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Point of View

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What Do Motor "Recovery" and "Compensation" Mean in Patients Following Stroke?

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There is a lack of consistency among researchers and clinicians in the use of terminology that describes changes in motor ability following neurological injury. Specifically, the terms and definitions of *motor compensation* and *motor recovery* have been used in different ways, which is a potential barrier to interdisciplinary communication. This Point of View describes the problem and offers a solution in the form of definitions of compensation and recovery at the neuronal, motor performance, and functional levels within the framework of the International Classification of Functioning model.

Keywords: *Rehabilitation; Terminology; Recovery; Compensation; Stroke; Hemiplegia*

Research initiatives to define the effectiveness of neurological rehabilitation have seen a steady growth over the past decade. This "growth spurt" has, for the most part, been precipitated by advances in our understanding of mechanisms of neuroplasticity and the exciting possibility for sensorimotor rehabilitation to exploit this hitherto unrecognized potential. The evidence for neuroplasticity in the adult brain of the nonhuman primate model of stroke[1] as well as in humans[2-4] has offered new hope to those treating patients with long-term disability and underlies the increasing interest in finding new and more effective ways to maximize this potential. Apart from scientific advances, another reason for the increased activity in this area may be because of the growth in numbers of highly qualified rehabilitation researchers and, consequently, the increase in the number of good-quality controlled studies on rehabilitation effectiveness. The field of rehabilitation research has seen an exponential escalation over the past 20 years. In 1985, the Rehabilitation Special Interest Social at the Society for Neuroscience Annual Meeting attracted just enough people to justify a dinner reservation for 1 table at a Dallas restaurant. In 2007, more than 400 researchers filled 3 adjoining rooms at the San Diego Convention Center. One reason for the increase in the number of researchers is the realization and recognition that rehabilitation is an interdisciplinary undertaking. In addition to those with backgrounds in professional rehabilitation therapy, investigators representing diverse fields including engineering, physiology, neuroscience, and medicine now identify themselves with rehabilitation. Indeed, this expansion is a desirable result of progress in science, because recovery from neurological insult is a multifaceted problem that requires teamwork and dialogue, not only among professional disciplines but also between scientists undertaking both basic and applied investigative approaches.

The Problem

With the advent of greater interdisciplinary dialogue, "growing pains" have inevitably surfaced. Profession-specific operational definitions of terminology in neuroscience and clinical rehabilitation used to describe concepts important to neuroplasticity do not always coincide and may confound interdisciplinary communication. With this reality confronting us, the purpose of this article is to delineate the terminology and definitions for describing recovery and compensation of motor activity and function in patients who have sustained pathology in the central nervous system using stroke as a primary example.

In the general literature, the term *recovery* has been used to refer simultaneously to the restitution of damaged structures or functions and as a term to describe clinical improvements regardless of how these may have occurred (ie, through restitution or adaptation). Thus, common terminology describing recovery and compensation used by fundamental and clinical researchers and clinicians often conflict, are misinterpreted, or

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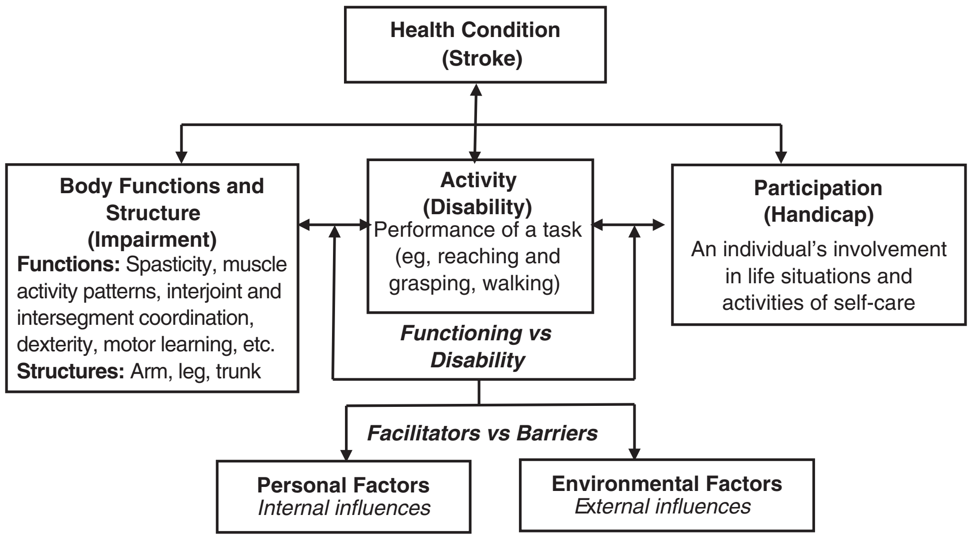
Figure 1
World Health Organization International Classification of Functioning Model



are poorly defined. Such concepts often fail to include underlying aspects of mechanism as a primary basis for their differentiation. In fact, they may often be used interchangeably. For example, Tecchio et al[5] attribute changes in brain activation levels and symmetry to motor *recovery* in the upper limb based on changes in NIH Stroke Scale scores, a scale that does not discriminate between motor recovery and compensation in task accomplishment (see below). We aim to provide unambiguous definitions of recovery and compensation using the framework of the World Health Organization International Classification of Functioning (ICF) model (Figure 1). We limit this point of view to the motor system recognizing that any treatment of motor control without taking into account perception, sensation, and cognition is likely to be incomplete.

The ICF distinguishes between the underlying pathophysiology of the Health Condition, impairments at the Body Function/Structure level, disability at the Activity level, and handicaps at the Participation level. We propose a classification of recovery and compensation based on the first 2 levels of the ICF model. We do not extend the classification to the Participation level of the ICF because clear distinctions between processes of recovery and compensation are more difficult to identify. This effort is undertaken to encourage clinicians and interdisciplinary groups interested in rehabilitation to discontinue the inadvertent reference to these 2 concepts as though they were one and the same.

The Meaning of Recovery From Stroke

Stroke is the third leading cause of death in Western countries and contributes significantly to the incidence of long-term physical disabilities and handicaps. More than 700 000 Americans are affected by a new or recurring stroke each year. In 2007, the resulting impact in health care was reflected in more than $62.7 billion in direct and indirect costs.[6,7] Up to 85% of the approximately 566 000 stroke survivors experience hemiparesis, resulting in impairment of 1 upper extremity (UE) immediately after stroke, and between 55% and 75% of survivors continue to experience limitations in UE function, which are associated with diminished health-related quality of life, even 3 to 6 months later.[8-11] Defined in terms of the capacity of the patient to perform movement in the same way as age-matched nondisabled subjects, UE sensorimotor recovery may be slower or more complex than that of the lower limb. One explanation for poor recovery of arm function may be the greater emphasis placed on retraining gait and mobility in an effort to mobilize the patient as quickly as possible and to minimize costly hospital stays.[12] Movements of the UE are also far less stereotypical than those of the lower extremity (LE), involving a wider inventory of coordinated trunk and multi–joint movements to manipulate objects in the environment. Clinical outcome scales meant to measure improvement mainly focus on task accomplishment and are often not qualitatively sensitive enough to discriminate improvement in how the task is performed. Admittedly, the focus of stroke rehabilitation is to maximize functional motor ability, such as to walk safely from one room to another or to turn a doorknob to open a door, in the limited time available for treatment. With the emphasis placed on task accomplishment, there is little time to focus on qualitative aspects of movement.

Without attention to the quality of task performance, however, it is not possible to distinguish between "recovery" and "compensation" at the level of the basic motor patterns employed.

Even if measurement of the quality of task accomplishment is desired, few valid and reliable clinical measurement tools exist to quantify elemental motor patterns, such as active ranges of joint movement and interjoint coordination used during the performance of common motor tasks (but see Reaching Performance Scale for the UE[13]). Skilled motor ability is based on the learner acquiring classes of elemental motor behaviors, such as muscle or movement synergies, and learning how to apply them in different combinations to accomplish desired motor tasks.[14-17] Assuming that neurological injury leads to the loss of skilled motor behavior, motor relearning would depend on the reacquisition of such elemental motor patterns (recovery) or, in the absence of reacquisition, adaptation of remaining (compensation) or integration of alternative (substitution) motor elements. If we are to make progress in changing how physical rehabilitation is viewed and reimbursed by third-party payers, we have to demonstrate that functional motor outcomes are superior when therapeutic intervention is aimed at the reacquisition of motor elements underlying functional task accomplishment (ie, muscle activation patterns and kinematics). However, empirical evidence for this demonstration will remain elusive until we have a clear understanding and dialogue on what is meant by recovery and compensation at different levels.

Recovery and Compensation in Relation to the Degree of Sensorimotor Impairment

The lack of distinction between compensation and recovery raises concerns about the extent to which rehabilitation specialists strive for improvements in movement quality (ie, reduction in motor impairment) among their patients. Here, *recovery* of motor performance is defined as the reappearance of elemental motor patterns present prior to central nervous system injury. Motor *compensation* is defined as the appearance of new motor patterns resulting from the adaptation of remaining motor elements or substitution, meaning that functions are taken over, replaced, or substituted by different end effectors or body segments. In this context, an *end effector* is defined as a body part such as the hand or foot that interacts with an object or the environment.

A distinction is made as to the extent to which rehabilitation specialists focus interventions on motor compensation or recovery in patients with different levels of motor impairment.[18] Indeed, for some patients with severe impairment and poor prognosis, compensatory or substitutive movements may be encouraged to maximize functional ability. For example, in the lower limb, strategies to increase walking speed include using larger arm and leg swing amplitudes on the nonparetic side than on the paretic side of the body.[19] In the upper limb, motor compensations can include the use of movement patterns that incorporate trunk displacement and rotation, scapular elevation, shoulder abduction, and internal rotation.[20,21] The use of increased trunk movement to assist arm and hand transport[22,23] and to aid in hand positioning/orientation for grasping[24] are examples of adaptive compensatory strategies. The degree of motor compensations used to transport or manipulate objects is also related to the severity of the hemiparesis.[20,25] Severely impaired patients might make more improvements that have functional consequences if they use acquired or taught adaptive compensatory movement patterns. For example, patients with hemiparesis used less elbow extension and shoulder horizontal adduction while incorporating forward trunk bending and increased shoulder elevation during reaching to compensate for the decrease of the effective arm length. As suggested above, this compensation may be a means by which the motor system achieves better functional arm and hand positioning in the presence of distal impairment.

However, for most patients with mild-to-moderate hemiparesis, previous studies have shown that compensatory trunk movements can be decreased with appropriate interventions such as trunk restraint for arm reaching tasks.[26] Several arguments support an emphasis on striving for functional improvements via the reduction in impairment. First, recent research on the capacity for neuronal plasticity suggests that given appropriate training motor improvements of the upper limb can continue well into the chronic stage of stroke.[27-30] Second, although compensatory movements may help patients perform tasks in the short term, the presence of compensation may be associated with long-term problems such as reduced range of joint motion and pain.[31,32] Third, permitting the use of motor compensations could lead to a pattern of learned nonuse,[33,34] limiting the capacity for subsequent gains in motor function of the paretic arm or leg.

The Need for Clarity in Terminology

The extent to which functional gains result from the recovery of lost motor patterns and/or the development of compensatory movements[35] and how rehabilitation influences these processes are unclear.[19,32,36,37] Part of the problem is the lack of consensus among clinicians and researchers of different disciplines on the definition of *functional recovery*. This term is often used without distinguishing whether the "recovery" is occurring at the Body Functions/Structure or the Activity level.[38,39] Thus, there is often no consensus about whether "recovery" is because of true motor recovery or compensation at each of these levels. In an attempt to improve knowledge exchange between fundamental researchers, clinical researchers, and clinicians, we propose definitions of recovery and compensation at 3 different levels at which each may occur (Table 1). Although most fundamental researchers studying neuronal plasticity and brain reorganization after stroke agree on the definition of recovery/compensation at the neuronal level, this distinction has not been stressed at the Body Functions/Structure and Activity levels. As a result, there is much confusion in the interpretation of the efficacy of different treatment interventions, often leading to equivocal results in which changes at each level are mutually confounded.

The Solution

An important factor contributing to the issue of distinguishing between motor recovery and compensation is the lack of

Table 1
Definitions of Motor Recovery and Motor Compensation at 3 Different Levels

Level	Recovery	Compensation
ICF: Health Condition (neuronal)	*Restoring function in neural tissue that was initially lost after injury*. May be seen as reactivation in brain areas previously inactivated by the circulatory event. Although this is not expected to occur in the area of the primary brain lesion, it may occur in areas surrounding the lesion (penumbra) and in the diaschisis.	*Neural tissue acquires a function that it did not have prior to injury*. May be seen as activation in alternative brain areas not normally observed in nondisabled individuals.
ICF: Body Functions/ Structure (performance)	*Restoring the ability to perform a movement in the same manner as it was performed before injury*. This may occur through the reappearance of premorbid movement patterns during task accomplishment (voluntary joint range of motion, temporal and spatial interjoint coordination, etc).	*Performing an old movement in a new manner*. May be seen as the appearance of alternative movement patterns (ie, recruitment of additional or different degrees of freedom, changes in muscle activation patterns such as increased agonist/antagonist coactivation, delays in timing between movements of adjacent joints, etc) during the accomplishment of a task.
ICF: Activity (functional)	*Successful task accomplishment using limbs or end effectors typically used by nondisabled individuals*.[a]	*Successful task accomplishment using alternate limbs or end effectors*. For example, opening a package of chips using 1 hand and the mouth instead of 2 hands.

Abbreviation: ICF, World Health Organization International Classification of Functioning.
[a]Note that task performance may be successful using compensatory motor strategies and movement patterns.

precision in measurement of motor improvement. Motor performance measures should be specifically selected so as to distinguish recovery of premorbid movement patterns during attempts to perform a task from alternative movement patterns adopted by or taught to the patient to compensate the loss of these movement patterns. For example, during performance of a key turning task, it would be necessary to distinguish between task accomplishment using compensatory trunk side bending and desirable motor patterns such as forearm supination. Motor scales that assess disability (Activity level) rather than impairment (Body Functions/Structure level) cannot reliably make this distinction. The distinction is particularly important in interpretation of functional magnetic resonance imaging (fMRI) and other neuroimaging studies, because compensatory strategies are also likely to cause novel activation patterns; for example, use of proximal body segments to assist in distal arm movement might lead to activation in both hemispheres because proximal muscles have more bilateral cortical representation, as opposed to bilateral activation caused by syndeskisis—but this activation would not indicate neuronal recovery.

In the following sections, we distinguish between compensation and recovery at 3 different levels of the motor system within the ICF classification: Health Condition (neuronal), Body Function/Structure (impairment), and Activity.[40]

Health Condition Level: Neuronal Level

Recovery at the neuronal level is characterized by reactivation in brain areas previously nonactivated by the circulatory event. In this sense, recovery refers to restitution or repair of structures to their original state. Although not expected to occur in the area of the primary brain lesion, this activation may occur in areas surrounding the lesion (penumbra) and in the area of diaschisis. Imaging studies have also shown that cortical areas on both sides of the brain may be involved in motor recovery.[41] Recovery can also be attributed to postischemic neuronal restructuring of brain circuits. We suggest restricting the word *recovery* to restitution or repair of structures or functions and to refer to other changes that occur following neurological injury as *improvements* or *changes*.

Compensation at the neuronal level is characterized by activation in alternative brain areas not normally observed in nondisabled individuals. Functional imaging studies (fMRI) describe a dynamic pattern of task-related brain activation in patients recovering from acute stroke that is initially greater than controls in contralesional sensorimotor and premotor cortex, ipsilesional cerebellum, bilateral SMA, and parietal cortex.[42-47] Note that changes in hemodynamic reactivity should be interpreted in light of evidence that patients with stroke may have altered hemodynamic responses because of vascular disease or infarction.[48,49] Nevertheless, the initial increase in activation is reportedly followed by a decrease, but the relationship of this dynamic process to recovery is not well understood in either acute or chronic stroke. Indeed, a relationship between recovery and changes in brain activation patterns has not always been found.[50-53] Animal studies using more detailed measures of cortical function show that motor map expansion and the level of motor improvement after stroke are not linearly related. Although only animals demonstrating significant motor improvements show motor map expansion, adjuvant therapies that further enhance motor performance do not produce similar gains in motor map reorganization.[54,55] Thus, the relationship between measures of brain reorganization and behavioral improvement is complex.

The problem of relating changes in motor-related brain activation patterns to functional recovery in chronic stroke patients is compounded by the strong likelihood that functional improvement can result from an increase in compensatory movements instead of true motor recovery. Most studies use only clinical measures to evaluate functional change.[3,34,56] An important consideration here is the distinction between clinical *impairment* and *function* measures. *Impairment scales* measure specific motor aspects that may limit but are not related to task accomplishment (spasticity, strength, isolated joint motion, ie, Fugl-Meyer Scale[57]), whereas *functional scales* measure the level of task success (key turning, jar opening, ie, TEMPA Scale[58]). Functional gains, however, can occur even in the absence of motor recovery (ie, lost motor patterns have not returned).[22,59] For example, even with intensive task-oriented training, chronic stroke patients with poor motor recovery may improve movement speed and precision by recruiting the trunk to guide hand movement instead of using elbow extension and shoulder flexion.[26] Thus, fMRI changes may be misinterpreted as being associated with motor recovery when only compensation has occurred, as demonstrated in animal studies where the restoration of movement representations in residual motor cortex after stroke can be accompanied by motor map reorganization.[55,60] In other words, the increased fMRI signal within a given cortical area can reflect both neural recovery and compensation. This issue is separate from that of whether it is necessary in all patients for functional improvement to result from true motor recovery.

Body Function/Structure (Performance) Level

We distinguish between *recovery* and *compensation* in terms of how the movement is performed (Body Function/Structure level) and movement outcome (Activity level). At the Body Function/Structure level, the emphasis is on the quality of movement regardless of movement outcome or task accomplishment. Recovery at this level is characterized by the reappearance of premorbid movement patterns during task accomplishment. Evaluations at this level include muscle tone, electromyographic (EMG) activation and coactivation patterns, movement kinematics characterizing the range of passive and active joint movement, and temporal and spatial interjoint coordination. True motor recovery at this level, therefore, could be characterized, for example, by a decrease in spasticity or by a reduction in trunk displacement during a reaching or pointing movement.

Adaptive compensation at this level would be characterized by the appearance of alternative movement patterns during the accomplishment of a task. *Substitutive compensation* would reflect the use of different effectors to replace lost motor elements. It should be recognized that both adaptive and substitutive compensation may occur in various combinations at the performance level. An example of adaptive compensation is the use of excessive shoulder elevation and retraction to lift the arm when the active range of shoulder flexion is decreased.[61,62] At the level of the wrist and hand, alternative grasping strategies such as anchoring the fingers on the object to achieve a passive grasp can compensate for the lack of active finger extension.[59] In the leg, increased walking speed has been linked to greater amplitude of swinging of the nonparetic arm and leg when compared with the paretic arm and leg.[19] An example of substitutive compensation is the use of increased trunk forward displacement or rotation in place of active elbow extension to bring the hand to the object during unilateral reaching in subjects with poststroke hemiparesis.[22,32]

Numerous valid and reliable clinical scales measure impairments at this level. Scales such as the Modified Ashworth Scale[63] and the Composite Spasticity Index[64] document the presence or absence of resistance to passive range of motion associated with spasticity. The motor deficit may be quantified in terms of range of active joint motion and muscle strength as the ability of the patient to perform movements of individual joints or groups of adjacent joints. Scales such as the Fugl-Meyer Stroke Assessment Scale,[65] the Chedoke-McMaster Stroke Scale,[66] and the Reaching Performance Scale[13] measure upper limb impairment at the Body Function/Structure level. Although these scales may offer the clinician an appreciation of impairments, more detailed kinematic analysis of motor patterns during the performance of functional tasks would provide even more relevant information about movement patterns and motor compensations.[22,32]

Activity Level

Recovery at the Activity level requires that the task is performed using the same end effectors and joints in the same movement patterns typically used by nondisabled individuals. In contrast, *compensation* at this level often takes the form of substitution and would be noted if the patient were able to accomplish the task using alternate joints or end effectors. An example of the latter would be opening a package of food using 1 hand and the mouth instead of 2 hands. On some scales that measure functional ability, this patient would get a perfect score for accomplishing the task if the scale does not mention how the task is to be performed. Other scales allow for a partial score to be given if the task is partially completed or done too slowly or with difficulty. Thus, an activity may be successful or partially successful using compensatory motor strategies and movement patterns at the Body Structure or Function level or through substitution at the Activity level, but such scales do not provide information on specific strategies used.

Most evaluations at the Activity level neither specify how the task is accomplished nor which compensatory movements were used in place of motor patterns observed in nondisabled individuals. Examples of scales that measure function and not motor patterns per se are the Barthel Index,[67] the Box and Blocks Test,[68] the Frenchay Arm Test,[69] the Jebsen Taylor Hand Function test,[70] the Motricity Index,[71] the Action Research Arm Test (ARAT),[72] and the TEMPA test.[58] Difficulties arise in interpretation of studies that use such functional tests to indicate recovery because scores on these tests may improve either when the intervention results in improvements in motor patterns or in increasing compensations and the distinction between them is not made. An example of a relatively new scale that attempts to incorporate both measures of task success as well as movement quality during task accomplishment is the Wolf Motor Function Test.[73] More tests of this type that provide an appreciation of movement quality are needed in rehabilitation to better distinguish between motor recovery and compensation at the Activity level.

Conclusion

With the advent of increasing knowledge about neuronal plasticity and how the rehabilitation process influences neuronal connectivity as well as behavioral and functional activity, fundamental and clinical neuroscientists and clinicians are obligated to use a common terminology to improve communication. Consensus in the use of terms will assist in the distinction between compensation from true motor recovery at Health Condition (neuronal), Body Function/Structure (impairment), and Activity (disability) levels. This distinction can be achieved by measuring both motor impairment and function. If possible, studies should include functional measures along with measures at the impairment level (EMG and kinematics) to be able to distinguish between recovery and compensation.

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