
Termination of motor rehabilitation is often recommended as patients with cerebrovascular accident (CVA) become more chronic and/or when they fail to respond positively to motor rehabilitation (commonly termed a “plateau”). Managed-care programs frequently reinforce this practice by restricting care to patients responding to therapy and/or to the most acute patients. When neuromuscular adaptation occurs in exercise, rather than terminating the current regimen, a variety of techniques (eg, modifying intensity, attempting different modalities) are used to facilitate neuromuscular adaptations. After presenting the concepts of the motor recovery plateau and adaptation, we similarly posit that patients with CVA adapt to therapeutic exercise but that this is not indicative of a diminished capacity for motor improvement. Instead, like traditional exercise circumstances, adaptive states can be overcome by modifying regimen aspects (eg, intensity, introducing new exercises). Findings suggesting that patients with chronic CVA can benefit from motor rehabilitation programs that apply novel or different parameters and modalities. The objectives of this commentary are to (1) to encourage practitioners to reconsider the notion of the motor recovery plateau, (2) to reconsider chronic CVA patients’ ability to recover motor function, and (3) to use different modalities when accommodation is exhibited.

Key Words: Cerebrovascular accident; Exercise; Rehabilitation; Stroke.

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STROKE IS THE LEADING cause of disability in the United States, and stroke motor sequelae are a primary reason for stroke’s disabling impact. Yet, despite compromised ability to perform activities of daily living (ADLs), diminished quality of life, and millions of dollars spent annually, the efficacy of traditional stroke motor rehabilitation techniques is heterogeneous in delivery and has not been supported in randomized controlled trials. Given anticipated growth in stroke incidence and prevalence, and, thus, an increased number of people expected to exhibit stroke-induced impairments, determining appropriate care plans for stroke patients is a priority.

After medical stabilization, stroke survivors are typically administered motor rehabilitation regimens by using Bobath’s approaches and proprioceptive neuromuscular facilitation techniques. For most stroke patients, these therapies are funded through private insurance, Medicare, and/or Medicaid. However, managed-care providers frequently terminate therapy reimbursement when patients fail to show discernible improvements within a focused time frame, such as changes in FIM instrument scores. It is usually argued that such recovery “plateaus” reflect diminished capacity for additional motor improvement, warranting discharge. Although repeated practice conveys motor skill learning, managed-care providers also often restrict the number of motor rehabilitation sessions, and motor therapy is usually only reimbursed when provided to the most acute stroke patients. Similarly, it is a common clinical tenet that stroke patients past a certain time window are unlikely to benefit from motor rehabilitation.

Although such discharge patterns have become customary, there may be reason to reconsider them. Data have repeatedly shown that chronic (>1y poststroke) stroke patients can exhibit substantial motor improvement after participation in novel rehabilitation protocols requiring task-specific, repeated motor practice. In many such studies, patients who improved had been told by their clinicians that additional motor improvement was not to be expected, and they had been discharged from motor therapy because of plateauing. Such task-specific, repeated practice regimens have also induced lasting cortical reorganizations that appear to precede motor improvement. These data suggest that lasting neural and functional changes can occur in stroke patients who have supposedly plateaued. These findings also warrant reconsidering expected stroke motor recovery trajectories because previous recovery trajectory depictions were based on patient responses to rehabilitation protocols now known to be ineffective.

Given such improvements in chronic stroke patients who had supposedly plateaued, is there a motor recovery plateau? And, if not, what may be the processes underlying decrements or plateaus during motor rehabilitation? In this commentary, we revisit the concept of the motor recovery plateau, as well as discuss neuromuscular adaptation, in which patients become neurophysiologically accustomed to exercise regimens to which they have had repeated exposure. Like an athlete who repeatedly executes the same training regimen until adaptation has occurred, we posit that many stroke patients experiencing plateaus may actually be adapting to their therapeutic motor exercise regimens. It is our contention that this adaptive state is not indicative of a diminished capacity for motor improvement; instead, as in traditional exercise circumstances, a leveling in response to exercise is an indicator that regimen aspects should be modified (eg, intensity, introducing new exercises). Positive findings from recent motor intervention studies, in which novel training regimens were successfully used with chronic stroke patients, will be presented to support this hypothesis.
Many rehabilitation professionals may be less familiar with data on neuromuscular adaptation, which emanate mostly from exercise physiology literature, or with recent findings regarding late recovery after stroke. The objectives of the commentary are (1) to encourage practitioners and managed care providers to reconsider the notion of a motor recovery plateau in stroke, (2) to encourage practitioners and managed care providers to reconsider chronic stroke patients’ ability to recover motor function, and (3) to encourage practitioners to use different modalities when adaptation is possibly being exhibited. We propose that researchers and practitioners reconsider how motor learning occurs after stroke and that potential for motor learning continues to exist during situations in which patients no longer respond to a particular intervention.

NEUROMUSCULAR ADAPTATION AFTER EXERCISE

With origins in evolutionary biology, adaptation generally refers to a biologic system or unit altering its structure or function to accommodate to external conditions or stimuli. For our purposes, we use the term “adaptation” to describe a series of neuromuscular processes whereby the human body becomes accustomed to progressively greater workloads in response to repeated overloading, usually via physical exercise. Sometimes these changes result in changes in structure or function; at other times, no discernible changes may be available. This is a commonly used definition in the exercise science literature, and we refer the reader elsewhere for more information.

As previously noted, repeated physical practice conveys improved motor performance. Such motor improvements are largely caused by temporary, practice-induced, changes (eg, increases in heart rate, increases in blood pressure, temporary cortical reorganizations), which, if practice is repeated over time, elicit long-term neuromuscular adaptations. For example, temporary increases in muscle size during the first 2 weeks of strength training are primarily neural, whereas muscle hypertrophy is produced by resistance training for as much as 4 months. Over time, repeated hypertrophic conditions also yield lasting changes in the number of contractile proteins within the exercised muscles, and in muscle fiber–type ratios, and in muscle strength. Similar long-term adaptations occur at the muscle-tissue level, such as increases in muscle activation patterns that occur in response to resistance training. Lasting neural adaptations also occur during resistance exercise regimens and are sometimes more pivotal to adaptation than muscular factors such as hypertrophy. Examples include changed electromyography-to-force ratios and increased neuromuscular junction size. Long-term, use-dependent changes in the topography of cortical maps are also thought to accompany repeated physical practice, although the time course of these changes in concert with physical practice is still unknown. For example, Karni et al reported enlargement in the primary motor cortices of healthy participants engaging in daily practice of several motor tasks. Classen et al similarly showed that even simple thumb movements repeated over a short period of time induce lasting cortical representational changes and that these representations enlarge as learning occurs. People learning Braille also exhibit lasting changes in cortical representations, corresponding to the digits being used and enhanced tactile representations, as do musicians who play instruments requiring repeated digit use and dexterity.

Together, these data suggest that considerable neuromuscular adaptation occurs in response to repeated physical activity participation. However, adaptations also follow specific time courses, with the largest adaptive changes typically taking place early in training and slowing or leveling off as training continues. Indeed, if an individual begins a running exercise regimen and has never run before, initial changes in endurance will be dramatic. However, after training for 6 to 8 weeks, the gains will be small in comparison. Eventually, if the regimen is not varied, either by modifying the exercise regimen and/or by continually overloading the muscles, a performance plateau will occur. Such plateaus are common in all areas of neuromuscular performance and are typified by stabilization of maximal motor performance at some peak level in response to a stable training stimulus, presumably because of neuromuscular adaptation. This phenomenon was described by Garhammer as general adaptation syndrome and is characterized by 3 phases. First is the alarm phase, in which a new stress (ie, resistance training) may cause excessive soreness, fatigue, and perhaps even a temporary drop in performance. Second is the resistance phase, in which the body adapts to the stimulus and returns to a normal, albeit enhanced functional level. During this phase, the hormonal milieu responds to increases in neuromuscular stimulation by increasing anabolism to support biochemical, structural, and mechanical changes in muscle physiology. And third is the exhaustion phase, in which continued training at similar sets and repetitions with increased intensity will eventually lead to a plateau and subsequent decline in function, as the hormonal milieu shifts to one favoring catabolism in response to an increase in stress hormones relative to the available anabolic mediators.

“Breaking Through” the Plateau

A repeated finding has been that occurrence of a performance plateau is not indicative of the individual losing capacity to experience additional gains, nor does it warrant cessation from exercise. Indeed, in nonclinical populations, such plateaus have been observed and overcome through a variety of interventions, with the most notable example being periodization. Periodization consists of varying the training regimen by breaking it into smaller training phases, during which different skills, regimen durations, and/or regimen intensities are used. Periods of relative rest, diminished intensity, and variations in sets and repetitions were first described by the Russian strength coach Matveyev, in 1966, as a way of “tricking” the body into new alarm and resistance phases, in response to a periodization schedule developed to counteract the above-mentioned exhaustion phase encountered in the exhaustion phase. Periodization has been particularly endorsed in the strength training community, with recent investigations successfully demonstrating its efficacy. For example, in a comparison of linear and daily undulating (variable) strength training protocols, Rhea et al showed significantly greater increases in strength for experienced lifters provided 12 weeks of daily undulations in protocol, although significant gains were also made in those participating in the 12-week linear training protocol. Although muscle biopsies were not performed, there was no significant change in body composition or anthropometric measures shown in either group, which suggests no significant change in muscle size or composition. Rhea speculated that the undulating protocol, therefore, placed a greater stress on the neurologic components of the neuromuscular system, resulting in the significantly greater gains in strength expression.

Recently, Hakkinen et al showed neuromuscular adaptations to periodized strength training in both middle-aged and elderly subjects. During the first 6 months of the program, all subjects trained twice weekly with 3 to 5 sets per session, loads of 50% to 80% 1-repetition maximum, and fewer repetitions as intensity increased. Group A then underwent a 3-week period of detraining (no resistance training), followed by a repeat of...
the previously used strength training protocol during the final 21 weeks. Conversely, group B spent the remaining 24 weeks in detraining. The first 6 months of training showed large increases in both dynamic and isometric maximal strength, as well as explosive jumping and walking performances. The gains were associated with considerable increases in maximal voluntary neural activation of agonist muscles in both age groups and with significantly reduced coactivation of antagonist muscles in the elderly group. Many other studies have also reported that periodization mitigates performance plateaus. Plateaus can also be ameliorated by modifying exercise intensity or by changing other regimen aspects.

MOTOR RECOVERY IN STROKE

As previously noted, traditional stroke motor rehabilitation has not been found to be efficacious in randomized controlled studies. Moreover, findings of large studies examining short- and long-term responses to traditional stroke motor rehabilitation suggest that, after a certain period of time, patients are less likely to regain function. Some of the most convincing support for this contention has come from the Copenhagen Stroke Study, a national stroke study accumulating stroke incidence and outcomes from thousands of patients. Included in Copenhagen Stroke Study reports have been data suggesting that motor recovery should not be expected more than 5 months after insult. Data from other studies appear to support this precept, with others arguing similarly that motor recovery should not be expected more than 6 to 12 months after injury. An unfortunate effect is that it is common for practitioners to advise patients not to expect motor recovery after 6 months (Page SJ, unpublished data, 2003) and for insurers not to reimburse for motor therapy for more chronic stroke patients. These practices may cause the patients themselves not to expect motor recovery, creating a self-fulfilling prophesy in which recovery is not realized. There are also some data suggesting that learned helplessness can occur in such circumstances, in which low expectations for recovery, combined with inability to perform ADLs, result in a feeling of helplessness or “giving up,” which generalizes to other aspects of the patient’s life.

Adaptation and Periodization in Stroke

As previously discussed, adaptation is a common and often desirable exercise training occurrence in healthy people, arising when they become physiologically accustomed to the exercise regimen. Examples include cardiovascular adaptations in response to aerobic exercise regimens, as well as neuromuscular adaptations in response to resistance exercise or repeated physical practice. When adaptation occurs, the remedy for such states is to adjust delivery of exercise such that positive adaptations continue to occur. Examples, supported by research, include modifying the exercise intensity, modifying the exercise session duration, and/or changing the routine itself to load different muscles or the same muscles in different ways.

Stroke motor therapy is largely predicated on traditional exercise principles tested in younger, healthy subjects, with concepts such as specificity, therapy duration, intensity, and frequency being critical considerations to therapeutic regimen efficacy. Physiologic reactions observed when stroke patients exercise are similar to those observed when nondisabled subjects exercise, including improved cardiovascular response and increases in muscle strength. Older people can, in fact, often gain fitness and function with lower levels of training and across much longer time periods than nondisabled, healthy persons. Throughout the motor rehabilitation regimen, a stroke patient will almost always be treated by the same therapist in the same clinic for the same session duration. Because motor relearning is usually slow, patients will also frequently perform nearly identical exercises from session to session, so that deficit areas are thoroughly targeted. Given that various combinations of therapeutic exercise conditions—including intensity, duration, frequency, environment, clinician, and even exercises—may go unchanged from 1 session to the next, and given similar exercise responses in stroke patients and nondisabled people, we submit that what has long been termed the motor recovery plateau may actually be neuromuscular adaptation to the therapeutic exercise regimen. It is also reasonable to question whether enough repetition or systematic progression is occurring during traditional motor rehabilitation. This hypothesis has broad implications, because as noted earlier, current therapy termination decisions are predicated on the existence of such a plateau, which means that no improvement can be anticipated and patients should be discharged. In contrast, if data show that patients can continue to improve months or even years after injury and therapy discharge, this would disprove the notion of a plateau and argue for providing patients with novel, modified regimens when adaptation is exhibited.

In fact, numerous study results do show that chronic stroke patients who had plateaued exhibit substantial motor improvements after participation in task-specific, repeated practice protocols. Moreover, a common characteristic has been that these protocols require participation in challenging exercise regimens dissimilar to those that they received during rehabilitation stays—a core characteristic of regimens that break adaptive patterns. For example:

- Improved, more-affected, upper-limb use and function were reported in pilot studies in which chronic stroke patients participated in constraint-induced movement therapy (CIMT). CIMT emphasizes massed practice with the affected upper limb in 2 ways: (1) participants’ less affected upper limbs are restricted during 6-hour activity sessions using their more-affected limbs on 6 hours of a 2-week period and (2) participants engage in 6-hour activity sessions using their more-affected limbs on 10 weekdays of the same 2-week period.
- Because of limitations in CIMT clinical practicality and adherence to CIMT, a modified CIMT (mCIMT) has been developed that combines structured, 30-minute functional practice sessions with restriction of the less-affected upper limb 5 days a week for 5 hours, both during a 10-week period. Besides being reimbursable within many managed-care plans, mCIMT can be implemented on an outpatient basis. Moreover, by using randomized controlled methods, mCIMT substantially improved motor function in stroke patients who were discharged from therapy, supposedly because they had “plateaued,” including chronic stroke patients.
- A task-specific, 30-minute, 2-week reaching program, designed by Dean and Shepherd, significantly improved discharged stroke patients’ reaching distance and time required to perform reaching tasks; the program also improved muscle activation, load through the more-affected leg, and ability to transfer between sitting and standing positions. Galea et al also reported that a 3-week program, featuring 45-minute, task-specific, upper-limb training, improved motor function, dexterity, and use of discharged “plateaued” patients’ more-affected upper limbs. Other task-specific regimens, using various novel modalities and/or intensities, have also reported significant success in increasing use and function of the more affected limbs of stroke patients who had supposedly “plateaued.”
Researchers from around the world have corroborated that chronic and subacute stroke patients who had plateaued can exhibit motor improvements after novel rehabilitation regimens. This suggests that something other than a permanent plateau is occurring. These states appear to be temporary, perhaps brought about by necessarily consistent therapy regimens that, as an unintended side effect, cause neuromuscular adaptation. Like traditional exercise circumstances, evidence suggests that the remedy for adaptive states in stroke rehabilitation appears to be adjusting delivery and/or the mode of rehabilitation and challenge of therapeutic exercise such that positive adaptations continue to occur. When this practice is followed, data show that patients continue to recover.

CONCLUSIONS
Termination of motor rehabilitation is often recommended as stroke patients become more chronic and/or when they fail to respond positively to motor rehabilitation. Managed-care programs frequently reinforce this practice by restricting care to patients who respond to therapy and/or to the most acute patients.

When neuromuscular adaptation occurs in exercise with healthy adults, rather than terminating the current regimen, a variety of techniques (eg, modifying intensity, attempting different modalities) are used to facilitate positive, neuromuscular adaptations. Given that therapeutic exercise conditions—including intensity, duration, frequency, environment, clinician, and even exercises—are largely unchanged from 1 session to the next, and given similar exercise responses in stroke patients and nondisabled subjects, we similarly argue that stroke patients adapt to therapeutic exercise. These adaptations may take many forms after stroke. For example, behavioral adaptations, such as hemiakinesia (recently called learned nonuse), in which patients do not use the affected side, can be manifest in smaller cortical representations of the body part not being used.  

Similarly, behavioral adaptations, such as hemiakinesia, as well as reduced activity after stroke, can cause gross and microscopic skeletal muscle atrophy and other metabolic abnormalities in hemiparetic muscle. However, these adaptations are not indicative of a diminished capacity for motor improvement. Instead, like traditional exercise circumstances, adaptive states can be overcome by modifying regimen aspects (eg, intensity, introducing new exercises); regimens such as mCIMT can overcome hemiakinesia and neural adaptations, whereas exercise training regimens can overcome musculoskeletal adaptations.

Much is still to be learned about exercise in stroke, including the critical elements of training that will induce further motor improvements, neuromuscular adaptations after stroke, and the optimal application of motor learning and exercise to extend the window for meaningful functional gains.

References
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