	Non-dominant	0.001	0.002	0.000
GRASSP-M prehension/dexterity time	**Dominant**	0.002	0.062	0.001
	Non-dominant	0.005	0.019	0.000

(*P* ≤ .016) refers to a significant difference between groups and the *P*-value reflects a Bonferroni Correction.

Table 3. GRASSP-M Discriminative Values for Assessment of Degenerative Cervical Myelopathy:

GRASSP-M	**Control**	**Mild**	**Moderate**	**Severe**
GRASSP-Str (0-50)	50	48-46 note which muscles	45-40	Less than 40
GRASSP-Sens (0-12)	11-12	10	9-8	Less than 8
GRASSP-PD (0-9)	8-9	8-7	6-5	Less than 5

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Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
Kalsi-Ryan et al. 2019 Post-hoc analysis of datasets for the GRASSP cross-sectional and longitudinal studies to calculate the psychometric properties of the GRASSP V2 Five clinics in Canada (Toronto Rehabilitation Institute, ON; GF Strong, BC; Hamilton Health Sciences-2 sites, ON; St. Michael's Hospital, ON; and Toronto	**Cross sectional study:** Chronic and traumatic tetraplegia (n = 72). Mean age: 39.7 ± 10.7 yr. Gender: NR. Level of injury: C6=38. Mean time since injury: NR. AIS scale: A=28, B=18, C=14, D=12. **Longitudinal study:** Traumatic cervical SCI (n = 127). Mean age: 49.3 ± 23.8 yr. Gender: NR. Level of injury: C1-C2=18, C3=20, C4=41, C5=29, C6=11, C7=3, C8=2, T1=3. Mean time since injury: NR.	**Concurrent validity:** All associations between GRASSP subscores, SCIM, SCIM-SS, and CUE-Q were positive and of moderate strength with P < 0.001. Table 1.	**Inter rater and test retest reliability:** The reliability values re-calculated for the modified subtests actually indicate improved reliability for both inter rater and test retest reliability. Table 2.	**Responsiveness:** The modified subtests rendered values that show the GV2 to be responsive, however, not as sensitive to the GV1 when considering the GR-PP subtest alone. Table 3. **MDD:** The re-calculated values for the modified subtests are also decreased from the GV1. Table 4.

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Western Hospital, ON), two clinics in USA (Rehab Institute of Chicago, IL and Thomas Jefferson University, PA), and five in Europe (Klinik Hohe Warte Bayreuth, D; Unfallklinik Murnau, D; University Hospital Balgrist, CH; Universitätsklinik Heidelberg, D; and Swiss Paraplegic Center, CH)	AIS scale: A=29, B=17, C=26, D=55.			
	Table 1. Concurrent validity values for GV2 subscores:			

	SCIM	**SCIM-SS**	**CUE-Q**
GRASSP Sensibility	0.53	0.72	0.79
GRASSP Strength	0.59	0.74	0.76

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GRASSP Prehension	0.71	0.82	0.83

Table 2. Reliability values of subtest scores within GV2:

Subtest	Inter-rater reliability		Test-retest reliability	
	ICC	CI	ICC	CI
GR-Palmar Sensation Right	0.84	0.75-0.90	0.95	0.90-0.97
GR-Palmar Sensation Left	0.93	0.89-0.95	0.97	0.94-0.98
GR-Strength Right	0.95	0.93-0.97	0.98	0.98-0.99
GR-Strength left	0.95	0.92-0.97	0.98	0.96-0.98
GR-Prehension ability right	0.95	0.92-0.97	0.98	0.96-0.99
GR-Prehension ability left	0.95	0.92-0.97	0.98	0.97-0.99
GR-Prehension performance right	0.97	0.92-0.98	0.96	0.92-0.97
GR-Prehension performance left	0.96	0.95-0.98	0.97	0.94-0.98

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	Table 3. Descriptive statistics and responsiveness values for GV2 new subtests			

Group	**GV2 Subtest**	**N**	**Baseline**	**1 month**	**6 month**	**12 month**
Whole	GR-Sens	71	13.6 (7.7)	14.3 (8.3)	18.1 (6.7)	18.4 (6.4)
AB	GR-Sens	17	11 (8.5)	10.1 (7.9)	14.8 (8.8)	15.4 (8.6)
CD	GR-Sens	47	14.2 (7.2)	16.3 (7.8)	19.1 (5.5)	19.5 (4.9)
Whole	GR-PP	108		16.4 (14.9)	23.5 (14.5)	25.9 (13.2)
AB	GR-PP	33		5.1 (8.7)	13.4 (13.6)	14.7 (12.7)
CD	GR-PP	64		26.8 (14.1)	32.1 (12.3)	31.3 (9.8)
Group	GV2 Subtest	N	Mean Diff	SRM	ES	SE
Whole BL-6mo	GR-Sens	102	3.41 (3.97)	.84	.41	.39
AB BL-6mo	GR-Sens	17	3.89 (4.65)	.86	.45	1.13
CD BL-6mo	GR-Sens	43	3.15 (3.56)	.88	.41	.54
Whole BL-12mo	GR-Sens	60	5.8 (4.5)	1.28	.77	.58
AB BL-12mo	GR-Sens	17	5.65 (5.1)	1.11	.69	1.24
CD BL-12mo	GR-Sens	42	5.8 (4.3)	1.35	.81	.67
Whole 1mo-6mo	GR-PP	99	8.7 (9.4)	.93	.62	.94
AB 1mo-6mo	GR-PP	33	8.5 (9.7)	.88	.97	1.7
CD 1mo-6mo	GR-PP	64	5.76 (8.6)	.67	.41	1.1
Whole 1mo-12mo	GR-PP	89	9.7 (8.6)	1.12	.66	.91
AB 1mo-12mo	GR-PP	31	9.9 (8.1)	1.22	1.11	1.47

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CD 1mo-12mo	GR-PP	58	9.6 (8.8)	1.10	.69	1.15

GR-Sens = GRASSP Sensation; GR-PP = GRASSP Prehension Performance; Mean Diff = Mean Difference; SRM = Standardized Response Mean; ES = Effect Size; SE = Standard Error of Mean.

Table 4. MDD values for subtest scores within GV2

	SEM	SRD	# of items	SRD/ items	Change in Scores
GR-Palmar Sensation Right (0–12)	1.41	3.27	3	1.09	4 pts or more
GR-Palmar Sensation Left (0–12)	0.93	2.68	3	0.89	4 pts or more
GR-Strength Right (0–50)	3.34	9.23	10	0.92	5 pts or more
GR-Strength Left (0–50)	3.47	9.59	10	0.95	5 pts or more
GR-Prehension Ability Right (0–12)	0.99	2.76	3	0.92	4 pts or more
GR-Prehension Ability Left (0–12)	0.98	2.76	3	0.92	4 pts or more
GR-Prehension Performance Right (0–20)	1.08	2.89	4	0.75	3 pts or more

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<tr><td></td><td colspan="4">
<table>
<tr><td>GR-Prehension Performance Left (0–20)</td><td>1.12</td><td>2.94</td><td>4</td><td>0.74</td><td>3 pts or more</td></tr>
<tr><td>GR-Strength (0–100) R + L</td><td>5.51</td><td>15.20</td><td>20</td><td>6.71</td><td>7 pts or more</td></tr>
<tr><td>GR-Palmar Sensation (0–24) R + L</td><td>2.31</td><td>4.21</td><td>6</td><td>0.70</td><td>3 pts or more</td></tr>
<tr><td>GR-Prehension Ability (0–24) R + L</td><td>1.81</td><td>4.90</td><td>6</td><td>0.81</td><td>4 pts or more</td></tr>
<tr><td>GR-Prehension Performance (0–40) R + L</td><td>2.48</td><td>4.36</td><td>8</td><td>0.55</td><td>3 pts or more</td></tr>
</table>
GR-GRASSP; SEM-Standard Error of Measure; SRD-Smallest RealDifference.
</td></tr>
<tr><td>Marino et al.
2018

Cross-sectional</td><td>N=69 (tetraplegic)
60 acute, 9 chronic injuries
Mean age: 41.9±18.1 years
25 motor complete
AIS: 8A, 17B, 22C, 22D</td><td></td><td></td><td>Interpretability: Standardized Response Mean (SRM)=0.88
Minimum Detectable Difference (MDD)=9.7 for the combined score and 6.0/5.3 points for the right/left side scores.</td></tr>
</table>

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Mulcahey et al. 2017 Psychometric study to validate the GRASSP in pediatric SCI populations and establish the lower age of test administration US, Pennsylvania, Maryland, Illinois, Michigan, California, Texas	N=47 children with tetraplegia 28 Male, 19 Female AIS: 14A, 4B, 10C, 8D, 11 Unknown Age groups: - 5, 3-5 years - 15, 6-12 years - 12, 13-15 years - 15, 16-17 years	Correlation between GRASSP and SCIM r=0.33-0.66 Correlation between GRASSP and SCIM-SC r=0.37-0.70 Correlation between GRASSP and CUE-Q r=0.40-0.84	**Test-retest, inter-rater, intra-rater:** Test-retest reliability ICC=0.99	
Kalsi-Ryan et al. 2016 Multicenter, observational, longitudinal, cohort study	N=53 (48M, 5F) Mean (SD) age 49.6 (15.6) All acute SCI, 0-10 days post-injury AIS-A/B/C/D: 11/5/16/21 51 cervical, 2 thoracic	Table 1.		**Responsiveness:** Mean Difference, Std Error, Std Response Mean and Effect Sizes (Mean diff; SE; SRM; ES) at different post-injury intervals: GRASSP Strength:

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5 centers (7 sites) in Ontario, Canada				- 1 month -> 3 month: 11.55; 1.62; 1.02; 0.45 - 1 month -> 6 month: 16.24; 2.13; 1.16; 0.62 - 1 month -> 12 month: 21.64; 2.50; 1.46; 0.83 GRASSP Sensation: - 1 month -> 3 month: 5.10; 0.76; 0.96; 0.36 - 1 month -> 6 month: 6.28; 1.07; 0.90; 0.45 - 1 month -> 12 month: 7.41; 1.26; 0.95; 0.53 GRASSP Prehension Ability: - 1 month -> 3 month: 3.73; 0.69; 0.77; 0.47 - 1 month -> 6 month: 4.16; 0.79; 0.80; 0.52

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				- 1 month -> 12 month: 5.79; 1.02; 0.91; 0.72 GRASSP Prehension Performance: - 1 month -> 3 month: 9.22; 0.90; 1.46; 0.42 - 1 month -> 6 month: 11.00; 0.96; 1.73; 0.50 - 1 month -> 12 month: 14.60; 1.11; 2.11; 0.69 Breakdown by motor completeness and other time intervals available in article **Interpretability:** Table 2.

Table 1. Pearson Correlations (p≤0.001):

	1 month	3 months	6 months	12 months
UEMS/GR-st	0.89	0.952	0.963	0.955
UEMS/GR-sen	0.608	0.651	0.736	0.571
ISNCSCI-LT/GR-st	0.532	0.304	0.415	0.368

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ISNCSCI-LT/GR-sen	0.640	0.307	0.658	0.479
GR-st/SCIM-SS	0.942	0.784	0.854	0.836
GR-st/CUE-Q	0.820	0.771	0.859	0.815
GR-sen/SCIM-SS	0.574	0.643	0.684	0.577
GR-sen/CUE-Q	0.715	0.657	0.695	0.518
GR-pa/SCIM-SS	0.766	0.740	0.839	0.770
GR-pa/CUE-Q	0.798	0.698	0.804	0.719
GR-pp/SCIM-SS	0.866	0.740	0.911	0.844
GR-pp/CUE-Q	0.858	0.817	0.903	0.805

GR-st = GRASSP Strength

GR-sen = GRASSP Sensation

GR-pa = GRASSP prehension ability

GR-pp = GRASSP prehension performance

ISNCSCI-LT = ISNCSCI Light Touch Score (see also ASIA-LT)

UEMS = ASIA Upper Extremity Motor Score

Table 2. Minimal Detectable Values:

	SEM	SRD	# of Items	Score Change
Sensation right (0–24)	2.88	7.96	1.5	More than 2 pts
Sensation left (0–24)	2.32	6.41	0.5	More than 2 pts
Strength right (0–50)	3.34	9.23	1	More than 5 pts

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<table>
<tr><td>Strength left (0–50)</td><td>3.47</td><td>9.59</td><td>1</td><td>More than 5 pts</td></tr>
<tr><td>Prehension ability right (0–12)</td><td>0.99</td><td>2.76</td><td>0.5</td><td>More than 2 pts</td></tr>
<tr><td>Prehension ability left (0–12)</td><td>0.98</td><td>2.76</td><td>0.5</td><td>More than 2 pts</td></tr>
<tr><td>Prehension performance right (0–30)</td><td>2.16</td><td>5.97</td><td>0.5</td><td>More than 3 pts</td></tr>
<tr><td>Prehension performance left (0–30)</td><td>1.93</td><td>5.33</td><td>0.5</td><td>More than 3 pts</td></tr>
<tr><td>Bilateral strength (0–100)</td><td>5.5</td><td>15.2</td><td>6.7</td><td>More than 7 pts</td></tr>
<tr><td>Bilateral dorsal sensation (0-–4)</td><td>2.4</td><td>6.6</td><td>3.6</td><td>More than 4 pts</td></tr>
<tr><td>Bilateral palmar sensation (0–24)</td><td>2.4</td><td>6.6</td><td>3.6</td><td>More than 4 pts</td></tr>
<tr><td>Bilateral prehension ability (0–24)</td><td>1.8</td><td>4.9</td><td>4.8</td><td>More than 5 pts</td></tr>
<tr><td>Bilateral prehension performance (0–24)</td><td>3.5</td><td>9.7</td><td>6.2</td><td>More than 6 pts</td></tr>
</table>
</td></tr>
<tr><td>Velstra et al.
2016
prospective longitudinal</td><td>N = 61, 45 male
Mean age 47, SD = 19
Acute (16-40 days after injury) tetraplegia at recruitment</td><td>Backward multiple binary logistic regression reveals that combinations of select predictors have similar</td><td></td><td></td></tr>
</table>

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multicenter study 5 European SCI centers; Recruitment between 2009 ~ 2012	58/61 traumatic SCI AIS at 1 month: A=16, B=10, C=7, D=28	predictive accuracy as that of 10 predictors: Combination of FDP & Delto predicting GRASSP-QtG at 6 months: - Sensitivity = 86.4% (74.7-93.3%), Specificity = 86.5% (75.5-93.0%) All 10* unilateral muscle predictors predicting GRASSP-QtG at 6 months: - Sensitivity = 86.4% (74.7-93.3%), Specificity = 86.5% (75.5-93.0%) Combination of ElbowFlex, WristExt, EDC & FPL predicting		

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		SCIM-Self-care at 6 months: - Sensitivity = 81.8% (61.5-92.7%), Specificity = 89.2% (75.7-97.2%) All 10* bilateral muscle predictors predicting SCIM-Self-care at 6 months: - Sensitivity = 86.4% (66.7-95.3%), Specificity = 89.2% (75.3-95.7%) Combination of WristExt, FDP, Delto & FPL predicting SCIM-Mobility at 6 months: - Sensitivity = 96% (80.5-99.3%), Specificity =		

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		91.2% (77.0-96.7%) All 10* bilateral strength predictors predicting SCIM-Mobility at 6 months: - Sensitivity = 92% (75.0-97.8%), Specificity = 91.2% (77.0-96.7%) UEMS = Upper extremity motor score GRASSP-MMT = GRASSP Manual muscle testing *Predictors included: - ElbowFlex = Elbow flexors (UEMS) - WristExt = Wrist extensors (UEMS) - Triceps = Elbow extensors (UEMS) - FDP = Long finger flexors (UEMS)		

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		- AbdDigV = Small finger abductors (UEMS) - Delto = M. anterior deltoid (GRASSP-MMT) - EDC = M. extensor digitorum communis (GRASSP-MMT) - OPP = M. opponens pollicis (GRASSP-MMT) - FPL = M. flexor pollicis longus (GRASSP-MMT) - DI1 = M. first dorsal interosseus (GRASSP-MMT) URP-CTREE analysis revealed that GRASSP-QlG subtest** can accurately predicted upper-limb function: - "The combination of proximal and		

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		distal upper limb muscles as well as the early ability to initiate simplified grasp movements (ie, CylGrasp, LatPinch, and TTPinch), predicted upper limb function very well" (p300) **Predictors included: - CylGrasp = Cylindrical grasp - LatPinch = Lateral key pinch TTPinch = Tip-to-tip pinch		
Velstra et al. 2015 Prospective longitudinal	N = 74, (23F, 51M) Age: 49 ± 18	Spearman Correlations ($p<0.0001$): At 1 month postinjury:		**Responsiveness:** Responsiveness between first month

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multicenter study 5 European SCI Rehab centers	SCI patients <= 10 days post-injury at enrollment AIS at 1 month: A=18, B=12, C=10, D=34 69/74 traumatic SCI	- GRASSP-MMT subscale & SCIM-selfcare = 0.78 - GRASSP-MMT subscale & ASIA UEMS = 0.95 - GRASSP-SWM subscale & SCIM-selfcare = 0.63 - GRASSP-QtG subscale & SCIM-selfcare = 0.85 At 12 month postinjury: - GRASSP-MMT subscale & SCIM-selfcare = 0.82 - GRASSP-MMT subscale & ASIA UEMS = 0.88 - GRASSP-SWM subscale & SCIM-selfcare = 0.56		and 1 year postinjury (measured by SRM): AIS A-D (For AIS A-B, or C-D specific data, refer to article) GRASSP-MMT: 1.48 (large) GRASSP-SWM: 0.64 (moderate) GRASSP-QlG: 0.99 (large) GRASSP-QtG: 1.03 (large) SRMs with respect to 1~3, 1~6, 1~12, 3~12, 3~6, 6~12 months post-injury: In all patients: GRASSP-MMT subtest: 0.79-1.48 GRASSP-SWM subtest: 0.14-0.93 GRASSP-QlG subtest: 0.34-0.99

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		- GRASSP-QtG subscale & SCIM-selfcare = 0.82 Data at 3 & 6 month also available in article Predictive validity: ROC analysis (AUC & 95%CI): Btwn 1-3 month postinjury: - Change in GRASSP-MMT: 0.81 (0.71~0.91) ($p<0.001$) - Change in GRASSP-SWM: 0.77 (0.65~0.89) ($p<0.001$) - Change in GRASSP-QtG: 0.71 (0.57~0.85) ($p<0.001$) Btwn 3-6 month postinjury:		GRASSP-QtG subtest: 0.50-1.03 In AIS-A/B patients: GRASSP-MMT subtest: 0.82 -1.56 GRASSP-SWM subtest: 0.31-0.94 GRASSP-QlG subtest: 0.22-1.02 GRASSP-QtG subtest: 0.42-1.10 In AIS-C/D patients: GRASSP-MMT subtest: 0.68-1.50 GRASSP-SWM subtest: 0.02-0.54 GRASSP-QlG subtest: 0.41-1.02 GRASSP-QtG subtest: 0.55-1.17

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		- Change in GRASSP-MMT: 0.87 (0.77~0.97) (p<0.001) - Change in GRASSP-SWM: 0.68 (0.53~0.82) (p<0.05) - Change in GRASSP-QtG: 0.81 (0.70~0.93) (p<0.001) Btwn 6-12 month postinjury: - Change in GRASSP-MMT: 0.71 (0.58~0.85) (p<0.01) - Change in GRASSP-SWM: 0.86 (0.76~0.96) (p<0.001) - Change in GRASSP-QtG: 0.82 (0.70~0.94) (p<0.001)		

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		(GRASSP-MMT = Manual Muscle Testing subscale – based on Daniels and Worthington, 1995)		
Velstra et al. 2014 Prospective longitudinal multicenter study	N=61 (16F, 45M) Age: 46 ± 19 All acute (16-40 days after injury) tetraplegia patients from cervical SCI 56/61 traumatic SCI AIS at 1 month: A=16, B=9, C=7, D=29	Spearman correlations with SCIM: MMT (1 month) subscale and SCIM self-care subscale: - at 6 months (r=0.821, p<0.001) - at 12 months (r= 0.820, (p<0.001) SWM subscale (1 month) and SCIM self-care subscale: - At 6 months: r=0.781, p<0.001; - At 12 months, r= 0.643, p<0.001 Predictive validity: Area Under Curve (95%CI) (p<0.001),		

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		Sensitivity/specificity (95%CI): GRASSP-MMT subtest (@1mth) as predictor of: - SCIM-self-care (@6mth): AUC = 0.917(0.680-0.926); Sens = 81.8%(70.1-89.4); Spec = 92.1%(81.9-96.4) - SCIM-self-care (@12mth): 0.917(0.849-0.984); Sens = 82.8%(67.2-87.8); Spec = 72.4%(59.8-82.2) GRASSP-SWM subtest (@1mth) as predictor of: - SCIM-self-care (@6mth): 0.803(0.680-0.926); Sens = 68.2%(55.7-78.7);		

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		Spec = 78.9%(66.4-86.9) SCIM-self-care (@12mth): 0.842(0.737-0.947); Sens =79.3%(67.2-87.8); Spec = 75.9%(63.5-85)		
Kalsi-Ryan et al. 2012 Cross-sectional multi-center trial focused on establishing the reliability and validity of GRASSP Test-retest reliability study: N=45 (North American centers) Inter-rater reliability study & Construct	Study site: (total N=72) Toronto Rehabilitation Institute, Canada (N=15) Vancouver Coastal Health, Canada (N=10) Rehabilitation Institute of Chicago, USA (N=10) Thomas Jefferson University, USA (N=10) Balgrist University Hospital, Switzerland (N=9) Krakenhaus Hohe Worte, Germany (N=8) Traumacenter Murnau, Germany (N=10)	Construct validity: precision of GRASSP was established by comparing the sensation and strength subtest items to the sensory and motor upper limb items in the ISNCSCI. On average, 54% of the sample showed discordance in sensory innervation when assessed with the GRASSP due to the additional test locations of sensory testing included (added palmar	**Test-retest, inter-rater, intra-rater:** All ICC values had a significance level of p<.001. Table 4. ICC = intra-class correlation coefficient CI = confidence interval ICC for inter-rater reliability ranged between 0.84 – 0.96. ICC for test-retest reliability ranged between 0.86 - 0.98.	**Interpretability:** Table 5.

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Author Year Research Design Setting (country)	Demographics and Injury Characteristics of Sample	Validity	Reliability	Responsiveness Interpretability
validity study: N=72 Seven centers collected data: Rehabilitation Institute of Chicago, Chicago, Illinois; Toronto Rehabilitation Institute, Toronto, Ontario; Vancouver Coastal Health, Vancouver, British Columbia; Thomas Jefferson University, Philadelphia, Pennsylvania; Balgrist University Hospital, Switzerland;	Sample description: Mean age (years): 39.7 (10.7) Time post-injury (years): 7.6 (6.1) AIS complete: n=28 (39%) AIS incomplete: n=44 (61%) C6-C7 AIS motor level: 52.5% C4-C6 AIS sensory level: 66.0% Chronic tetraplegia AIS grades: A: 38.8% B: 25.2% C: 16.6% D: 19.4% Each site engaged two examiners who were either occupational or	locations and increased response levels of the SWM). Table 1. On average, 53% of the sample showed a different degree of motor innervation when assessed with the GRASSP due to the added muscles in the GRASSP, and the designation of the most caudal level in the ISNCSCI. Table 2. Concurrent validity: Spearman correlation coefficients were used to establish the association between GRASSP subtests and the CUE, SCIM-total and SCIM-SS (self-care subscale).		

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Krakenhaus Hohe Worte, Germany; Traumacenter Murnau, Germany.	physical therapists who had expertise with SCI. In total 14 examiners were involved in the study, 12 of whom were occupational therapists and two of whom were physical therapists. Two workshops (one in Europe and one in North America) were conducted to train the examiners on the study protocol and appropriate use of all study measures. Inclusion and exclusion criteria: Individuals with chronic (more than 6 months after injury) traumatic tetraplegia who were neurologically and medically stable, between the ages of	All associations were positive and significant (P<.0001). Table 3. *Right and left data were combined for the analyses SCIM-SS showed stronger association than SCIM-total with GRASSP subtests. CUE showed the strongest associations with GRASSP, indicating strong association between self-perceived function and tested impairment.		

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	16 and 65 and able to provide informed consent were included in the study. Individuals with moderate brain injury who were neurologically unstable or individuals with any other pathology causing upper limb impairment were excluded.			

Table 1.

	Agreement		Discordance	
ISNCSCI sensory level:	**n**	**n (%)**	**1* n (%)**	**2* n (%)**
Total sample (R)	72	32 (44)	16 (22)	24 (33)
Total sample (L)	72	34 (47)	13 (18)	25 (35)
C2-C4 (R)	29	14 (19)	7 (10)	8 (11)
C2-C4 (L)	29	12 (17)	6 (8)	11 (15)
C5 (R)	11	5 (7)	4 (6)	2 (3)
C5 (L)	9	5 (7)	3 (4)	1 (1)
C6 (R)	17	6 (8)	5 (7)	6 (8)
C6 (L)	19	8 (11)	4 (6)	7 (10)
C7 (R)	8	4 (6)	0 (0)	4 (6)

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C7 (L)	6	3 (4)	0 (0)	3 (4)
C8 and below (R)	7	3 (4)	0 (0)	4 (6)
C8 and below (L)	9	6 (8)	0 (0)	3 (4)

1* = discordance due to added palmar test locations in GRASSP

2* = discordance due to increased response levels (SWM) used in GRASSP

Table 2.

	Agreement		**Discordance**	
ISNCSCI motor level:	**n**	**n (%)**	**1* n (%)**	**2* n (%)**
Total sample (R)	72	36 (50)	19 (26)	17 (24)
Total sample (L)	72	34 (47)	20 (28)	17 (24)
C2-C4 (R)	10	1 (1)	6 (8)	3 (4)
C2-C4 (L)	14	6 (8)	6 (8)	1 (1)
C5 (R)	10	3 (4)	2 (3)	5 (7)
C5 (L)	9	3 (4)	1 (1)	5 (7)
C6 (R)	23	13 (18)	3 (4)	7 (10)
C6 (L)	21	11 (15)	5 (7)	4 (6)
C7 (R)	17	9 (12)	6 (8)	2 (3)
C7 (L)	16	6 (8)	7 (10)	3 (4)
C8 (R)	4	2 (3)	2 (3)	0 (0)
C8 (L)	5	1 (1)	1 (1)	3 (4)
T1 and below (R)	8	8 (11)	0 (0)	0 (0)
T1 and below (L)	7	7 (10)	0 (0)	0 (0)

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Table 3.

Subtest score	SCIM	SCIM-SS	CUE
Sensation total (R+L)	0.57	0.74	0.77
Strength total (R+L)	0.59	0.74	0.76
Prehension performance total (R+L)	0.68	0.79	0.83

Table 4.

GRASSP Subtest:	Inter-rater reliability		Test-retest reliability	
	ICC	CI	ICC	CI
Sensation right	0.84	0.75-0.89	0.95	0.91-0.97
Sensation left	0.91	0.86-0.94	0.86	0.76-0.92
Strength right	0.95	0.93-0.97	0.98	0.98-0.99
Strength left	0.95	0.92-0.97	0.98	0.96-0.98
Prehension ability right	0.95	0.92-0.97	0.98	0.96-0.99
Prehension ability left	0.95	0.92-0.97	0.98	0.97-0.99
Prehension performance right	0.95	0.92-0.97	0.93	0.88-0.96

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Prehension performance left	0.96	0.93-0.97	0.96	0.93-0.98

Table 5. Mean (SD) scores for GRASSP items and SEM, MDC (calculated from data in Kalsi-Ryan et al. 2012):

GRASSP items:	Mean		SD		SEM		MDC	
	R	L	R	L	R	L	R	L
Strength (0-50)	24.3	25.1	13.0	13.5	1.8	1.9	5.1	5.3
Dorsal sensation (0-12)	6.5	6.7	3.2	3.1	--	--	--	--
Palmar sensation (0-12)	7.1	7.2	3.6	3.3	--	--	--	--
Prehension ability (0-12)	4.9	5.1	4.5	4.3	0.6	0.6	1.8	1.7
Prehension performance (0-30)	15.6	14.7	9.6	8.9	2.5	1.8	7.0	4.9

R=right, L=left

Table 6. GRASSP subtest scores of four representative examples (right side data only):

	GRASSP subtest scores				
ISNCSCI sensory/motor AIS	**Dorsal sensation (0-12)**	**Palmar sensation (0-12)**	**Strength (0-50)**	**Prehension ability (0-12)**	**Prehension performance (0-30)**
C5/C4/A	4	3	5	0	0
C7/C6/A	6	9	23	10	21
C5/C6/D	10	10	26	5	16
C4/T1/D	12	12	45	12	27

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Kalsi-Ryan et al. 2013 Cross-sectional multi-center trial focused on determining the association between the impairment domains (sensation, motor, and prehension) and the construct of "sensorimotor upper limb function" by testing the hypothetical model (based on the theoretical framework)	Same sample as Kalsi-Ryan et al. 2012 above.	Structural equation modeling rendered the strength of association between impairment, function and the latent trait variable of sensorimotor upper limb function. The SEM results show a very good fit of the model to the data; the model explained 72% of the variance in "sensorimotor upper limb function." The very high value of R^2 was substantiated by the goodness-of-fit indices. The goodness-of-fit indices were greater than the accepted thresholds (χ^2 = 14.3, *P* = .11; CFI =		

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Same sample as Kalsi-Ryan et al. 2012 above.		.99, TLI = .97, and RMSEA = .09, SRMR = .02), which implies that the R^2 value is reliable and the relationship among variables are also reliable. Prehension has a significant positive effect on upper limb function and strength and palmar sensation both have a direct and indirect effect through prehension on upper limb function. Based on the SEM, palmar sensation showed a direct and indirect relationship to upper limb function. The relationship mediated through prehension is larger (0.19 + 0.32) than the direct relationship		

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		(0.31); but both direct and indirect relationships are statistically significant. Strength also showed a direct and indirect relationship to upper limb function. The relationship mediated through prehension is larger (0.68 + 0.31) than the direct relationship to upper limb function, but both direct and indirect relationships are statistically significant. Therefore, sensorimotor upper limb function can be predicted by palmar sensation and strength through prehension. The values on the right of the latent trait 0.89, 0.80, 0.92, 0.93) simply confirm that		

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		sensorimotor upper limb function is adequately estimated by the variables used. The values are very high and significant, which would be expected as the SCIM and CUE are functionally relevant tests and the construct of “sensorimotor upper limb function” is well defined by impairments that are functionally relevant. Essentially, changes in strength and sensation are most likely to have an effect on upper limb function when associated with improvement in prehension.		
Kalsi-Ryan et al. 2009	Study site: (total N=72)	Strength of observed relationships between	**Test-retest, inter-rater, intra-rater:**	

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Cross-sectional study assessed a cohort of neurologically stable patients with tetraplegia using a preliminary version of the GRASSP Seven centers collected data: Rehabilitation Institute of Chicago, Chicago, Illinois; Toronto Rehabilitation Institute, Toronto, Ontario; Vancouver Coastal Health, Vancouver, British Columbia;	Toronto Rehabilitation Institute, Canada (N=15) Vancouver Coastal Health, Canada (N=10) Rehabilitation Institute of Chicago, USA (N=10) Thomas Jefferson University, USA (N=10) Balgrist University Hospital, Switzerland (N=9) Krakenhaus Hohe Worte, Germany (N=8) Traumacenter Murnau, Germany (N=10) Sample description: C6-C7 AIS motor level: 52.5% C4-C6 AIS sensory level: 66.0% AIS grades:	GRASSP impairment components and functional measures (SCIM, SCIM self-care subscore, and prehension) were used to exclude items and tests from the final GRASSP. A similar method was used to determine which individual items from the MMT should be retained based on the strength of association to function. Out of 11 muscles, 10 were included into the GRASSP; only the muscle abductor policis brevis failed to demonstrate significant association between impairment and function, and was excluded.	Kalsi-Ryan et al. 2009 reports inter/intra-rater reliability for components of the GRASSP, as found in other articles (referenced). Components of the GRASSP and inter / intra reliability: Sensibility domain: - Light touch / Semmes Weinstein monofilament (SMW): inter/intra = 0.965 - Static 2 point disc: inter/intra = 0.989 Strength and tone domain:	

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Thomas Jefferson University, Philadelphia, Pennsylvania; Balgrist University Hospital, Switzerland; Krakenhaus Hohe Worte, Germany; Traumacenter Murnau, Germany.	A: 38.8% B: 25.2% C: 16.6% D: 19.4%	The final GRASSP consisted of: strength, Semmes Weinstein monofilaments (SWM) and grasp function (quantitative grasp = Qn-Grasp). Items eliminated were: tone (Ashworth) and static two-point discrimination (S2PD). The final GRASSP (version I) consists of SWM, Manual Muscle Test (MMT) – 10 muscles and prehension testing.	- strength: inter-rater = 0.880 - tone: inter-rater: 0.750 Prehension domain: - quantitative (performance) – adapted from Sollerman: inter-rater = 0.980	