Published in final edited form as:

Arch Phys Med Rehabil. 2012 August ; 93(8): 1395–1399. doi:10.1016/j.apmr.2012.03.005.

Optimizing Language for Stroke Motor Rehabilitation: Recommendations from the ACRM Stroke Movement Interventions Subcommittee

Stephen J. Page, Ph.D.¹ [Associate Professor], Arlene Schmid, Ph.D., OTR/L² [Assistant Professor], and Jocelyn Harris, Ph.D., OT³ [Assistant Professor]

¹School of Allied Medical Professions and Director of the Neuromotor Recovery and Rehabilitation Laboratory (the “RehabLab”) at the School of Health and Rehabilitation Sciences, College of Medicine, The Ohio State University Medical Center, Columbus, OH

²School of Health and Rehabilitation Sciences at Indiana University School of Medicine, Indianapolis, IN

³School of Rehabilitation Sciences at McMaster University

Abstract

As knowledge and interest in stroke motor rehabilitation continue to increase, consistent terminologies that are specific to this discipline must be established. Such language is critical to effective rehabilitative team communication, and is important to facilitating communication among the diverse groups interested in the science and practice of stroke motor rehabilitation. The purpose of this paper is to provide operational definitions for three concepts that are common - and commonly mislabeled - attributes of stroke motor rehabilitation interventions: intensity, duration, and frequency. In developing these guidelines, conceptual frameworks used in the pharmaceutical, exercise, and rehabilitative therapy realms were used. Implications of these definitions for research and clinical practice are also discussed.

In the last decade, interest in the science of neurorehabilitation has increased considerably. In the sub-discipline of stroke motor rehabilitation, similar growth has occurred, fueled by greater understanding of neuroplasticity in both animal¹ and human models,^{2,3} and by the prospect of response to rehabilitative interventions even years after ictus. Concurrently, an increased quality, diversity, and availability of tools that objectively measure in vivo biological processes accompanying behavioral changes (e.g., functional magnetic resonance imaging; transcranial magnetic stimulation) has become available. The advent of such objective measurement has generated new scientific questions, and increased understanding of the conditions under which motor therapies are most successful. Regardless of the reasons for its growth, the burgeoning interest in stroke motor rehabilitation is evidenced by the increasing number of published stroke rehabilitation trials, greater inclusion of such trials in a wider array of scientific journals, the genesis of special interest groups dedicated to the science of stroke motor rehabilitation, and increased attendance at meetings and interest groups targeting neurorehabilitation (e.g., joint, annual meeting of the American Congress of Rehabilitation Medicine/American Society of Neurorehabilitation; Rehabilitation Special Interest Section of the Society of Neuroscience’s annual conference).

While rehabilitation science is a relatively young discipline,⁴ stroke motor rehabilitation as a formal area of inquiry is even younger. Nonetheless, a large number of studies have shown the potent, widespread body system changes that co-occur with provision of stroke motor therapies. Specifically, in addition to increased movement capability, such regimens frequently elicit neural,⁵ motor behavior,^{6,7} peripheral,^{8,9} affective,^{10,11} and even cardiovascular adaptations.^{12,13} Other work¹⁴ suggests that stroke motor therapies can impact domains of function that are not primarily targeted, such as speech production. In short, stroke motor rehabilitation is a potent therapeutic agent impacting a myriad of body systems in addition to movement.

As stroke motor rehabilitation continues to grow as an area of scientific interest and its knowledge base continues to evolve, standards and terminologies specific to this area must be established. One method of accomplishing both outcomes is by applying established concepts and/or frameworks from other disciplines to this emerging sub-discipline. In this paper, we apply terminology commonly used in pharmaceutical and exercise research and practice to describe several aspects of stroke motor therapies. Specifically, the purpose of this paper is to provide operational definitions for three concepts that are common - and commonly mislabeled - attributes of stroke motor rehabilitation interventions: intensity, duration, and frequency. Implications of these definitions for research and clinical practice are also discussed.

There are several benefits to be gained from adopting the specific terminologies suggested in this paper. First, such language provides a method of framing unmet research areas in stroke motor rehabilitation, including dosing schedule (i.e., duration of treatment, frequency of treatment), purity of treatment, and delivery method. Such framing is necessary to operationalize concepts and will aid in investigations of the optimal calibration of stroke motor therapies with various impairments and etiologies. Secondly, the specificity proposed herein is critical to effective rehabilitative team communication. Finally, clinical and scientific initiatives in stroke motor rehabilitation are becoming increasingly interdisciplinary. A common language used by the diverse groups involved in stroke motor rehabilitation is fundamental to effective communication and collaboration.

Intensity

Background

Perhaps no other construct in the stroke motor rehabilitation literature has been referenced with greater variability than “intensity.” Most commonly, authors have used “intensity” to describe the length of time occupied by a single training session or a group of rehabilitative sessions. For example, in a series of important studies examining the stroke motor recovery trajectory, Kwakkel and colleagues^{15,16} operationalized “intensity” as the amount of therapist to subject contact administered in 15-minute blocks. The authors termed this same construct as “duration” in their later work.¹⁷ In a somewhat similar fashion, Rodgers and colleagues¹⁸ operationalized “intensity” as the total amount of upper extremity (UE) therapy provided to a patient during a particular working day.

In some cases, researchers have used the terms “intensity” and “duration” interchangeably within the same document or line of research. For example, a series of papers resulting from a National Institutes of Health workshop on optimal timing, duration, and intensity of stroke rehabilitative interventions¹⁹ did not disclose operational definitions for these terms before they then discussed them. Perhaps as a consequence of this ambiguity, some contributors to this series used the term “intensity” to describe the amount of stroke rehabilitative services provided to patients,²⁰ while others²¹ operationally defined “intensity” as the amount of patient effort put forth during participation in an intervention. Such variances have also been

observed in the constraint-induced movement therapy (CIMT) literature, in which authors have: (a) described CIMT and its comparators as “intense” in reference to the number of training hours required. This conceptualization equates “intensity” to be the same as “duration;” (b) noted that CIMT “...differs from conventional physical rehabilitation in its duration and intensity,”^{22 p.1045} meaning that the construct of “intensity” is conceptually different than “duration;” and (c) used the term “intensity” to refer to the number of practice units per block of time during which CIMT activities are practiced.²³

Definition Recommended by this Committee

For decades, oft-cited position statements in the exercise literature²⁴ - as well as position statements describing the application of exercise to stroke survivors²⁵ and older adults²⁶ - have defined “intensity” as the amount of effort and/or work that an individual puts forth during a single training session or a specific movement attempt. Likewise, several prominent texts describing exercise applications to a variety of populations^{27,28} have operationalized “intensity” as the amount of work or energy that an individual expends during an exercise session. Accordingly, the construct has typically been measured using perceived exertion,²⁹ the difference between maximal oxygen uptake and resting oxygen uptake (%VO₂R), and/or heart rate.²⁴

Increasingly, exercise concepts have been applied to stroke motor rehabilitation.^{30,31} This provides a basis for their adoption into stroke motor rehabilitation. Building on decades of exercise studies and established position statements, this sub-committee supports a definition of “intensity” for stroke motor rehabilitation that addresses the individual effort being expended during a particular motor rehabilitation session or exercise. We recommend the following definition of “intensity:” “the amount of physical or mental work put forth by the client during a particular movement or series of movements, exercise, or activity during a defined period of time.” Thus, the more work that a participant puts forth in a particular session or exercise, the higher the intensity level that he/she is likely exhibiting.

It is important to acknowledge that “intensity” may also refer to psychological effort exhibited during a particular movement or activity. For instance, movements requiring minute physical exertion levels (e.g., threading a needle; reaching for an object) can often be sufficiently mentally exacting for a stroke survivor that they require high levels of intensity. Future researchers will, thus, also want to focus on the development and validation of measures of psychological effort or “intensity.”^{e.g.,³²} Such measures would quantify the effort associated with performance of particular tasks during therapy sessions or at home. This information would, in turn, help to adapt the demands of the task according to the needs and abilities of the client (e.g., need for rest periods; type of movement feedback).

Using our proposed definition of intensity as a guideline, we recommend that future research efforts focus on examining the validity of already-established measures of intensity when administered during stroke motor therapy. An example of these efforts may be using Borg’s perceived level of exertion when asking the patient to characterize the amount of physical effort put forth during a particular movement attempt, such as attempting to reach for an object. This constitutes a slight variation from its more-common use as a measure of physical effort during aerobic interventions, and would help clinicians to understand how different levels of effort may affect movement quality (e.g., clonus when effort level is high) and/or outcomes. Alternatively, an objective measure of physical effort, such as heart rate, may be more desirable, if the goal of a particular intervention is to increase the patient’s physical capacity, or if the clinicians wishes to assure patient safety during a particularly taxing intervention, such as using a treadmill. It may also be the case that some measures using self-report methods are suboptimal with particular stroke survivors (e.g., individuals with cognitive, sensory deficits), as the patients may be unable to ascertain their levels of

effort or physiological stress. For example, a study by Tang and colleagues³³ showed that even the use of more objective measures (e.g., heart rate) may not be entirely straightforward in the stroke population due to autonomic nervous system changes in this population. Thus, researchers must examine the interplay between stroke sequelae and the validity of intensity measures, as well as possibly developing alternative measures of intensity for this population.

Dosing

Inappropriate use of pharmaceutical therapies has repeatedly been shown to undermine patient safety and outcomes. For example, medication non-adherence has been determined a cardiovascular risk factor.³⁴ Consequently, careful monitoring of the dosing of such regimens is fundamental to safe, efficacious treatment.

Rehabilitative therapies are similar to pharmacologic therapies in that they often elicit a myriad of motor, behavioral, neural, and other body system responses. Consequently, like medications, it is plausible that variances in recommended dosing schedules of motor therapy may significantly impact outcomes and, in some cases, patient health. Yet, there remains great variability in the dosing schedules with which stroke motor therapies are administered. The establishment of conventions regarding dosing of stroke motor therapies cannot occur without clear, consistent definitions of their underlying constructs.

Duration and Frequency

Background—As with other medical subdisciplines, we conceptualize “dosing” in stroke motor rehabilitation to encompass the total amount of activity performed during the training period. Yet, while many post-stroke motor rehabilitation therapies have been investigated,³⁵ the terminology used to describe the constructs that impact this quantity of activity has varied. For example, Kwakkel and Wagenaar¹⁷ longitudinally monitored the walking speeds of 53 subjects who were administered one of three different interventions emphasizing UE training, lower extremity training, or immobilization of the LE’s and UE’s using an inflatable splint. The authors operationalized “duration” as “...the amount of therapy, as measured in 15-minute increments of face-to-face contact between subject and therapist...” In contrast, others have defined “duration” to be the total amount of patient time spent exercising,³⁶ or have combined the terms, not making a differentiation between the two.

While a complete review is beyond the scope of this paper, it is worth noting that the total amount of training has varied across studies, often when testing the same intervention. Moreover, this occurred in studies that were not explicitly seeking to optimize dosing. For example, some robotic UE trials have provided 3 hours a week over 12 weeks (360 hours) of practice³⁷, whereas others using the same intervention have provided 3 hours a week for 6^{38,39} or 8 weeks,⁴⁰ or 4–5 hours for 6 weeks.⁴¹ Likewise, while CIMT appears to increase UE use and movement, there remains no agreed-upon frequency and duration for this training modality. For example, a Phase 3, multicenter, CIMT trial,⁴² administered UE motor therapy in six-hour durations, with a frequency of five days per week. Yet, others have shown that modifications to the duration^{43,44} and/or frequency⁴⁵ of the UE training sessions also significantly increase UE use and movement, and cause neural changes.⁴⁶ Such variability makes it difficult to determine the most efficacious dose at which responses can be seen, which hinders optimization of strategies to promote motor recovery.

In addition to obscuring the ability to make interpretations about efficacy across studies, variability in dosing hinders initiation of promising lines of research or development of new clinical pathways. For example, one of the authors (A.S.) found such variability challenging in initiating a line of research examining yoga as a stroke rehabilitative intervention based

on the older adult literature. Specifically, there is great variability concerning the optimal frequency and duration with which yoga should be administered (e.g., yoga literature variances included 4 to 12 or more week interventions, with sessions ranging from 30 to 90 minutes).^{47,48} In the end, such variability may force researchers and clinicians to make an educated guess concerning the appropriate frequency and duration for the intervention.

Definition Recommended by this Committee—In the larger medical and exercise contexts from which rehabilitation derives many of its practices, “duration” is usually defined as the length of time during which a single session is administered (measured in minutes, but other units of measurement can also be used). “Duration” could also be applied in describing the total amount of time that an intervention period occupies. “Frequency” has usually been defined as how often during a fixed time period the regimen is administered (e.g., how many times per week a patient is administered a particular regimen). This committee endorses the above definitions for use in stroke motor rehabilitation.

As with many medication regimens (e.g., blood pressure medication), a frequent challenge for stroke patients is full adherence with a prescribed exercise or rehabilitation prescription. For example, Shaughnessy et al. found that 42% of their sample of stroke survivors exercised never or less than once a week.⁴⁹ Clinicians must have appropriate terminology to describe the prescribed aspects of the assigned regimens so that consistent measures of deviation from these prescribed regimens can be developed. It is also important to acknowledge that changes to health care and reimbursement policies frequently impact the frequency and duration of post-stroke rehabilitation. Without such terminology in place, the ability to precisely and consistently quantify the impact of these changes on programming for people with stroke will remain elusive, and undermine ability to advocate for rehabilitation services for people with stroke.

Delivery Method

Background

“Delivery” commonly refers to the technique or approach by which treatment is administered. Methods of delivery as defined in pharmaceutical trials are usually based on the body system that is targeted as well as knowledge of the medication’s expected mechanisms of action (e.g. cell physiology, biochemistry).⁵⁰ Specific delivery parameters may include the form in which the drug is administered (e.g. liquid, solid, powder), the method with which it is delivered (e.g. needle, pill, patch) and, when appropriate, the method of delivery within the body (e.g. cutaneous or subcutaneous). These specifics are detailed in trials to provide safe and effective guidance in clinical situations.

Definition Recommendation by this Committee

At present, stroke motor rehabilitation trials often present the rationale and outcomes for a particular approach, but do not consistently provide sufficient detail outlining the delivery methods used. The absence of this information undermines ability for clinical replication and production of quality systematic reviews and meta-analyses, which are the foundation for establishing guidelines for effective therapies for stroke motor recovery.

This subcommittee endorses the development of standards for detailing how behavioral interventions were provided in published research. This would include stroke motor therapies. Such specificity may include the development of a standardized rubric for detailing the contents of a specific therapy regimen in the same way that the CONSORT diagram provides a framework for reporting the flow of subjects through a clinical trial. Such a rubric could detail repetitions of particular therapeutic elements, duration of each

element, delivery mechanism (e.g., mechanical; manual), and targeted areas for recovery for each element (e.g. peripheral, central nervous system). Such a rubric would allow for greater replication of clinical research protocols in actual clinical environments.

Other Directions and Conclusions

Rationale for development of this paper included an increasingly large and diverse array of clinicians and scientists involved in stroke motor rehabilitation, and the realization that stroke motor therapies wield wide and diverse systemic impacts in comparison to pharmacologic agents. Consequently, greater care – including more specificity and consistency in language - must be taken in describing the delivery of these regimens.

In addition to the areas of intensity, duration, frequency, and delivery method, an additional area in need of standardization in language and practice is the “window” during which a regimen should be administered. Like other constructs described in this paper, this is an area that was discussed - but not defined - in the aforementioned NIH white paper.¹⁹ Despite this oversight, “window” has recently been shown to be an important factor affecting efficacy of stroke motor therapies. For example, in acute stroke (< 30 days post ictus), CIMT is no more efficacious than time-matched affected arm training,⁵¹ yet is known to be efficacious when delivered in the months and years after ictus.^{22,23,42–46}

Contemplating stroke rehabilitative therapies in the same light as medications also necessitates reconsidering issues of expertise and specialization. In other fields, a discipline’s movement toward greater rigor, establishment, and specificity is often marked by the development of its own journals, conferences, special interest groups, and certifications. This is considered a necessary step, both to remain current with the evolving literature, and to assure clinician competency and scientific rigor.

The rapid evolution of stroke motor rehabilitation – as well as the wide systemic impact that stroke motor rehabilitation conveys - necessitate that clinicians in this area remain familiar with its increasingly specialized knowledge base. However, this is not always the case. For example, some therapists may have little specific training in stroke rehabilitation beyond that which they received during their clinical training, and/or may rely on information and practices from that training as the bases for their practices, even if the training occurred years ago.⁵² It is this subcommittee’s contention that specific stroke rehabilitative training and knowledge are fundamental to appropriate, evidence-based, safe stroke motor rehabilitation. One way that such training can occur is through a common language that is shared by all members of the rehabilitative team, as well as in the larger discipline. This allows for shared communication and goal setting strategies that, in turn, allow for advocacy for the discipline, including for better training of its professionals.

Conclusion

Stroke remains the leading cause of disability in the United States. Moreover, the factors that contribute to stroke incidence (e.g., advanced age; obesity; diabetes) are increasing. These factors are expected to conspire to produce an increased prevalence of stroke survivors exhibiting motor impairments that undermine independence and quality of life.

Such trends are being addressed by an increasingly large, diverse group of scientists and practitioners interested in stroke motor rehabilitation. However, as more individuals become interested in the science and practice of stroke motor rehabilitation and its knowledge base becomes more sophisticated, a common, specific language is needed to permit discourse and shared understandings. A logical source for such terminologies is from the more-established areas of medicine and exercise, on which many stroke motor rehabilitation practices are

based. Given these needs, this paper identifies definitions for intensity and dosing for use in stroke motor rehabilitation. This paper also identifies the concepts of delivery method and window as areas for future refinement.

Acknowledgments

We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated AND, if applicable, we certify that all financial and material support for this research (eg, NIH or NHS grants) and work are clearly identified in the title page of the manuscript. There is no device or drug described in this study.

This paper is a product of the Movement Interventions sub-committee of the American Congress of Rehabilitation Medicine.

ABBREVIATIONS

UE	Upper extremity
CIMT	constraint-induced movement therapy

References

1. Nudo RJ, Milliken G. Reorganization of movement representations in primary motor cortex following focal ischemic infarcts in adult squirrel monkeys. *J Neurophysiol*. 1996; 75:2144–2149. [PubMed: 8734610]
2. Yen CL, Wang RY, Liao KK, Huang CC, Yang YR. Gait training induced change in corticomotor excitability in patients with chronic stroke. *Neurorehabil Neural Repair*. 2008; 22:22–30. [PubMed: 17507641]
3. Szaflarski JP, Page SJ, Kissela BM, Lee JH, Levine P, Strakowski SM. Cortical reorganization following modified constraint-induced movement therapy: a study of 4 patients with chronic stroke. *Arch Phys Med Rehabil*. 2006 Aug; 87(8):1052–8. [PubMed: 16876549]
4. Folz TJ, Opitz JL, Peters DJ, Gelfman R. The history of physical medicine and rehabilitation as recorded in the diary of Dr. Frank Krusen: Part 2. Forging ahead (1943–1947). *Arch Phys Med Rehabil*. 1997 Apr; 78(4):446–50. [PubMed: 9111469]
5. Hodics T, Cohen LG, Cramer SC. Functional imaging of intervention effects in stroke motor rehabilitation. *Arch Phys Med Rehabil*. 2006 Dec; 87(12 Suppl 2):S36–42. [PubMed: 17140878]
6. Uswatte G, Taub E. Implications of the learned nonuse formulation for measuring rehabilitation outcomes: lessons from Constraint-Induced Movement therapy. *Rehabil Psychol*. 2005; 50:34–42.
7. Page SJ, Levine P, Leonard AC. Effects of mental practice on affected limb use and function in chronic stroke. *Arch Phys Med Rehabil*. 2005 Mar; 86(3):399–402. [PubMed: 15759218]
8. Ryan AS, Ivey FM, Prior S, Li G, Hafer-Macko C. Skeletal Muscle Hypertrophy and Muscle Myostatin Reduction After Resistive Training in Stroke Survivors. *Stroke*. 2011; 42:416–420. [PubMed: 21164115]
9. Wu, Chin-Li, 1,2; Huang, Mao-Hsiung, 1, 3; Lee, Chia-Ling, 1; Liu, Chin-Wei, 1; Lin, Li-Jung, 1; Chen, Chia-Hsin. Effect on spasticity after performance of dynamic-repeated-passive ankle joint motion exercise in chronic stroke patients. *Kaohsiung J Med Sci*. 2006; 22:610–7. [PubMed: 17116622]
10. Stuart M, Benvenuti F, Macko R, Taviani A, Segenni L, Mayer F, Sorkin JD, Stanhope SJ, Macellari V, Weinrich M. Community-Based Adaptive Physical Activity Program for Chronic Stroke: Feasibility, Safety, and Efficacy of the Empoli Model. *Neurorehabilitation and Neural Repair*. 2009; 23:726–734.
11. Lai S, Studenski S, Richards L, Perera S, Reker D, Rigler S, Duncan PW. Therapeutic Exercise and Depressive Symptoms After Stroke. *J Am Geriatr Soc*. 2006; 54:240–247. [PubMed: 16460374]

12. Pang M, Eng JJ, Dawson AS, MacKay H, Harris JE. A community-based fitness and mobility exercise program for older adults with chronic stroke: a randomized, controlled trial. *Journal of the American Geriatric Society*. 2005; 53:1667–74.
13. Tang A, Marzolini S, Oh P, McIlroy WE, Brooks D. Feasibility and effects of adapted cardiac rehabilitation after stroke: a prospective trial. *BMC Neurol*. 2010 Jun 9;10:40. [PubMed: 20529376]
14. Harnish S, Meinzer M, Trinastic J, Fitzgerald D, Page SJ. Language changes coincide with motor and fMRI changes following upper extremity motor therapy for hemiparesis: a brief report. *Brain Imaging Behav*. 2011 Oct 12. [Epub ahead of print].
15. Kwakkel G, Wagenaar RC, Twisk JW, Lankhorst GJ, Koetsier JC. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet*. 1999 Jul 17; 354(9174): 191–6. [PubMed: 10421300]
16. Kwakkel G, Kollen BJ, Wagenaar RC. Long term effects of intensity of upper and lower limb training after stroke: a randomised trial. *J Neurol Neurosurg Psychiatry*. 2002 Apr; 72(4):473–9. [PubMed: 11909906]
17. Kwakkel G, Wagenaar RC. Effect of duration of upper- and lower-extremity rehabilitation sessions and walking speed on recovery of interlimb coordination in hemiplegic gait. *Phys Ther*. 2002 May; 82(5):432–48. [PubMed: 11991797]
18. Rodgers H, Mackintosh J, Price C, Wood R, McNamee P, Fearon T, Marritt A, Curless R. Does an early increased-intensity interdisciplinary upper limb therapy programme following acute stroke improve outcome? *Clin Rehabil*. 2003 Sep; 17(6):579–89. [PubMed: 12971702]
19. National Institute of Child Health and Human Development. Timing, Intensity, and Duration of Rehabilitation for Hip and Stroke Fracture. Bethesda, MD: NIH; 2001.
20. Good, DC. Timing, Intensity, and Duration of Rehabilitation for Hip and Stroke Fracture (NICHD Eds). Bethesda, MD: NIH; 2001. Overview of stroke rehabilitation; p. 3-9.
21. Silver, KH. Timing, Intensity, and Duration of Rehabilitation for Hip and Stroke Fracture (NICHD Eds). Bethesda, MD: NIH; 2001. Chronic stroke: Therapeutic interventions; p. 20-25.
22. Taub E, Uswatte G, King DK, Morris D, Crago JE, Chatterjee A. A placebo-controlled trial of constraint-induced movement therapy for upper extremity after stroke. *Stroke*. 2006 Apr; 37(4): 1045–9. [PubMed: 16514097]
23. Dettmers C, Teske U, Hamzei F, Uswatte G, Taub E, Weiller C. Distributed form of constraint-induced movement therapy improves functional outcome and quality of life after stroke. *Arch Phys Med Rehabil*. 2005 Feb; 86(2):204–9. [PubMed: 15706544]
24. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. 7. Baltimore: Lippincott Williams & Wilkins; 2006.
25. Weiss A, Suzuki T, Bean J, et al. High intensity strength training improves strength and functional performance after stroke. *Am J Phys Med Rehabil*. 2000; 79:369–376. [PubMed: 10892623]
26. NELSON ME, REJESKI WJ, BLAIR SN, DUNCAN PW, JUDGE JO, KING AC, MACERA CA, CASTANEDASCEPPA C. Physical Activity and Public Health in Older Adults: Recommendation from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc*. 2007; 39:1435–1445. [PubMed: 17762378]
27. Taylor, M.; Johnson, A. Physiology of exercise and healthy aging. Human Kinetics; Champaign, IL: 2008.
28. Lockette, KF.; Keyes, AM. Conditioning with physical disabilities. Human Kinetics; Champaign, IL: 1994.
29. Borg, G. Borg's Perceived Exertion and Pain Scales. Human Kinetics; Champaign, IL: 1998.
30. Michael K, Goldberg AP, Treuth MS, Beans J, Normandt P, Macko RF. Progressive adaptive physical activity in stroke improves balance, gait, and fitness: preliminary results. *Top Stroke Rehabil*. 2009 Mar-Apr;16(2):133–9. [PubMed: 19581199]
31. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, Shephard T, et al. Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition,

- Physical Activity, and Metabolism; and the Stroke Council. *Stroke*. 2004 May; 35(5):1230–40. [PubMed: 15105522]
32. Macintosh BJ, McIlroy WE, Mraz R, Staines WR, Black SE, Graham SJ. Electrodermal recording and fMRI to inform sensorimotor recovery in stroke patients. *Neurorehabil Neural Repair*. 2008; 22:728–36. [PubMed: 18784267]
 33. Tang A, Sibley KM, Thomas SG, McIlroy WE, Brooks D. Maximal exercise test results in subacute stroke. *Arch Phys Med Rehabil*. 2006; 87:1100–05. [PubMed: 16876556]
 34. Munger MA, Van Tassel BW, LaFleur J. Medication nonadherence: an unrecognized cardiovascular risk factor. *Medscape general medicine*. 2007; 9(3):58. [PubMed: 18092064]
 35. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. *The Lancet Neurology*. 2009; 8(8):741–54.
 36. ACSM's Guidelines for Exercise Testing and Prescription. 8. Baltimore, MD: Lippincott Williams and Wilkins; 2010. General principles of exercise prescription.
 37. Lo AC, Guarino PD, Richards LG, Haselkorn JK, Wittenberg GF, Federman DG, et al. Robot-assisted therapy for long-term upper-limb impairment after stroke. *New England Journal of Medicine*. 2009; 362(19):1772–83. [PubMed: 20400552]
 38. Ferraro M, Palazzolo JJ, Krol J, Krebs HI, Hogan N, Volpe BT. Robot-aided sensorimotor arm training improves outcome in patients with chronic stroke. *Neurology*. 2003; 61(11):1604–7. [PubMed: 14663051]
 39. Stein J, Krebs HI, Frontera WR, Fasoli SE, Hughes R, Hogan N. Comparison of two techniques of robot-aided upper limb exercise training after stroke. *Am J Phys Med Rehabil*. 2004; 83(9):720–8. [PubMed: 15314537]
 40. Lum PS, Burgar CG, Shor PC, Majmundar M, Van der Loos M. Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. *Arch Phys Med Rehabil*. 2002; 83(7):952–9. [PubMed: 12098155]
 41. Krebs HI, Volpe BT, Aisen ML, Hogan N. Increasing productivity and quality of care: robot-aided neuro-rehabilitation. *J Rehabil Res Dev*. 2000; 37(6):639–52. [PubMed: 11321000]
 42. Wolf SL, Winstein CJ, Miller JP, Taub E, Uswatte G, Morris D, et al. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. *JAMA*. 2006; 296(17):2095–104. [PubMed: 17077374]
 43. Page SJ, Sisto SA, Levine P, McGrath RE. Efficacy of modified constraint-induced movement therapy in chronic stroke: a single-blinded randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*. 2004; 85(1):14–8. [PubMed: 14970962]
 44. Sterr A, Elbert T, Berthold I, Kolbel S, Rockstroh B, Taub E. Longer versus shorter daily constraint-induced movement therapy of chronic hemiparesis: an exploratory study. *Arch Phys Med Rehabil*. 2002; 83(10):1374–77. [PubMed: 12370871]
 45. Ro T, Noser E, Boake C, Johnson R, Gaber M, Speroni A, et al. Functional reorganization and recovery after constraint-induced movement therapy in subacute stroke: case reports. *Neurocase*. 2006; 12(1):50–60. [PubMed: 16517515]
 46. Szaflarski J, Page SJ, Kissela B, Levine P, Lee J. Use-dependent cortical reorganization after modified constraint-induced therapy. *Arch Phys Med Rehabil*. 2006 Aug; 87(8):1052–8. [PubMed: 16876549]
 47. Schmid AA, Van Puymbroeck M, Kocaja DM. Effect of a 12-week yoga intervention on fear of falling and balance in older adults: a pilot study. *Archives of Physical Medicine and Rehabilitation*. 2010; 91(4):576–83. [PubMed: 20382290]
 48. Hart CE, Tracy BL. Yoga as steadiness training: effects on motor variability in young adults. *J Strength Cond Res*. 2008; 22(5):1659–69. [PubMed: 18714217]
 49. Shaughnessy M, Resnick BM, Macko RF. Testing a model of post-stroke exercise behavior. *Rehabilitation Nursing*. 2006; 31(1):15. [PubMed: 16422040]
 50. Testa B. Drug metabolism for the perplexed medicinal chemist. *Chem Biodivers*. 2009; 6:2055–2070. [PubMed: 19937836]
 51. Boake C, Noser EA, Ro T, Baraniuk S, Gaber M, Johnson R, Salmeron ET, Tran TM, Lai JM, Taub E, Moye LA, Grotta JC, Levin HS. Constraint-induced movement therapy during early

stroke rehabilitation. *Neurorehabil Neural Repair*. 2007 Jan-Feb;21(1):14–24. [PubMed: 17172550]

52. Korner-Bitensky N, Menon-Nair A, Thomas A, Boutin E, Arafah AM. Practice style traits: do they help explain practice behaviours of stroke rehabilitation professionals? *J Rehabil Med*. 2007 Nov; 39(9):685–92. [PubMed: 17999005]