**SCALE: Selective Control Assessment of the Lower Extremity Score Sheet**

Date: _______________   Patient's Name: __________________________________   DOB: __________________   GMFCS level: _____

Diagnosis:  □ spastic diplegia  □ spastic quadriplegia  □ spastic hemiplegia  R  L  other: ___________________________

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Total Limb Score  L= R=

**Resisted Synergy**

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<td>knee extension with resisted limb extension</td>
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**Descriptors**

- hip flexion contracture
- adductor contracture or spasticity
- knee flexion contracture
- hamstring tightness
- plantar flexion contracture
- plantar flexor spasticity
- inverts or everts, not pure dorsiflexion
- primarily moves toes
- mirrors motion on opposite limb
- motion slower than 3 second verbal count
- moves one direction only (note motion achieved)
- movement of other joints
- motion ≤ 50% of available ROM

**Other comments regarding test:**

____________________________________________________________________________________________

__________________________________  Examiner
 SCALE: Directions for administration

The patient must be able to follow simple motor commands. To test this ability, ask the patient to move his or her least affected body part. Before asking the patient to perform each joint test, passively move the joint to assess ROM. To assure understanding, demonstrate the movement sequence while supporting the limb. The language in the instructions to the patient is suggested and may be modified as needed to elicit optimum performance for individual patients. To guide patients in the desired speed of movement, provide a verbal three-second count during the task. Multiple attempts are allowed and feedback to improve performance is acceptable.

**General instructions to patient** – “I am going to ask you to move in a certain way. Move the way I ask you to move. Try not to move any other part of your body. If you have any questions or you don’t understand what I am asking you to do, please tell me.”

**Hip**

**Position** – Side lying with the hip and knee fully extended. Support the limb medially at the knee and ankle. For stability, you may flex the lower untested limb. The tested motion is hip flexion while keeping the knee extended. Assess hip flexion ROM with the knee extended, as it may be limited by hamstring tightness. If the patient has difficulty with this task because of hamstring tightness, then ask him or her to extend, flex then extend the hip while keeping the knee flexed 90°. Evaluate hip extension ROM to assure an adequate arc of motion to assess performance of the task.

**Instructions to patient** – Ask the patient to flex, extend then flex the hip while keeping the knee extended. For example: “Move your leg forward, back then forward again while keeping your knee straight. I will take you through the motion first, and then I’d like you to do it yourself.”

**Knee**

**Position** – The remaining tests are done in sitting with legs over the edge of the exam table. During the remaining tests you may allow the patient to lean back on his or her hands so the trunk is approximately 20° from vertical to compensate for hamstring tightness.

**Instructions** – Ask the patient to extend, flex then extend the knee while keeping the hip flexed. For example: “Straighten your knee as much as you can, then bend it and straighten again. Try to do this without leaning further back or moving your other leg. I will take you through the motion first, and then I’d like you to do it yourself.”

**Limb Extension Synergy** – If quadriceps weakness is suspected, limb extension synergy may be assessed. Allow the patient to lean back on his or her hands or be supported so the trunk is approximately 45° from vertical. Position the limb in hip and knee flexion with ankle dorsiflexion. Ask the patient to push against your hand, extending the knee and plantar flexing the foot and toes. Resist at the metatarsal heads and compare knee extension excursion to the amount achieved during the knee selective voluntary motor control test.

**Ankle**

**Position** – Sitting, as in the knee extension test. The knee is extended and the examiner supports the calf. Assess passive ankle dorsiflexion ROM with the knee extended. The knee may be flexed to approximately 20° if needed to accommodate hamstring and/or gastrocnemius tightness.

**Instructions to patient** – Ask patient to dorsiflex, plantar flex then dorsiflex the ankle while maintaining knee extension. For example: “Keeping your knee straight while I support your leg, move your foot up, down then up again. I will take you through the motion first, then I’d like you to do it yourself.”

**Limb Flexion Synergy (Confusion Test)** – If dorsiflexor muscle weakness is suspected, limb flexion synergy may be assessed. Ask the patient to flex the hip while keeping the knee flexed. Resist hip flexion at the distal thigh. Compare dorsiflexion excursion to the amount achieved during the ankle selective voluntary motor control test.

**Foot/Subtalar Joint**

**Position** – Sitting, as in the knee and ankle tests. The calf is supported.

**Instructions to patient** – Ask patient to invert, evert then invert while maintaining knee extension. For example: “Move your ankle in, then out then in again while I support your leg. I will take you through the motion first, then I’d like you to do it yourself.”

**Toes**

**Position** – Sitting, as in the ankle test. The heel is supported.

**Instructions to patient** – Ask patient to flex, extend then flex toes without moving ankle or knee. For example: “Curl all your toes down, then up then down again while I support your leg. I will take you through the motion first, then I’d like you to do it yourself.”
SCALE: Selective Control Assessment of the Lower Extremity
Instructions for Grading

Each joint is scored either 2, 1 or 0 points. These are summed for a Total Limb Score. The number of points for each grade is in parentheses. For each joint, check the joint score and all applicable descriptors on the SCALE Score Sheet.

Hip
Normal (2) Flexes, extends then flexes again. During flexion, movement occurs without knee flexion, within a three-second verbal count and without mirror movement (the same movement on the contralateral limb). If alternate hip extension test is used, extends, flexes then extends again. During extension, movement occurs without knee extension, within a three-second verbal count and without mirror movement.
Impaired (1) One or more of the following occur: extends or flexes ≤ 50% of available range of motion in the test position, performs task slower than three-second verbal count, exhibits mirror movements, movement occurs in only one direction or motion at untested joint occurs.
Unable (0) Does not flex or extend hip or does so only with simultaneous knee movement.

Knee
Normal (2) Extends, flexes and extends again. Movement occurs within three-second verbal count, without motion of the trunk or other joints and without mirror movement. A Normal grade may be given if the knee extends > 50% of available range of motion in the test position.
Impaired (1) One or more of the following occur: extends ≤ 50% of available range of motion, performs task slower than three-second verbal count, exhibits mirror movements, movement occurs in only one direction or motion at untested joint occurs.
Unable (0) Does not extend or only extends with simultaneous hip or ankle movement.

Ankle
Normal (2) Dorsiflexes, plantar flexes and dorsiflexes again. Movement occurs within a three-second verbal count, without motion at other joints and without mirror movement. At least 15° of ankle motion in the sagittal plane must be observed.
Impaired (1) One or more of the following occur: dorsiflexes ≤ 50% of available passive range of motion in the test position or active range during Limb Flexion Synergy, performs task slower than three-second verbal count, exhibits mirror movements, movement occurs in only one direction or motion at untested joint occurs. An “Impaired” grade is given if the motion is accompanied by toe extension or ankle inversion.
Unable (0) Does not dorsiflex or only dorsiflexes with hip and knee flexion.

Foot/Subtalar Joint
Normal (2) Inverts, everts and inverts again. Movement occurs within a three-second verbal count, without motion at other joints and without mirror movement. Active eversion must occur.
Impaired (1) One or more of the following occur: inverts or everts ≤ 50% of available range of motion, performs task slower than three-second verbal count, exhibits mirror movements, movement occurs in only one direction or motion at untested joint occurs.
Unable (0) Does not invert or evert or movement occurs only in synergy pattern. May dorsiflex, plantar flex or not move ankle at all.

Toes
Normal (2) Flexes, extends and flexes again. Movement occurs within a three-second verbal count, without motion at other joints and without mirror movement. Motion should occur at all five toes.
Impaired (1) One or more of the following occur: flexes or extends ≤ 50% of available range of motion, performs task slower than three-second verbal count, exhibits mirror movements, movement occurs in only one direction or motion at untested joint occurs.
Unable (0) Does not flex or extend toes.

Difference between Unable and Impaired
Unable (total synergy) has simultaneous movement at two or more joints. For every degree of motion at the desired joint, concomitant obligatory motion that is a part of the synergy pattern occurs at another joint in the limb. Patients with impaired motor control may be able to move the desired joint through a small arc of motion without any other joint motion, however a portion of the motion is accompanied by motion at an adjacent joint.

Difference between Impaired and Normal
Normal motor control is the ability to isolate joint motion through more than 50% of the available ROM within a three-second verbal count in an alternating fashion. The motion occurs without accompanying motion at any other joints of either limb. The inability to perform this task is impaired.
Selective Control Assessment of the Lower Extremity (SCALE): development, validation, and interrater reliability of a clinical tool for patients with cerebral palsy

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PUBLICATION DATA
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LIST OF ABBREVIATIONS
CST Corticospinal tract
ICC Intraclass correlation coefficient
PWM Periventricular white matter
SCALE Selective Control Assessment of the Lower Extremity
SVMC Selective voluntary motor control

ACKNOWLEDGMENTS
We acknowledge statistical consultation from Jeffrey Gornbein, and contributions from Beth Trevino, Sarah Copeland, and Evan Goldberg. We thank all of the clinical experts and the volunteer patients and their families for their participation, and the Lena Longo Foundation and the Brianna Fund for financial support.

Normal selective voluntary motor control (SVMC) can be defined as the ability to perform isolated joint movement without using mass flexor/extensor patterns or undesired movement at other joints, such as mirroring. SVMC is an important determinant of function, yet a valid, reliable assessment tool is lacking. The Selective Control Assessment of the Lower Extremity (SCALE) is a clinical tool developed to quantify SVMC in patients with cerebral palsy (CP). This paper describes the development, utility, validation, and interrater reliability of SCALE. Content validity was based on review by 14 experienced clinicians. Mean agreement was 91.9% (range 71.4–100%) for statements about content, administration, and grading. SCALE scores were compared with Gross Motor Function Classification System Expanded and Revised (GMFCS-ER) levels for 51 participants with spastic diplegic, hemiplegic, and quadriplegic CP (GMFCS levels I – IV, 21 males, 30 females; mean age 11y 11mo [SD 4y 9mo]; range 5–23y). Construct validity was supported by significant inverse correlation (Spearman’s r = -0.83, p < 0.001) between SCALE scores and GMFCS levels. Six clinicians rated 20 participants with spastic CP (seven males, 13 females, mean age 12y 3mo [SD 5y 5mo], range 7–23y) using SCALE. A high level of interrater reliability was demonstrated by intraclass correlation coefficients ranging from 0.88 to 0.91 (p < 0.001).

Children with spastic cerebral palsy (CP) exhibit multiple impairments that contribute to functional motor deficits. Although spasticity and contractures may be more obvious impairments, underlying deficits in selective motor control can negatively affect function to a greater degree. 1,2 Assessment of selective motor control in lower extremities in patients with CP has received little attention, despite growing support for it as a predictive factor of functional ability. 1,3–4

Selective motor control has been defined as ‘... the ability to isolate the activation of muscles in a selected pattern in response to demands of a voluntary movement or posture.’ 5 The term ‘selective voluntary motor control’ (SVMC) differentiates the deliberate performance of isolated movements upon request from habitual selective muscle activation during functional tasks, such as walking. Voluntary movement is produced through the corticospinal tracts (CSTs), which control both directionality and force production. 6 Damage to the CSTs interferes with the force, speed, timing, and pattern of volitional movements. 7 Injury to CSTs within the periventricular white matter (PWM) has been correlated with motor disability in CP. 8 Damage to PWM was the most common finding in brain scans of children with spastic diplegia, and was
Evidence of SVMC impairment in CP has been shown. Timing errors in muscle recruitment during attempted maximal voluntary contractions exemplify the inability to recruit an individual muscle group selectively without inappropriate antagonist muscle activity. In addition, simultaneous associated movements at contralateral joints, for example mirror movements, have been described. Mass patterns of flexion and extension, which have historically been referred to as ‘synergies,’ are seen in the absence of SVMC. In patients with CP, these flexor and extensor patterns of the lower extremities are described as persistence of the immature patterns observed during typical infant kicking and stepping. Tightly coupled hip, knee, and ankle movements occur in term and preterm infants with and without damage to white matter. These movements become disassociated or uncoupled over time in infants without brain lesions, but persist in preterm infants with damage to white matter. These mass movement patterns are observed and have been measured using electromyography during gait and voluntary movement in children and adults with CP.

Clinical examinations of SVMC in children with CP have been described, but a detailed tool to evaluate the entire lower limb has not been validated. Assessments vary as to the joint(s) tested, positions used, task(s) required, and grading criteria. Staudt and Peacock used SVMC as a prognostic factor when selecting candidates for selective posterior rhizotomy. These examination methods were further developed by Fowler et al. as a measure of severity to select and categorize participants in a randomized controlled trial. Grading was limited to knee and ankle joints with an overall limb classification of ‘good’, ‘fair’, or ‘poor’ SVMC. Mirror movements, reciprocation, and speed were not considered. Boyd and Graham introduced a 0- to 4-point scale to assess ankle dorsiflexion after botulinum toxin injections of the plantar flexors. Examiners were required to identify visually which muscles were the primary or secondary movers. This test was called ‘selective motor control of dorsiflexion’. Others have described it as a measure of CST function, although SVMC does not appear to be the primary focus. Specific muscles used to achieve dorsiflexion took precedence over the use of mass patterns in the scoring. Although others have graded mass limb flexion during dorsiflexion as the lowest level of SVMC, this test graded total limb flexion higher than recruitment of accessory muscles (toe extensors). Substitution of toe extensors during dorsiflexion may occur in the presence of plantar flexor contractures or tibialis anterior weakness and may not indicate SVMC impairment. Validation of the ‘selective motor control of dorsiflexion’ test could not be found in the literature, and a wide range of interrater reliability was reported. Valid and reliable tests have been developed for assessment of recovery stages in adults after stroke, but they are not ideal for patients with CP. Administration includes practice on the ‘non-affected side’ and testing in standing, which limits applicability for patients with bilateral lower-extremity involvement and interferes with observation of mirroring.

A valid, reliable assessment method that has clinical utility is needed for SVMC assessment of the entire lower extremity in patients with spastic CP. The purpose of this paper is to describe the development of a clinical tool entitled Selective Control Assessment of the Lower Extremity (SCALE) and present evidence of its validity and interrater reliability.

**METHOD**
Participants were individuals with spastic CP and clinicians. Clinicians participating in content validation were recruited from physical therapy clinics, hospitals, and universities. Participants with CP were recruited from the UCLA/Orthopaedic Hospital Center for Cerebral Palsy. The institutional review board at this institution approved the study. Informed consent was obtained from all participating clinicians, and informed assent/consent was obtained from all participants with CP and/or their parent or legal guardian.

**The SCALE tool**
The SCALE tool was designed for clinical administration and scoring by healthcare professionals, to be used in less than 15 minutes without specialized equipment. The tool includes ‘Directions for Administration,’ ‘Instructions for Grading,’ and a ‘Score Sheet.’ Hip, knee, ankle, subtalar, and toe joints are assessed bilaterally. One representative reciprocal movement that varies from the mass flexor/extensor patterns is chosen to assess SVMC for each joint. Evaluations are performed in the sitting position, except for hip flexion, which is tested in the side-lying position to allow for adequate joint excursion. Sitting and side-lying positions allow evaluation of patients who are unable to stand, permit observation of contralateral limb movements, and enable the patient to visualize their limb in case of proprioceptive deficits. The following factors were used to develop the assessment and grading criteria: (1) ability to move each joint selectively; (2) involuntary movement at other joints including the contralateral limb; (3) ability to reciprocate movement; (4) speed of movement; and (5) generation of force as demonstrated by excursion within the available range of motion. These were based on components of CST function described in the lit-
rature7 and methods of motor control assessment that have been used historically.12,21

For each joint, the examiner first demonstrates the task by passively moving the limb through the desired movement sequence using a three-second verbal cadence. The approximate passive range of motion is noted for comparison with the observed range during the patient’s active effort. The patient is then asked to perform the desired motion at approximately the same speed without moving other joints of the extremity being tested or the contralateral limb. If unsuccessful, feedback is provided and additional attempts are allowed.

The hip assessment is performed with the patient in side-lying position. The examiner supports the weight of the limb but does not assist the movement. The patient is asked to flex, extend, and flex the hip while maintaining the knee in extension. This movement pattern was chosen over hip extension because it was easier for patients to perform as they could easily visualize their limb. For patients with severe hamstring tightness, the ability to extend the hip with the knee flexed can be used as an alternative test.

The remainder of the assessment is performed in the sitting position. The patient is asked to perform the following movement patterns: knee extension and flexion; ankle dorsiflexion and planar flexion with the knee extended; subtalar inversion and eversion; and toe flexion and extension in a reciprocating pattern to a verbal cadence (e.g. ‘flex, extend, flex’). SVMC is graded at each joint as ‘Normal’ (2 points), ‘Impaired’ (1 point), or ‘Unable’ (0 points).

A grade of ‘Normal’ is given when the desired movement sequence is completed within the verbal count without movement of untested ipsilateral or contralateral lower extremity joints. A grade of ‘Impaired’ is given when the patient isolates motion during part of the task, but demonstrates any of the following errors: movement occurs in only one direction; observed movement is less than 50% of the approximate available passive range of motion found during the passive demonstration; movement occurs at a non-tested joint (including mirror movements); or the time for execution exceeds the approximate 3-second verbal cadence. A grade of ‘Unable’ is given when the requested movement sequence is not initiated or when it is performed using a synergistic mass flexor or extensor pattern. A synergistic mass movement pattern is defined as a simultaneous, obligatory flexor or extensor pattern at two or more joints.21,24 If the patient does not initiate the requested movement sequence, extensor and flexor synergy patterns may be elicited using manual resistance to verify muscle force-generating capacity. A SCALE score for each limb is obtained by summing the points assigned to each joint for a maximum of 10 points per limb.

Content validity

Content validity is ‘... the extent to which a measure is a complete representation of the concept of interest’ and is established by evaluation of the instrument by knowledgeable peers.25 Content validity of the SCALE tool was established using written feedback from 14 expert clinicians. Expert clinicians were defined as those having 10 or more years of experience in evaluating patients with CP (experience range 10–40y, mean: 21y 2mo). They included 12 physical therapists, one occupational therapist, and one physician. Clinicians participated in an educational session that included an overview of test administration using videos or photographs of patients. They were provided with written procedures and the prototype SCALE tool. Participants were given an opportunity to ask questions and completed a written feedback form containing 32 statements about the tool design (Table I). For each statement, participants were asked to check ‘agree’, ‘disagree’,

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<th>Statements rated for overall test (five statements)</th>
<th>Statements rated for grading (seven statements)</th>
<th>Statements rated for each of five tests: hip, knee, ankle, subtalar, and toe joints (20 statements)</th>
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<td>1. The position used is optimal for assessment of the desired motion.</td>
<td>1. The speed is appropriate (within three-second verbal cadence).</td>
<td>Each of 32 statements was rated as Agree, Disagree, or Undecided</td>
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<td>2. The instructions for the patient are clear.</td>
<td>2. The range of motion required for the tests is appropriate to adequately differentiate between scores of Normal, Impaired, and Unable.</td>
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<td>3. The criteria are clear to adequately differentiate between scores of Normal, Impaired, and Unable.</td>
<td>3. The criteria are clear to adequately differentiate between scores of Normal, Impaired, and Unable.</td>
<td>Statements rated for grading (seven statements)</td>
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<td>4. The grades Unable and Impaired are clearly distinguishable.</td>
<td>4. The grades Unable and Impaired are clearly distinguishable.</td>
<td>Statements rated for each of five tests: hip, knee, ankle, subtalar, and toe joints (20 statements)</td>
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<td>5. The descriptions provided to elucidate the difference between grades of Unable and Impaired are adequate.</td>
<td>5. The descriptions provided to elucidate the difference between grades of Normal and Impaired are adequate.</td>
<td>Statements rated for each of five tests: hip, knee, ankle, subtalar, and toe joints (20 statements)</td>
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<td>6. The grades Normal and Impaired are clearly distinguishable.</td>
<td>6. The grades Normal and Impaired are clearly distinguishable.</td>
<td>Statements rated for overall test (five statements)</td>
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<td>7. The descriptions provided to elucidate the difference between grades of Normal and Impaired are adequate.</td>
<td>7. The descriptions provided to elucidate the difference between grades of Normal and Impaired are adequate.</td>
<td>Statements rated for overall test (five statements)</td>
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<td>1. The order of test administration is appropriate.</td>
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<td>2. The inclusion of a resisted flexor synergy pattern is needed or useful.</td>
<td>2. The inclusion of a resisted flexor synergy pattern is needed or useful.</td>
<td>Statements rated for overall test (five statements)</td>
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<td>3. The inclusion of a resisted extensor synergy pattern is needed or useful.</td>
<td>3. The inclusion of a resisted extensor synergy pattern is needed or useful.</td>
<td>Statements rated for overall test (five statements)</td>
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<td>4. The Total Limb Score is needed or useful.</td>
<td>Statements rated for overall test (five statements)</td>
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<td>5. The Total Limb Score categories are appropriately distributed.</td>
<td>5. The Total Limb Score categories are appropriately distributed.</td>
<td>Statements rated for overall test (five statements)</td>
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or ‘undecided’. If they disagreed or were undecided, they were asked to provide an explanation and suggest changes. The frequency of each response was obtained for all statements. A minimum of 90% ‘agree’ responses was set for the content covered in each statement to be accepted without amendments to the SCALE tool. Amendments to the preliminary version of SCALE were made based on expert feedback.

**Interrater reliability**

The interrater reliability of clinical administration and scoring of SCALE was performed by two groups of three trained raters for 20 participants with spastic CP. The six raters included three physical therapists, one pediatrician, one pediatric neurologist, and a pediatric orthopedic surgeon with a range of 1 to 29 years of experience in assessing patients with CP. Standardized training on the administration and scoring of SCALE was provided. To participate as a rater, clinicians were required to score 20 videotaped examples (four for each of the five joints) with an accuracy of 90% or higher and demonstrate appropriate test procedures during a practice examination.

To minimize potential patient fatigue, consecutive assessments were limited to three. Therefore, the six clinicians were divided into two teams (A and B), each containing three raters. Team A raters performed SCALE examinations on 10 participants with CP, and Team B examined 12 (Table II). The raters assessed the patients in random order and there was no communication among them about scores. Intraclass correlation coefficients (ICCs) and corresponding 95% confidence intervals (CIs) were calculated for the SCALE scores obtained for left and right limbs separately for each team.

**Construct validity**

According to Sim and Arnell,26 ‘... evidence of construct validity can be gained by seeking a positive correlation between measures of the original concept and those of other concepts to which the original concept is known to be positively related.’ Construct validity of SCALE was evaluated by determining the relationship between SCALE scores and an independent assessment of function using the expanded and revised edition of the Gross Motor Function Classification System (GMFCS-ER).27,28 This is a five-level system that stratifies the severity of mobility impairment up to the age of 18 years. Level I represents the highest level of mobility, and level V the lowest. For participants aged 19 years and older, the 13- to 18-year-old age band was used to determine the level. Although SCALE and the GMFCS measure different aspects of a patient’s disability, individuals with higher SCALE scores would be expected to have less overall impairment of lower extremity function, resulting in a higher mobility level (indicated by a lower GMFCS level).

Fifty-one individuals with spastic CP in GMFCS levels I to IV, participated (Table III). Ten individuals with CP at GMFCS level V were screened for participation, but none were enrolled owing to one or more of the following factors: diagnosis of dyskinetic or mixed spastic/dyskinetic CP; inability to consent to participate; or inability to follow a simple motor direction. The SCALE assessment was administered by one of two experienced therapists who participated in the interrater reliability trials. Right and left

<table>
<thead>
<tr>
<th>Table II: Characteristics of participants for interrater reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total</strong> (n=20)</td>
</tr>
<tr>
<td><strong>Age (y:mo)</strong></td>
</tr>
<tr>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Range</td>
</tr>
</tbody>
</table>

| **Sex (n)** | | |
| Female | 13 | 6 | 9 |
| Male | 7 | 4 | 3 |

| **Distribution of impairment (n)** | | |
| Diplegia | 16 | 11 | 5 |
| Hemiplegia | 3 | 1 | 2 |
| Quadriplegia | 1 | 1 | 0 |

| **GMFCS level (n)** | | |
| I | 3 | 1 | 2 |
| II | 6 | 4 | 3 |
| III | 8 | 3 | 4 |
| IV | 3 | 2 | 1 |

*Two participants were evaluated by both teams of raters. GMFCS, Gross Motor Function Classification System.

<table>
<thead>
<tr>
<th>Table III: Characteristics of participants for construct validity (n=51)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y:mo)</strong></td>
</tr>
<tr>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Range</td>
</tr>
</tbody>
</table>

| **Sex (n)** | | |
| Female | 30 | 30 |
| Male | 21 | 21 |

| **Distribution of impairment (n)** | | |
| Diplegia | 35 | 35 |
| Diplegia with hemiplegic overlay | 5 | 5 |
| Hemiplegia | 6 | 6 |
| Quadriplegia | 5 | 5 |

| **GMFCS level (n)** | | |
| I | 10 | 10 |
| II | 12 | 12 |
| III | 19 | 19 |
| IV | 10 | 10 |

GMFCS, Gross Motor Function Classification System.
SCALE scores were summed for each participant as an overall representation of lower extremity SVMC ability for comparison with GMFCS levels. Spearman’s rank correlation coefficients were computed to examine the relationship between the scores. All statistical analyses used JMP version 6.0 (SAS, Cary, NC, USA) and SPSS version 15.0, (SPSS, Chicago, IL, USA).

RESULTS

Content validity

Responses from expert clinicians were tabulated and the percentage agreement was determined for each statement individually and for the total group of responses. Of the total of 448 potential responses from all clinicians, 18 (4%) were blank and not included in subsequent analyses. There were 395 responses indicating ‘agreement’ with the tool (91.9%; range 71.4–100%; Table IV).

Twenty-four of the 32 statements rated by the experts met the 90% agreement criterion and no change was made to the corresponding items on the SCALE tool. To meet the 90% criterion, there could be no more than one ‘undecided’ or ‘disagree’ response. Eight of the 32 statements did not reach our minimum of 90% agreement (Table IV). For these statements, at least two experts responded with either ‘undecided’ or ‘disagree’. ‘Undecided’ was chosen more frequently than ‘disagree’ (16 responses versus 5). Explanations and suggestions associated with these statements were critically examined and modifications to the SCALE tool were made.

No suggestions or explanations were offered for statements related to position or grading for testing at the knee; therefore the associated SCALE items were not revised. Some experts recommended that additional assessment of hip extension with knee flexion be included. We chose only one movement sequence per joint to limit complexity and time requirements of SCALE. The option for use of an alternative hip extension test was clarified in the ‘Directions for Test Administration.’ Two experts questioned the examiner’s support of the limb during the hip test. Although use of a device such as a powder board would eliminate potential examiner influence, it is not practical in most clinical environments. Use of a supported standing position was suggested, but not implemented, because it would preclude use of the tool for severely affected patients and would interfere with observation of mirroring. Concern was expressed that the target population might not comprehend the ankle movement sequence instructions, so the patient instructions were simplified and made more universally understandable. We clarified that the script is suggested rather than mandatory, and that modifications may be made to elicit optimum performance. Although some experts checked ‘undecided’ or ‘disagree’ for inclusion of resisted flexor and extensor synergy patterns, others included strong written support of these components. Confirming the patient’s ability to move actively in the mass flexor/extensor patterns was considered to be an essential component of the clinical examination by the SCALE developers and several experts. Although two experts questioned the usefulness of a total limb score, one of them acknowledged its value for research. Experts commented on the overall clinical usefulness and ease of administration of SCALE. The revised SCALE tool incorporating all changes is presented in Appendix SI (supporting information, published online).

Interrater reliability

The reliability testing showed relatively high ICCs. ICCs and 95% CIs for the left and right limbs for both teams of

Table IV: Summary of expert responses

<table>
<thead>
<tr>
<th>Summary of responses to all 32 statements</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Blank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eight statements with less than 90% agreement:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip: The movements are appropriate to determine SVMC</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hip: Support or assistance given to patient is appropriate</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Knee: Position used is optimal to assess desired motion</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ankle: The instructions for the patient are clear</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Grading: ‘Unable’ and ‘Impaired’ are clearly distinguishable</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Inclusion of a resisted flexor synergy pattern is needed or useful</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Inclusion of a resisted extensor synergy pattern is needed or useful</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>The total limb score is needed or useful</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

SVMC, selective voluntary motor control.
raters are presented in Table V. ICCs ranged from 0.88 to 0.91 and all were significant at \( p < 0.001 \).

**Construct validity**

SCALE scores were significantly inversely correlated with GMFCS levels (Spearman’s rank correlation coefficient = −0.83, \( p < 0.001 \)). The mean SCALE score declined from 15.0 for participants at GMFCS level I to 3.1 for participants at GMFCS level IV (Fig. 1). SCALE scores showed a clear downward trend; however, scores for participants at GMFCS level III showed considerable overlap in range with participants at levels II and IV.

**DISCUSSION**

These results support content validity, construct validity, and interrater reliability of the SCALE tool. Content validity was substantiated by strong overall agreement among 14 expert clinicians and feedback was used for amendments and clarifications to the tool. Construct validity of SCALE was demonstrated by significant correlation with another severity measure, the GMFCS. Because SVMC is only one factor affecting functional mobility, a perfect correlation between these two assessments was not expected. Impairments such as balance, spasticity, contractures, bone and joint deformity, weakness, obesity, or de-conditioning are other contributing factors that may explain the wider range of scores obtained for patients requiring hand-held mobility devices for walking (GMFCS level III). For example, the individual with highest SCALE score within GMFCS level III (Fig. 1) had vision impairment. Although he could walk short distances without assistance, he routinely used a walker. The participant with the lowest SCALE score at GMFCS level III relied on good upper-body strength and was able to ambulate using a walker, despite lack of lower extremity SVMC. We found that SCALE assessment for individuals assigned to GMFCS level V was not feasible as most had a predominant motor disorder of dyskinesia rather than spasticity, and many were unable to follow motor commands.

Interrater reliability of clinical assessments was high among six raters representing four different clinical specialties with a wide range of experience. Not all differences among scores can be attributed to raters because performance of patients on repeat testing may vary with practice, boredom, or fatigue. Because of this, only three consecutive assessments were performed. Videotaped assessment could have been used to increase the number of raters assessing a single testing session; however, this study was designed to evaluate reliability of both administration and scoring as would occur in a clinical setting.

Clinical utility is supported by both expert assessment and high interrater reliability. SCALE is detailed yet simple enough for expedient examination of patients with a wide range of physical and intellectual impairments. It requires minimal training, can be performed within 10 to 15 minutes, and does not require equipment. Because the ability to follow simple motor commands is necessary, it is least suitable for patients under 4 years of age and those with severe motor and intellectual impairments (GMFCS V). Although scoring may not be possible for these patients, SVMC can be described based on observations of spontaneous movements. In our experience, patients classified at GMFCS level V were more likely to have dyskinesia, which SCALE was not designed to address. Although designed for use in CP, SCALE may be useful for assessment of patients with other types of neurological involvement such as hereditary spastic paraparesis, traumatic brain injury, multiple sclerosis, or stroke.

**CONCLUSION**

Evidence for construct and content validity is presented here as the first step in the validation of SCALE. Recent work has shown that SCALE scores are correlated with

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**Table V: Interrater reliability of SCALE**

<table>
<thead>
<tr>
<th>Group</th>
<th>Limb</th>
<th>ICC</th>
<th>95% CIs</th>
<th>( p ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Left</td>
<td>0.88</td>
<td>0.69, 0.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>A</td>
<td>Right</td>
<td>0.89</td>
<td>0.72, 0.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>B</td>
<td>Left</td>
<td>0.90</td>
<td>0.77, 0.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>B</td>
<td>Right</td>
<td>0.91</td>
<td>0.79, 0.97</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

SCALE, Selective Control Assessment of the Lower Extremity.
laboratory measures of intersegmental coordination during gait, further supporting its validity. This study demonstrated high interrater reliability of the SCALE total limb scores. Ongoing research is examining SVMC impairment at individual joints. Studies of intrarater, test–retest reliability, and long-term stability of SCALE scores are underway. SVMC assessment is believed to be most important for use as a prognostic indicator for treatment planning. As there is a wide range of responses to various treatments in this population of patients, SVMC ability may guide the selection of medical, surgical, or rehabilitative interventions. Introduction of SCALE should provide a meaningful and universal tool for clinicians and researchers.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SI: SCALE: Selective Control Assessment of the Lower Extremity.

This material is available as part of the online article from http://dx.doi.org/10.1111/j.1469-8749.2008.03186.x (this will link you directly to the article).

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REFERENCES


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**Book Review: Clinical Manual of Child and Adolescent Psychopharmacology**

Edited by Robert L Findling


$US 62.00 (Paperback), 497 pages

ISBN 978-1-58562-250-4

This timely book is an essential tool in the clinician’s fast changing therapeutic armamentarium. It is both small and useful enough to warrant being carried around by a practitioner as it is very relevant to all professionals who work with children and adolescents.

The book is organized into 10 chapters, with manageable sections designed to support evidence-based best practice. Compared with similar books, it is mid-range in price. It provides excellent value by demystifying the science underpinning cutting edge psychopharmacotherapy, whilst its ‘clinical pearls’ provide memorable take-home messages.

The experts cover developmental aspects vital in understanding fundamental differences between paediatric and adult psychopharmacology and common pitfalls in the area. The chapter on attention-deficit–hyperactivity disorder provides a timely overview of current potential safety concerns around stimulant prescribing. It does so in a very sensible manner. More emphasis on non-pharmacological interventions as adjuncts would have been welcome given more space. Disruptive behaviour disorders and aggression are considered in a holistic manner whilst reminding clinicians of the need for children and parents to be empowered to take personal responsibility. The anxiety and depression chapters helpfully cover combination treatments with cognitive behaviour therapy, as well as paediatric-specific research on suicidality. All of which will prove reassuring to prescribers and patients alike.

A chapter on bipolar disorders provides a very practical approach to managing adverse effects and deft handling of this potentially contentious area. Multimodal treatment research in the field of autistic spectrum disorders provides gratifying clarity with an excellent target symptom algorithm. Tic disorders and their common comorbidities are skilfully discussed.

The chapter dealing with schizophrenia and psychosis provides very practical management tips for side effects. Further discussion about metformin and statins as potential treatments for hyperglycaemia and hyperlipidaemia arising from atypical antipsychotics would also have been welcome.

The last chapter on disorders seen in general medical settings commends this book to a wider medical readership. It considers sleep disturbance, delirium, and a range of common medical conditions with psychiatric sequelae.

This comprehensive manual will empower practitioners to join up research with best practice. Thus it promotes both a more critical and a more thoughtful approach to intelligent prescribing.

Richard Soppitt MBCHB MRCPSYCH MMEDSC

Honorary Senior Research Fellow, CHSS, Canterbury, UK.
Lower-extremity selective voluntary motor control in patients with spastic cerebral palsy: increased distal motor impairment

EILEEN G FOWLER | LORETTA A STAUDT | MARCIA B GREENBERG

AIM Multiple impairments contribute to motor deficits in spastic cerebral palsy (CP). Selective voluntary motor control (SVMC), namely isolation of joint movement upon request, is important, but frequently overlooked. This study evaluated the proximal to distal distribution of SVMC impairment among lower extremity joints.

METHOD Using a recently developed tool, the Selective Control Assessment of the Lower Extremity (SCALE), we evaluated the SVMC of the hip, knee, ankle, subtalar joint, and toes in a cross-sectional, observational study of 47 participants with spastic, diplegic, hemiplegic, and quadriplegic CP (22 males, 25 females; mean age 11y 9mo, SD 4y 8mo; Gross Motor Function Classification System levels I–VI).

RESULTS Statistically significant decreases in SCALE scores from hip to toes were found using the Page statistical test for trend (p<0.001). Statistically significant differences (p<0.05) were found between all joint pairs, except toes versus subtalar, toes versus ankle, and right ankle versus subtalar joints. Cross-tabulation of score frequencies for all pairs revealed that proximal joint scores were higher or equal to distal ones 81 to 100% of the time. Excluding toes versus subtalar joints, proximal scores exceeded distal ones 94 to 100% of the time.

INTERPRETATION We confirmed increasing proximal to distal SVMC impairment, which may have implications for treatment and research.

Individuals with cerebral palsy (CP) have limitations in motor function resulting from multiple impairments including spasticity, contractures, weakness, and diminished selective motor control. Selective motor control has been defined as ‘... the ability to isolate the activation of muscles in a selected pattern in response to demands of a voluntary movement or posture.’

Selective voluntary motor control (SVMC) describes the performance of specific isolated joint movements upon request, as opposed to the habitual activation of selected muscles during functional tasks. SVMC at the ankle is a strong predictor of functional movement ability in children with CP, and SVMC has been used as a prognostic factor in selecting candidates for selective posterior rhizotomy. We recently reported the development, validity, and reliability of the Selective Control Assessment of the Lower Extremity (SCALE). SCALE is a clinical tool designed to assess SVMC of the entire lower extremity by summing the scores for five joints (hip, knee, ankle, subtalar joint, and toes).

Voluntary isolated joint movements require activation of the corticospinal tracts (CSTs). In patients with CP, damage to these tracts commonly occurs in the periventricular area. Damage to the periventricular white matter is the most frequent abnormal magnetic resonance imaging (MRI) finding associated with the spastic diplegic form of CP and it is found in more than one-third of those with hemiplegia and quadriplegia. Strong correlations between damage to the CSTs and motor impairment have been reported for children with CP.

The CSTs have a specific anatomical arrangement as they descend from the motor cortex to the spinal motor neuron pools. In the periventricular area, motor fibers leading to the lower extremities are more likely to be damaged than those supplying the upper extremities because of their more medial position. This anatomical relationship has been confirmed in recent studies using MRI tractography. The somatotopic organization of the lower extremity in the sensorimotor cortex suggests that distal lower-extremity tracts are closer to the ventricle and more vulnerable than those of proximal lower-extremity muscles (Fig. 1).

Evidence exists of increased distal impairment of lower-extremity motor function in children with spastic CP, but studies specifically examining the relationship between SVMC of proximal compared with distal lower-extremity joints have not been reported. Tedroff et al. evaluated the temporal sequence of muscle recruitment during maximal voluntary contractions in patients with
hemiplegic and diplegic CP compared with participants without disability. Inappropriate activation of non-agonists before agonists was more prevalent in distal than proximal musculature in children with CP. During gait, Wakeling et al.\(^4\) reported that disordered muscle firing occurred more frequently in distal than proximal musculature in children with spastic diplegia. In addition, greater muscle weakness has been quantified at the ankle joint than at more proximal joints.\(^{15-17}\)

The aim of this study was to analyse the distribution of SVMC scores among lower-extremity joints in patients with spastic CP using the SCALE tool. We hypothesized that SVMC impairment would be greater in distal than proximal joints.

**METHOD**

This cross-sectional, observational study was approved by the University of California, Los Angeles, institutional review board. All participants with CP, or their parent or legal guardian, provided informed assent and consent. Forty-seven individuals with spastic CP who attended the UCLA/Orthopaedic Hospital Center for Cerebral Palsy interdisciplinary clinic in Los Angeles volunteered to participate. Consecutive individuals who met inclusion criteria were invited to enroll. It was important to include participants across the spectrum of severity, based on Gross Motor Function Classification System (GMFCS) level. There were a minimum of nine participants representing each GMFCS level (I–IV). Previous work revealed that the SCALE assessment could not be performed for patients at GMFCS level V.\(^2\) This sample size was considered sufficient, based on previous work showing significant correlation between GMFCS levels and SCALE scores for 51 participants.\(^2\) Participant characteristics are presented in Table I. The following inclusion criteria were used: (1) diagnosis of spastic CP, (2) ability to follow simple directions, and (3) age between 4 and 25 years. The following exclusion criteria were used: (1) history of lower-extremity musculotendinous transfer or joint fusion, (2) neurosurgical or musculoskeletal surgery within the past year, (3) initial placement of baclofen pump within the past year, (4) botulinum toxin injections within 5 months, or (5) musculoskeletal injury within the past month.

One of three experienced raters performed the SCALE assessment for the right and left lower extremity of each participant. These raters previously demonstrated a high level of interrater reliability with intraclass correlation coefficients ranging from 0.88 to 0.91.\(^2\) Each participant was asked to perform specific non-synergistic reciprocal movements and scores of unable 0, impaired 1, or normal 2 were assigned for the hip, knee, ankle, subtalar, and toe joints for each side.\(^2\) All tests were performed in the sitting position, with the exception of the hip test, which was performed side-lying with the limb supported by the examiner. The patient was asked to perform the following reciprocal movement patterns: (1) hip flexion and extension with the knee extended, (2) knee extension and flexion, (3) ankle dorsiflexion and plantarflexion with the knee extended, (4) subtalar inversion and eversion, and (5) toe flexion and extension. A normal score (2) was given when the participant demonstrated isolated reciprocal joint motion through at least 50% of the available passive range of motion within an approximately 3-second verbal count. Unable (0) was assigned if the participant could not move the joint or if the attempted movement occurred in a synergistic pattern (simultaneous one-to-one movement at two or more joints of the same limb). A grade of impaired (1) was given if one or more of the following occurred: (1) the range of active movement was less than 50% of the participant’s available passive range of motion, (2) movement occurred in only one direction, (3) the task was performed slower than a 3-second verbal count, (4) motion at untested joints occurred (including mirror movement of the opposite limb). (See Data S1, the SCALE Score Sheet, Directions for Administration, and Instructions for Grading, supporting information, published online.)

Individual joint SCALE scores were compared using non-parametric repeated measures methods (Friedman procedure); the corresponding test for trend (Page test)\(^18\) was computed to analyse the relation among joints from hip to toes for the left

<table>
<thead>
<tr>
<th>Table I: Participant characteristics (n=47)</th>
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</thead>
<tbody>
<tr>
<td><strong>Age (y:mo)</strong></td>
</tr>
<tr>
<td><strong>Mean (SD)</strong></td>
</tr>
<tr>
<td><strong>Characteristic (n)</strong></td>
</tr>
<tr>
<td><strong>Sex</strong></td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
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<td><strong>Distribution of impairment</strong></td>
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<td>Hemiplegia</td>
</tr>
<tr>
<td>Quadriplegia</td>
</tr>
<tr>
<td><strong>GMFCS-ER level</strong></td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
</tbody>
</table>

GMFCS-ER, Gross Motor Function Classification Scale, Expanded and Revised edition.
and right lower limbs. Additionally, score frequencies for all pairs of joints were cross-tabulated for the left and right sides. When the proximal joint score was equal to or greater than the distal joint, we called this proximal to distal concordance (PDC). The percentage of PDC was calculated for all combinations of joint pairs within each limb. One hundred per cent PDC indicated that distal joint scores never exceeded those of proximal joints. StatXact 8.0 (Cytel Inc, Cambridge, MA, USA) was used for statistical computations.

RESULTS
Mean SCALE scores showed greater SVMC impairment in distal than proximal joints bilaterally (Fig. 2). A statistically significant decrease in SCALE scores from hip to toes was found using the Page statistical test for trend \((p<0.001)\). Significant differences were found between all pairwise SCALE score comparisons involving the hip and the knee joints bilaterally. The left ankle scores were significantly different from all other joint scores except the toes. The right ankle joint scores differed from the hip and knee scores and showed a tendency toward a difference from the subtalar joint score \((p=0.065)\). Comparisons between scores for toes versus subtalar, and toes versus ankle, did not show a significant difference for either limb. Table II presents \(p\) values for all pairwise comparisons using the Friedman test. The percentage PDC for cross-tabulations of joint score frequencies ranged from 81 to 100\% (Fig. 3). Excluding comparisons between score frequencies for toes and subtalar joints, the percentage PDC was 94 to 100\% (Fig. 3). Distal joint scores exceeded proximal ones for only nine limbs (seven participants) when comparisons involving the toes were excluded.

DISCUSSION
To our knowledge, this is the first study to report SVMC of the hip, knee, ankle, subtalar, and toe joints in individuals with spastic CP. Our hypothesis of greater distal than proximal SVMC impairment within each limb was mostly confirmed.

Figure 2: Mean Selective Control Assessment of the Lower Extremity (SCALE) scores by joint for left and right lower extremities. A score of 0.0 indicates the participant was unable to isolate or used the full synergy pattern, 1.0 indicates impaired motor control, and 2.0 indicates normal isolated movement. Error bars represent one standard deviation (+ for left and – for right). a, significant differences for all joint pairs on both left and right \((p<0.05)\); b, left ankle score was significantly different from left hip, knee, and subtalar joint scores \((p<0.05)\); c, right ankle joint score was significantly different from right hip and knee \((p<0.05)\) and showed a tendency toward a difference from the subtalar joint score \((p=0.065)\). Specific \(p\) values for all joint pairs are given in Table II.

STJ, subtalar joint.

Table II: Comparison between SCALE scores for five joints on the right and left with individual \(p\) values (Friedman test) and overall trend (Page test)

<table>
<thead>
<tr>
<th>Joint comparison</th>
<th>Left (p) value</th>
<th>Right (p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip vs knee</td>
<td>0.023</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hip vs ankle</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hip vs subtalar joint</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hip vs toes</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee vs ankle</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee vs subtalar joint</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee vs toes</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ankle vs subtalar joint</td>
<td>0.023</td>
<td>0.065</td>
</tr>
<tr>
<td>Ankle vs toes</td>
<td>0.227</td>
<td>0.180</td>
</tr>
<tr>
<td>Subtalar joint vs toes</td>
<td>0.424</td>
<td>0.774</td>
</tr>
<tr>
<td>Overall trend</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Significant at \(p=0.023\) and \(p<0.001\). SCALE, Selective Control Assessment of the Lower Extremity.

These results support the concept of increased vulnerability of CSTs associated with distal lower-extremity musculature. Previous research examining muscle strength\(^{15-17}\) similarly found increased deficits in distal joints. Impaired SVMC may be associated with the observations reported in these studies. To determine the relative influence of muscle strength (force-generating capacity) and SVMC (neurological recruitment by CSTs) on movement production, both test positioning and the movement pattern requested must be examined. In designing the SCALE ankle assessment for isolated motion out of synergy, we positioned the knee in extension when requesting ankle dorsiflexion. To verify force-generating ability at the ankle, a flexor synergy pattern was elicited separately by resisting hip flexion and noting the active ankle dorsiflexion. This phenomenon has been referred to as the ‘confusion test’.\(^{19}\) Participants in the present study with an absence of SVMC at the ankle (a SCALE score of 0) could demonstrate active ankle dorsiflexion only when using the total flexor synergy pattern. Wiley and Damiano\(^{15}\) found greater ankle dorsiflexor strength
deficits when the knee was extended rather than flexed, demonstrating the influence of impaired SVMC. Although these investigators concluded that distal muscles were generally weaker than proximal muscles, the hip extensors were an exception, being weaker than the ankle muscles. As the SCALE hip test was performed in an antigravity side-lying position, minimizing the need for muscle force-generating capacity, we found that SVMC at the hip exceeded that found at the ankle.

Tedroff et al.\textsuperscript{13} reported that during maximal voluntary contractions, children with spastic CP more frequently activated a muscle other than the intended prime mover first, especially when the prime mover was a more distal muscle. These results are consistent with our findings of decreased ability to perform isolated joint motion distally. As Tedroff et al. did not specify whether the participants performed isolated joint motion out of synergy, and we did not record electromyograms, direct comparisons are limited.

Excluding comparisons involving the toes, PDC exceptions in our study were rare, and could have been caused by scoring errors or other factors affecting patient performance, such as

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**Figure 3:** Cross-tabulations of Selective Control Assessment of the Lower Extremity score frequencies for (a) left and (b) right lower-extremity joints showing the percentage proximal to distal concordance (PDC). Shaded zones indicate relationships that violated PDC because the distal joint scores exceeded the proximal joint scores. STJ, subtalar joint.
as impaired motor planning. Some exceptions to the PDC appeared to be related to the presence of either restricted range of motion or mirror movements. Contractures or severe spasticity can mask underlying SVMC. One 15-year-old participant with spastic diplegia (GMFCS level I) had a subtalar score of 2, whereas the more proximal ankle joint was scored 1, owing to restricted range of motion. As this study supports increased proximal SVMC, it is possible that this participant’s ankle would have been scored 2 if tested at a younger age, before contracture development. The higher score at the subtalar joint predicts greater functional improvement after contracture release than if the score were 1 or 0. This is one example of how SVMC assessment, particularly as part of a periodic evaluation for children with spastic CP during development, may be helpful in predicting the potential for functional improvement after a specific treatment.

Mirror movements are simultaneous, obligatory movements that occur at contralateral joints during active movement. In adults without disability, most CSTs are crossed; however, extensive ipsilateral tracts are normally present in early development. In hemiparetic CP, there is evidence that surviving contralateral tracts may be competitively displaced by persistent ipsilateral tracts20,21, which may be responsible for mirroring.22 Using the SCALE tool, a score of 1 is given at a joint when the same movement pattern is observed contralaterally. Mirror movements negatively affected the PDC in the less involved limb for some participants with asymmetrical CP. In particular, two participants with spastic hemiplegia could isolate movement of their ankle joint on their non-hemiplegic side, but received scores of 1 owing to mirror ankle movement on their hemiplegic side. Mirroring did not occur during subtalar joint testing on their non-hemiplegic sides, giving these limbs a score of 2 at the more distal joint. Although the presence of mirroring is more likely to reflect a primary pathology for the hemiplegic limb, we assigned the SVMC impairment for the limb being assessed, as it is movement of this limb that elicits the abnormal movement pattern and any resulting functional problems. The effects of obligatory mirror movements on functional lower-extremity motor tasks such as walking are unknown and require further study.

The most frequent exceptions to the PDC occurred when the toes were graded as 1 and the subtalar joint was graded as 0, indicating absent subtalar SVMC with sparing at the toes. There are several possible explanations for these findings. One may be that the toes are not truly distal anatomically. Although the insertions of the toe musculature are more distal, the origin of muscles controlling the ankle, subtalar joint, and toes are similar. In addition, control of the subtalar joint appears to be more challenging than that of other joints. We observed that isolated motion of the subtalar joint was the most difficult movement sequence for participants with CP to understand and perform. Similar observations have been reported for patients after stroke. Eversion was described as a challenging movement in adults after stroke and is an indicator of the highest level of recovery for the lower extremity.23 Another possible explanation is that moving only one of multiple toe joints was sufficient to obtain a SCALE score of 1, reducing the relative potential for a score of 0 at the toes compared with the subtalar joint. Finally, there may be greater capacity for sparing of corticospinal fibers associated with toe movement owing to greater density of CSTs. In early mapping studies of the human motor cortex, the area of cortical representation for the great toe was exceeded only by the tongue, mouth, thumb, and fingers.8,9 More recent studies indicate that both toe musculature and tibialis anterior have a higher density of associated monosynaptic corticospinal projections than proximal lower-limb musculature.24

SVMC assessment and the proximal to distal distribution of impairment can be useful in treatment planning and in considering prognoses for the development of motor function in young children with CP. Based on the proximal to distal increase in SVMC impairment, patients who are assigned a score of 2 at the ankle or subtalar joint are more likely to have scores of 2 at the knee and hip. Although examining SVMC at the individual joint level can be helpful in treatment planning, the SCALE total limb score is more useful when describing a patient’s overall functional ability. For example, we have shown that SCALE total limb scores are significantly related to the performance of simultaneous hip flexion and knee extension, as normally occurs, during the terminal swing phase of gait.25

We believe this is the first systematic evaluation and comparison of SVMC among multiple lower-extremity joints in individuals with spastic CP. It confirms the increase in severity of impairment from proximal to distal joints. Although previous research supports greater impairment in distal muscles and joints, this phenomenon has received little attention. Anatomical and physiological mechanisms contributing to these findings require further study. Our results support selective vulnerability of the corticospinal tracts innervating distal musculature owing to their proximity to the ventricles. Although the participants in this study had a clinical diagnosis of spastic CP, damage to the periventricular white matter was not documented in this sample. Newer technologies allow documentation of precise damage to white matter tracts using MRI with diffusion tensor imaging. This may be useful in elucidating the relation between the injury and functional impairment; these studies are currently in progress.

SUPPORTING INFORMATION

Additional supporting information is available for this article online:

Data S1: The Selective Control Assessment of the Lower Extremity (SCALE), Score Sheet, Directions for Administration and Instructions for Grading.

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REFERENCES


