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LETTER TO THE EDITOR

Neurorehabilitation: bridging neurophysiology and clinical practice

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Dear Editor-in-Chief,

Sensorimotor impairment of upper limb (UL) movements after stroke persists over time in a large proportion of patients. At 6 months post-stroke, 50–70% of patients continue to have UL impairments. The most common deficits of the UL are paresis and spasticity leading to residual functional deficits. These impairments affect the ability to perform functional tasks and lead to decreased quality of life and participation [1].

The focus of early acute stroke management (i.e., 72 h post-stroke) is on stabilizing the medical condition of the patient [2, 3]. In the post-acute stage (i.e., < 3 months after stroke), the focus shifts to neurorehabilitation that may include exercise combined with technology such as robot-assisted training [4] or neuromuscular electrical stimulation for UL rehabilitation [5] that has been shown to play a key role in functional recovery. Clinical trials aiming at enhancing training-based neuroplasticity have incorporated different principles of motor learning [6] and treatment interventions. Nevertheless, recent results from multi-center rehabilitation clinical trials aimed at investigating different therapeutic interventions based on principles of enhancing neuroplasticity for UL impairment (i.e., task-oriented training, robotic training and exercise intensity, and timing of intervention) have been disappointing. In all trials to date, patients all improved to predicted levels (~ 70% of initial baseline sensorimotor impairment [7] as measured by the Fugl-Meyer assessment), while there were no improvements beyond these levels attributed to the use of one type of intervention over another [8]. Moreover, previous studies have shown that although stroke patients improve in clinical outcomes, they do not integrate their affected arm in daily life activities [9, 10]. This highlights an important gap about the transfer of motor skills acquired during rehabilitation and actual arm use in everyday life. Addressing this gap requires a better understanding of the neural mechanisms underlying neural motor control. While current rehabilitation treatments are more focused on interventions based on principles of motor learning and neuroplasticity [6] (e.g., repetition, task difficulty, and motivation), less attention has been given to the theoretical framework of neural motor control and how control processes are disrupted after stroke.

Several neurophysiological measures can be used to investigate changes in neuroplasticity after stroke. Motor-evoked potentials (MEP) elicited by transcranial magnetic stimulation over the motor cortex have been used as a biomarker of stroke recovery [11] and to track changes in cortical excitability following neurorehabilitation [12]. Electroencephalography (EEG) is widely used to detect electrical cortical activity. Emerging evidence suggests the potential of EEG as a biomarker of motor recovery after ischemic stroke [11]. Functional and structural neuroimaging (e.g., functional MRI) have also been used in patients with stroke. The integrity of the white matter has been shown to correlate with better motor outcomes [11]. These neurophysiological techniques may provide new insights about the mechanisms of neurorehabilitation and may help in the development of more targeted rehabilitation interventions.

Recently, Sörös et al. [13] described a case of clinically significant recovery of the UL beginning 23 years after a stroke. The patient experienced severe central nervous system damage (frontoparietal infarction) due to embolization from the subclavian artery and the innominate artery when he was 15 years old. The stroke led to a severe motor impairment of the left UL with no functional movements of the elbow and hand, i.e., Chedoke-McMaster Stroke Assessment (CMSA) score was 1/7 (no voluntary movement). Twenty-three years later, after swimming on a regular basis and intense physiotherapy, the patient showed some initial movements of his left fingers. Physiotherapy consisted of hand therapy using a spring-loaded hand orthosis that assisted finger extension while resisting finger flexion. CMSA arm (5/7; decreased

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spasticity, presence of voluntary movement and synergies) and hand (4/7; decreased spasticity, predominance of synergistic movement) scores significantly improved over the years (more details in [13]). Functional MRI revealed cortical activity reorganization during flexion movements of the more affected UL, i.e., bilateral activation in the supplementary motor area, sensorimotor cortex, and cerebellum. Effecting changes in cortical organization patterns might open new directions to enhance recovery after stroke. Further studies should focus on remediating damaged neural control processes, which can be better understood in the context of current theories of motor control.

A theoretical framework has been proposed that muscle activity is controlled by shifting the tonic spatial stretch reflex threshold (TSRT), a development of the equilibrium point theory (reviewed in [14]). According to this theory, limitations of TSRT regulation due to stroke lead to disruptions in muscle activation during voluntary movements (i.e., spasticity and abnormal coactivation [15], which may result in deficits in interjoint coordination). These limitations in the ability of the central nervous system to tune muscle activation in specific joint ranges may impair the production of functional movement (e.g., reaching and/or grasping) and obscure motor learning processes. Direct evidence of this relationship comes from Turpin et al., [16] where changes in elbow flexor TSRT regulation during passive and active elbow movements correlated with UL Fugl-Meyer Assessment scores. In another study, Subramanian et al. [17] showed that motor learning may be preserved in chronic stroke patients but masked in specific ranges of motion affected by spasticity. Specific spatial zones in the range of elbow flexion and extension were identified according to limitations in TSRT modulation, i.e., the threshold angle at which elbow flexor activity emerged when the elbow was passively stretched into extension. The latter is referred to as the spasticity zone and corresponds with the angular range in which elbow flexor spasticity was present at rest. These findings highlight how a theoretical framework of motor control might help to better understand motor impairments and their recovery in patients with stroke.

In conclusion, taking into account the reorganization of cortical areas due to neuroplasticity and recent neurophysiological findings, future research should translate current theories on the neural control of movement into clinically relevant findings. To this end, bridging neurophysiological knowledge and clinical practice should drive the research agenda of the scientific community.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

References

1. Aprile I, Piazzini DB, Bertolini C, Caliandro P, Pazzaglia C, Tonali P, Padua L (2006) Predictive variables on disability and quality of life in stroke outpatients undergoing rehabilitation. Neurol Sci 27(1):40–46. https://doi.org/10.1007/s10072-006-0563-5
2. Bornstein NM, Guekht A, Vester J, Heiss WD, Gusev E, Homberg V, Rahlfs VW, Bajenaru O, Popescu BO, Muresanu D (2018) Safety and efficacy of Cerebrolysin in early post-stroke recovery: a meta-analysis of nine randomized clinical trials. Neurol Sci 39(4): 629–640. https://doi.org/10.1007/s10072-017-3214-0
3. Agostoni E, Carolei A, Micieli G, Provinciali L, Toni D, Vidale S (2018) The organisation of the acute ischemic stroke management: key notes of the Italian Neurological Society and of the Italian Stroke Organization. Neurol Sci 39(3):415–422. https://doi.org/10.1007/s10072-017-3200-6
4. Bertani R, Melegari C, De Cola MC, Bramanti A, Bramanti P, Calabro RS (2017) Effects of robot-assisted upper limb rehabilitation in stroke patients: a systematic review with meta-analysis. Neurol Sci 38(9):1561–1569. https://doi.org/10.1007/s10072-017-2995-5
5. Monte-Silva K, Piscitelli D, Norouzi-Gheidari N, Batalla MAP, Archambault P, Levin MF (2019) Electromyogram-related neuromuscular electrical stimulation for restoring wrist and hand movement in poststroke hemiplegia: a systematic review and meta-analysis. Neurorehabil Neural Repair 33(2):96–111. https://doi.org/10.1177/1545968319826053
6. Kleim JA, Jones TA (2008) Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res 51(1):S225–S239. https://doi.org/10.1044/1092-4388(2008/018
7. Winters C, van Wegen EE, Daffertshofer A, Kwakkel G (2015) Generalizability of the proportional recovery model for the upper extremity after an ischemic stroke. Neurorehabil Neural Repair 29(7):614–622. https://doi.org/10.1177/1545968314562115
8. Stinear CM (2016) Stroke rehabilitation research needs to be different to make a difference. F1000Res 5. https://doi.org/10.12688/f1000research.8722.1
9. Rand D, Eng JJ (2012) Disparity between functional recovery and daily use of the upper and lower extremities during subacute stroke rehabilitation. Neurorehabil Neural Repair 26(1):76–84. https://doi.org/10.1177/1545968311408918
10. Rand D, Eng JJ (2015) Predicting daily use of the affected upper extremity 1 year after stroke. J Stroke Cerebrovasc Dis 24(2):274–283. https://doi.org/10.1016/j.jstrokecerebrovasdis.2014.07.039
11. Stinear CM (2017) Prediction of motor recovery after stroke: advances in biomarkers. Lancet Neurol 16(10):826–836. https://doi.org/10.1016/S1474-4422(17)30283-1
12. Dos Santos RBC, Galvao SCB, Frederico LMP, Amaral NSL, Carneiro MIS, de Moura Filho AG, Piscitelli D, Monte-Silva K (2019) Cortical and spinal excitability changes after repetitive transcranial magnetic stimulation combined to physiotherapy in stroke spastic patients. Neurol Sci 40:1199–1207. https://doi.org/10.1007/s10072-019-03765-y
13. Soros P, Teasell R, Hanley DF, Spence JD (2017) Motor recovery beginning 23 years after ischemic stroke. J Neurophysiol 118(2): 778–781. https://doi.org/10.1152/jn.00868.2016

14. Feldman AG (2015) Referent control of action and perception: challenging conventional theories in behavioral neuroscience. Springer, New York. https://doi.org/10.1007/978-1-4939-2736-4
15. Musampa NK, Mathieu PA, Levin MF (2007) Relationship between stretch reflex thresholds and voluntary arm muscle activation in patients with spasticity. Exp Brain Res 181(4):579–593. https://doi.org/10.1007/s00221-007-0956-6
16. Turpin NA, Feldman AG, Levin MF (2017) Stretch-reflex threshold modulation during active elbow movements in post-stroke survivors with spasticity. Clin Neurophysiol 128(10):1891–1897. https://doi.org/10.1016/j.clinph.2017.07.411
17. Subramanian SK, Feldman AG, Levin MF (2018) Spasticity may obscure motor learning ability after stroke. J Neurophysiol 119(1): 5–20. https://doi.org/10.1152/jn.00362.2017