ORIGINAL ARTICLE

Development of a Position-Specific Index of Muscle Strength to be Used in Stroke Evaluation

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ABSTRACT. Moriello C, Mayo NE. Development of a position-specific index of muscle strength to be used in stroke evaluation. Arch Phys Med Rehabil 2006;87:1490-5.

Objective: To develop a position-specific index of muscle strength for individuals with stroke.

Design: Cross-sectional design.

Setting: A major teaching hospital in a Canadian urban city.

Participants: Sixty-three patients with poststroke onset between 3 and 12 months.

Interventions: Not applicable.

Main Outcome Measure: The muscle strength of the lower-extremity muscles was tested bilaterally in multiple positions using hand-held dynamometry.

Results: A principal components analysis resulted in grouping the muscles of the affected and unaffected sides of the gravity related and gravity eliminated positions into 5 indices. The 5 indices were moderately to highly correlated (r^2 range, .59−.81) with each other and so were combined into 1 global index. The gravity related muscle strength on the affected side was, on average, 85% of the unaffected side (range, 37%–157%); the gravity eliminated muscle strength of the affected side was, on average, 92% of the unaffected side (range, 53%–121%).

Conclusions: This study resolves the methodologic issue of how to summarize multiple data points that relate to one construct, namely, strength of different muscle groups assessed in several positions.

Key Words: Lower extremity; Muscles; Rehabilitation; Stroke.

MUSCLE WEAKNESS ARISING both from disuse and from upper motoneuron inhibition[1] is a common consequence of stroke[2,3] and is manifested by a complete or partial inability to generate force. The side of the body contralateral to the brain lesion (affected side) is predominantly weaker than the ipsilateral side (less affected side).[4] Commonly, muscle strength of the affected lower extremity is reduced from 23% to 90% of the strength on the less affected side.[5] However, recently evidence is emerging that muscle weakness also occurs on the less affected side.[4] Muscle strength is an important construct to study in stroke because strength is required for the performance of basic activities of daily living, such as walking and stair climbing.[6-8] Methods to assess muscle strength vary, such as isokinetic dynamometry, manual muscle testing, and hand-held dynamometry. With isokinetic dynamometry, the limb is maintained at a constant speed throughout the testing maneuvers and muscular torque is measured at different speeds (0°/s to 300°/s). There is a standard protocol to follow for each muscle group and, although accurate, this method of testing requires specialized expensive equipment and an extensive amount of training on the equipment.

Manual muscle testing is the most widely used technique for assessing muscle strength in a clinical setting. There is a standard protocol for assessment of muscle strength. It is inexpensive, because equipment is not required; however, an extensive amount of training is required to obtain a reproducible assessment of muscle strength across time and across evaluators. A disadvantage of using this method is that muscle strength is rated on an ordinal scale rather than measured directly.

Hand-held dynamometry is another method of manually assessing muscle strength. It provides a measure in pounds or kilograms or newtons. The equipment is much more affordable than the isokinetic dynamometer. Training is required for use of this equipment; however, the training is more practice than technical. The disadvantage of using hand-held dynamometry in a stroke population is that standard protocols, such as described by Bohannon,[9] are not always applied and many clinicians revert to assessing patients in positions that are most convenient. Despite the disadvantages of using hand-held dynamometry, it seems to be the most appropriate method of assessing muscle strength in a clinical setting.

When hand-held dynamometry is used clinically, the strength of several muscle groups may be measured in several different positions. The amount of data accumulated as a result of muscle testing is often mystifying to clinicians because it is difficult to summarize strength for an individual when different muscles have been assessed in different positions. To condense these measures, a method to summarize strength may be useful. For the purposes of research, multiple measures render statistical analyses highly complex because of nonindependence of these measurements. Studies that have assessed the strength of the lower extremity, among persons with stroke, have presented results for 1 to 7 different muscles in 1 to 3 different positions, along with 1 to 3 trials.[5-8,10-27]

In studies of stroke recovery, strength can be either the outcome (dependent variable)[6,14,17,21,25] or the exposure (independent variable).[10-13,16,18-20,22,26] In both of these cases, the probability of finding an association increases with the number of associations tested; statistical methods available to deal with this problem, such as a Bonferroni adjustment, are very conservative and result in hypothesis testing at an overly small *P* value.[28] This type of correction for multiple comparisons increases the risk of a type II error and the study is likely to fail to reject the null hypothesis.

When strength is the outcome, the issue of multiple outcomes needs to be addressed statistically. There are numerous statistical methods for use with multiple outcomes; factor weights, *z* scores, average ranks, multivariate analysis of vari-

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ance and generalized estimating equations are available techniques.[29] In the rehabilitation literature, 2 methods predominate for creating global indices: factor weights and *z*-score transformation. Factor weights arising from a factor analysis or principal component analysis provide a weighting for each element that reflects the importance of that element to the global construct that is theoretically measured by the collection of elements. By using the factor weight, a linear combination of the weighted elements can be used as a method of deriving a global index of the construct. The *z*-score approach provides an estimate of how many standard deviations an individual's value on an element differs from the group mean for that element. This transformation expresses each element in the same units so that a global index can be created by simple addition. The *z*-score method is sample dependent and is useful for purposes of research. The factor weighting approach is more generalizable because the factor weightings from 1 sample could be applied to another sample provided the 2 samples are similar on important characteristics.[29] For example, factor weightings derived from a large population based sample of the U.S. general population are used to create 2 summary scales from 8 subscales of the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36). These factor weightings are applied when calculating individual scores for any patient using the SF-36.[30]

Other than the SF-36, few rehabilitation studies deal statistically with the issue of multiple outcomes. When assessing muscle strength, researchers have either selected only a few muscles to test or have used all of the muscle strength variables without considering their nonindependence. When numerous trials have been carried out for 1 muscle, strategies have been to take the best trial or an average. There have been studies that attempted to summarize muscle strength data,[8,14,24] but neither of the 2 above mentioned statistical methods was used. In the study by Chu et al,[14] the measures of strength for the muscles on 1 side of the body were summed. A study by Kim et al[24] performed a similar composite score in muscle strength, but they summed the change in muscle strength before and after an intervention for each side. Teixeira-Salmela et al[8] summed the muscle strength of both sides of the body together. This assumes that each muscle contributes equally to the global strength index, which may not be the case.

This issue of multiple rating of strength for a number of muscles in different positions is a feature common to all muscle testing methods; hence, a statistical way of summarizing this complex data would be helpful for research and clinically for summarizing strength in order to monitor change over time. Therefore the objective of this study was to develop a position-specific index of muscle strength to be used for assessing persons with stroke.

METHODS

Participants

A total of 63 persons with chronic stroke participated in this cross-sectional study. We recruited the subjects from among a pool of persons participating in 2 ongoing research studies; subjects were at least 3 months and no more than 1 year poststroke. The studies from which subjects were drawn excluded persons with cognitive deficits and receptive aphasia. For this substudy, subjects were eligible if they could walk independently for 10m with or without an aid, and were discharged from active rehabilitation. Subjects were excluded if they had any other neuromuscular conditions, failed a cardiology stress test, or, at the time of assessment, had uncontrolled hypertension (currently diagnosed as hypertensive and not on medications, or on medications but still hypertensive).

Main Outcome Measure

We assessed muscle strength using hand-held dynamometry with the Nicholas manual muscle tester.[a] The muscle testing was performed by the same evaluator (CM) for all subjects. Six muscle groups of the lower extremity were tested bilaterally using 3 trials of the hip flexors, hip extensors, knee flexors, knee extensors, ankle plantarflexors (gastrocnemius, soleus), and dorsiflexors. Muscle strength was assessed in a combination of gravity related positions, following a standardized protocol; each muscle group was tested against gravity, alternate against gravity, and with gravity eliminated positions. The intrarater reliability was high, ranging from .87 to .99. Table 1 provides details regarding subject positions. The break test method was used. The evaluator must push against the subject's limb until the maximal muscular effort is overcome and the joint gives way.[31] A total of 96 data points (16 different positions × 3 trials × 2 sides) were obtained for each person. The best score of the 3 trials was used for the analysis.

Data Analysis

We used basic descriptive statistics to describe the characteristics of the sample. Missing data arose because some persons were not comfortable in some of the testing positions. This occurred in less than 10% of the measures. In these circumstances values for the missing data elements were imputed using a linear regression model. For example, a regression equation was determined for the hip extensors in the against gravity, alternate against gravity, and gravity eliminated positions. If the subject's against gravity position was missing, it was imputed based on the linear relationship to the other 2 positions. This was performed for each group of muscles. For each muscle group, paired *t* tests were performed to assess if there were differences in strength between the different positions.

We used principal component analysis (PCA), with varimax rotation, to create a global index of strength. The goal of PCA is to summarize the patterns of correlations of the elements, to reduce the number of elements to a minimal number of factors.[32] It can be further defined as a linear combination of optimally weighted elements that explains a maximal amount of variance in the data set. There is the same number of principal components as elements, but ideally, the first principal component should explain at least 68% of the variability in the observed data.[32]

PCA yields eigenvalues, which reflect the amount of variance that is being accounted for by each component. Every variable contributes 1 unit of variance to the total variance of the data set. A component with an eigenvalue of greater than 1 means that the component is explaining a greater amount of variability than had been contributed by 1 other element. Therefore, components with an eigenvalue of 1 and greater are retained. Each element in the component receives a loading. The high loading elements, in a given component, will tend to have something in common. These loadings are used to determine the weight that each element contributes for that component.[32]

RESULTS

A total of 76 persons were approached; 8 did not meet the eligibility criteria and 5 refused to participate. The average age of the sample was 67 years and 68% were men. Forty percent of subjects had right hemiparesis, 51% of subjects had left hemiparesis, and 9% had no hemiparesis. The average onset since stroke was 4 months. The average gait speed was .89m/s and distance walked was 277m on the 6-minute walk test

Table 1: Description of Muscle Testing Position

Muscle	Gravity-Related Position	Position	Patient Position	Dynamometer Placement	Direction of Resistance
Hip flexion	Against gravity	Sitting	Sit at edge of bed (allowed to grasp edge of the bed for stabilization). The leg being tested is in a hip flexed position (thigh lifted off the bed).	Anterior thigh proximal to the knee	Hip extension (as patient attempts to maintain flexion)
Hip flexion	Alternate against	Supine	Knees and hips flexed. Patient lifts leg (foot should be off bed, keeping knee and hips flexed).	Anterior aspect of thigh proximal to knee joint	Hip extension
Hip extension	Against	Standing over table	The leg not being tested is slightly in knee flexion. The leg being tested is in hip extension and knee extension.	Posterior aspect of the thigh proximal to the knee	Hip flexion (as patient attempts to maintain hip extension)
Hip extension	Alternate against	Prone	Extend hip, with knee held in extension.	Posterior aspect of thigh, proximal to knee joint	Hip flexion
Knee flexion	Against	Prone	Knee flexed (angle <90°).	Posterior aspect of the leg proximal to the ankle joint	Knee extension
Knee extension	Against	Sitting	Knees flexed at a 90° angle. The evaluator's arm is positioned under the thigh of leg being tested, so that the leg is supported on the evaluator's arm.	Anterior aspect of leg, proximal to the ankle	Knee flexion (as patient attempts to extend the knee)
Ankle plantarflexors (gastrocnemius)	Against	Prone	Knee extended with feet over edge of bed. Ankle in dorsiflexion.	Sole of foot near toes	Dorsiflexion
Ankle plantarflexors (soleus)	Against	Prone	Knee flexed at 90° and ankle dorsiflexed.	Sole of foot near toes	Dorsiflexion
Ankle dorsiflexion	Against	Sitting	Feet on the floor, with the ankle in dorsiflexion.	Dorsum of forefoot	Plantarflexion (as patient attempts to maintain dorsiflexion)
Hip flexion	Eliminated	Side lying	Hip extended and knee flexed. Evaluator supports the top leg.	Anterior aspect of the thigh	Hip extension (as patient attempts to flex the hip)
Hip extension	Eliminated	Side lying	Hip and knee flexed. The leg touching the bed is at maximal knee and hip flexion (for stabilization). The top leg is the leg being tested and is supported by the therapist. The hip is flexed and the evaluator passively flexes the knee.	Posterior aspect of thigh proximal to the knee	Hip flexion (as patient attempts to extend the hip)
Knee flexion	Eliminated	Side lying	Knee extended. Evaluator supports the leg.	Posterior part of the leg, proximal to ankle joint	Knee extension (as patient attempts to flex the knee)
Knee extension	Eliminated	Side lying	Hip anatomic position with knee flexed. Evaluator supports leg.	Anterior aspect of leg proximal to ankle	Knee flexion (as patient attempts to extend knee)
Ankle plantarflexion (gastrocnemius)	Eliminated	Side lying	Top leg in maximal flexion. Bottom leg being tested and is in knee extension and ankle dorsiflexion, with support from evaluator.	Sole of foot	Plantarflexion (as patient attempts to maintain dorsiflexion)
Ankle plantarflexion (soleus)	Eliminated	Side lying	Same as above but with the knee flexed.	Same as above	Same as above
Ankle dorsiflexion	Eliminated	Side lying	Knee is slightly flexed with ankle plantarflexed. Leg on bed is being tested. The lower leg is stabilized by the evaluator.	Dorsum of forefoot	Dorsiflexion (as patient attempts to maintain plantarflexion)

Table 2: Average Muscle Strength of 63 Subjects According to Side and Position of Testing

	Affected			Unaffected		
Muscle	Against	Alternate	Eliminated	Against	Alternate	Eliminated
Hip Flexor						
Mean	7.1±4.4	7.7±3.9	7.3±2.4	8.8±4.5	8.7±3.1	8.2±2.4
Range	1.4–22.8	0.8–18.8	2.5–14.2	3.4–21.3	3.7–16.9	4.2–16.5
Hip Extensor						
Mean	6.2±2.7	6.1±4.0	9.1±2.5	6.8±2.7	6.9±4.0	9.3±2.3
Range	1.6–13.7	1.4–20.1	4.8–15.6	1.8–15.3	1.2–19.0	5.4–15.7
Knee Flexor						
Mean	5.6±3.3		7.6±3.1	6.7±3.2		8.2±2.8
Range	0.7–16.5		1.6–17.7	1.8–16.0		3.4–19.0
Knee Extensor						
Mean	8.5±3.5		5.8±2.3	10.0±3.0		6.6±1.9
Range	0.4–17.0		2.3–11.8	3.6–16.5		3.1–11.2
Ankle PF-Gastroc						
Mean	7.2±3.2		9.4±2.9	9.2±3.4		11.4±2.2
Range	0.8–16.0		1.6–18.0	2.0–19.5		6.5–16.1
Ankle PF-Soleus						
Mean	5.9±2.9		7.3±2.7	7.1±2.8		8.7±2.1
Range	1.4–12.3		0.9–13.1	1.9–12.8		4.1–14.0
Ankle DF						
Mean	9.5±3.5		9.0±3.0	10.5±3.3		9.9±2.7
Range	3.0–18.1		1.8–16.7	4.9–20.0		3.9–18.7

NOTE. Values are mean kilograms ± standard deviation (SD) and range.
Abbreviations: DF, dorsiflexor; Gastroc, gastrocnemius; PF, plantarflexor.

(6MWT). The average Berg Balance Scale was 48 out of a score of 56.

The mean muscle strength for the 3 trials for each muscle group is presented in table 2, according to affected and unaffected side and position. The *t* tests comparing against gravity tests and alternate against gravity tests were not significant, except for the hip flexors on both sides. The *t* tests comparing against gravity tests to gravity eliminated tests were significant except for hip flexors on both sides and affected side ankle dorsiflexors.

For the tests in gravity related positions, a single factor for each side emerged with factor loadings ranging from .70 to .92. For the tests in gravity eliminated positions, 1 significant factor emerged for the affected side with factor loadings all around .80 except for dorsiflexion, which loaded more weakly on this factor (.59). For the unaffected side in gravity eliminated positions, 2 factors emerged, 1 for hip and knee, and 1 for the muscles of the ankle.

Based on these results, it is statistically justified to create 5 indices. Position-specific indices of muscle strength were created by weighting each muscle by the factor loading and adding them. Index 1 (affected gravity related) and index 3 (unaffected gravity related) include the muscle strength for the hip flexors and extensors in both the against gravity and alternate against gravity positions. Because it would not make sense to allow these muscle groups to contribute twice to the index and in a clinical setting, it is likely that only 1 of these positions would be chosen, index 1 was further divided into index 1a, which includes the muscle strength for the affected against gravity positions and index 1b, which includes the affected alternate against gravity positions of the hip flexors and extensors. The same is done for index 3, therefore resulting in a total of 7 different position-specific indices depending on which positions are used for muscle testing. Table 3 provides a summary of the indices that were developed. The average score, intercorrelations and factor loadings of the individual and the position-specific indices are provided in table 4. Essentially, for the affected side, the weights for the hip flexors and hip extensors in the against gravity and alternate against gravity positions are identical indicating that either of these positions could be used to assess a person with stroke. Therefore, to create index 1, the formula would be:

$$\begin{aligned}&.92 \times \text{hip flexors against } \textit{or} \text{ alternate}\\&\quad + .88 \times \text{hip extensors against } \textit{or} \text{ alternate}\\&\quad + .88 \times \text{knee flexors against} + .73 \times \text{knee extensors against}\\&\quad + .82 \times \text{gastrocnemius against} + .87 \times \text{soleus against}\\&\quad + .79 \times \text{dorsiflexors against.}\end{aligned}$$

Furthermore, the indices were found to correlate moderately to highly with each other (r^2 range, .51–.99), allowing for the 7 indices to be further analyzed using the PCA. The PCA resulted in 1 common factor, indicating that the 7 indices can be combined into 1 global index.

The gravity related muscles of the affected side, were, on average, 85% (index 1 / index 3) of the muscle strength of the unaffected side with a range from 37% to 157%, depending on position. In other words, the affected gravity related muscles are, on average, 15% weaker than the unaffected independent of testing position. The affected gravity-eliminated muscle strength was, on average, 91% (index 2 / index 4 + index 5) of the strength of the unaffected side (range, 53%–121%). The affected muscles perform slightly better in gravity eliminated positions because they are only 9% weaker on the affected side in comparison to the gravity related muscles that are 15% weaker.

DISCUSSION

This study addressed the methodologic issue of how to summarize multiple data points that relate to 1 construct, namely, strength of different muscle groups assessed in several positions. The statistical approach was a PCA and what emerged was that the 96 elements (16 different positions × 3 trials × 2

Table 3: Equations for Creating the Position-Specific Indices of Muscle Strength of the Lower Extremity

	Affected Side			Unaffected			
Muscle Loading	Index 1a	Index 1b	Index 2	Index 3a	Index 3b	Index 4	Index 5
Hip flexor against gravity	.92	NA	NA	.89	NA	NA	NA
Hip flexor alternate against	NA	.91	NA	NA	.88	NA	NA
Hip extensor against gravity	.88	NA	NA	.85	NA	NA	NA
Hip extensor alternate against	NA	.88	NA	NA	.89	NA	NA
Knee flexor against gravity	.88	.88	NA	.92	.92	NA	NA
Knee extensor against gravity	.73	.73	NA	.70	.70	NA	NA
Gastrocnemius against gravity	.82	.82	NA	.80	.80	NA	NA
Soleus against gravity	.87	.87	NA	.84	.84	NA	NA
Dorsiflexor against gravity	.79	.79	NA	.74	.74	NA	NA
Hip flexor gravity eliminated	NA	NA	.82	NA	NA	.84	NA
Hip extensor gravity eliminated	NA	NA	.82	NA	NA	.65	NA
Knee flexor gravity eliminated	NA	NA	.88	NA	NA	.81	NA
Knee extensor gravity eliminated	NA	NA	.82	NA	NA	.85	NA
Gastrocnemius gravity eliminated	NA	NA	.80	NA	NA	NA	.85
Soleus gravity eliminated	NA	NA	.82	NA	NA	NA	.62
Dorsiflexor gravity eliminated	NA	NA	.59	NA	NA	NA	.76

Abbreviation: NA, not applicable.
Legend: Index 1a, affected gravity related against; index 1b, affected gravity related alternate; index 2, affected gravity eliminated; index 3a, unaffected gravity related against; index 3b, unaffected gravity related alternate; index 4, unaffected gravity eliminated hip and knee; index 5, unaffected gravity eliminated ankle.

sides) could be summarized by 5 indices, 2 for the affected limb, and 3 for the unaffected limb. It can be further divided into 7 indices by separating the against and alternate against gravity muscle strength. For the affected side, index 1 summed the strength with the gravity related and either gravity position could be used interchangeably. Index 2 summed the gravity eliminated. Index 3 is a summary of the unaffected gravity related muscles. The gravity eliminated muscle strength of the unaffected side is separated into hip and knee (index 4) and ankle (index 5).

A second finding is that these indices could themselves be summarized into 1 global measure, a finding that is probably more relevant for research than for clinical practice. There are advantages of developing the indices. Therapists can decide which muscles to assess depending on the functional level of the persons assessed. For example, for persons with stroke who are not functional in the upright, against gravity, position, that is, in standing or walking, therapists could assess strength in the gravity-eliminated position and have a summary index of overall strength. For the unaffected side, the strength of the hip and knee can be considered together but strength of the ankle should be considered separately.

Another finding from this study is that the muscles tested contribute almost equally to the global index of muscle strength. It would follow that the assessment of any one muscle provides almost as much information as all of the muscles. Clinically, an evaluator could choose to assess, for example, only the strength of the quadriceps. However, it is known that different muscles are more or less implicated in different functional tasks,[31] so that the choice would be task-specific. Research identifying those muscles that are most implicated in specific tasks is needed. The global index approach provides a form of "screening" for the relationship between strength and functional task. If the global index is significant, identifying the specific muscles implicated in the task could be the subject of research investigation. This study provides a global index which could be used by other investigators interested in the link between specific muscles and functional tasks.

Two issues affect strength in different positions. In general, more force is generated in positions where gravity is eliminated because all of the motor units are used to generate force against the testing device, whereas with gravity some of the motor units are used to maintain the upright position. However, gravity eliminated positions are also less stable and so the tester

Table 4: Mean Score, Correlation, and Factor Loadings of Indices

		Correlation (*r*)							
Index*	Mean	1a	1b	2	3a	3b	4	5	Factor Loading
1a	41.4±16.9	1.00							.94
1b	41.6±17.3	0.99[†]	1.00						.95
2	43.5±11.9	0.90[†]	0.90[†]	1.00					.92
3a	48.4±15.9	0.87[†]	0.88[†]	0.82[†]	1.00				.96
3b	48.5±16.0	0.84[†]	0.86[†]	0.81[†]	0.99[†]	1.00			.95
4	25.2±6.1	0.74[†]	0.76[†]	0.80[†]	0.87[†]	0.87[†]	1.00		.88
5	22.2±3.9	0.56[†]	0.59[†]	0.60[†]	0.61[†]	0.60[†]	0.51[†]	1.00	.69

NOTE. Values are mean ± SD or as otherwise noted.
*Each index is created as outlined in table 3.
[†] $P<.001$.

must be vigilant in ensuring stability. Our data demonstrate the phenomenon of muscle force being lower when tested in the gravity related positions rather than the gravity eliminated, with the exception of the knee extensors. This is likely due to the difficulty of stabilizing the knee extensor in the gravity eliminated position.

The sample of this study is somewhat typical of patients with stroke at this stage, because the distance walked during the 6MWT is comparable to subjects participating in other studies.[33-35] The average gait speed of this sample was .89m/s and the average distance walked during the 6MWT was 277m. The average degree of weakness for the affected gravity related muscle strength was 15% and 9% for the gravity eliminated muscle strength in comparison to the unaffected side. The results and conclusions from this study can be generalized to the stroke population who have the capacity to walk up to a distance of 623m in 6 minutes.

CONCLUSIONS

Creating summary indices for muscle strength may be a statistically efficient way of dealing with multiple data points. Clinically, this method would also provide a way of providing a measure of strength of the entire lower limb at 1 or more points in time. This was a small study, so the factor loadings may not be stable, and therefore it would be important to repeat this method in other samples and eventually accumulate enough data to provide population muscle position-specific weights.

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Supplier

a. Model 01160; Lafayette Instrument, PO Box 5729, 3700 Sagamore Pkwy N, Lafayette, IN 47903.