“What trains together, gains together”: strength training strengthens not only muscles but also neural networks

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“WHAT FIRES TOGETHER, WIRES TOGETHER” (8): on the cellular level, the use-dependent plasticity of neural networks has been known for over 60 years. Dependent on the timing of pre- and postsynaptic activation, transmission across synapses can either be facilitated or inhibited (2). On the level of the whole organism, these neural adaptations are thought to be the first step in a series of others to improve specific motor skills. Thus, depending on the learning stage, motor skill acquisition involves different physiological processes. In the human motor cortex, for instance, long-term potentiation (LTP) is thought to occur at existing synapses during the early phase of motor skill learning, whereas later phases involve neural processes like synaptogenesis (10).

Similar to motor skill learning, strength training comprises different stages, which differ with respect to the substrate of adaptation. The early force gains after strength training are thought to rely primarily on neural adaptations, while later on, structural changes within the tendomuscular system are considered to be predominant. So far, it is unknown whether the early neural plasticity after strength training relies on similar mechanisms than the one after motor skill training. Although previous electrophysiological strength training studies could indeed demonstrate that neural adaptations take place at the spinal and supraspinal level, the findings of those reports are inconsistent (for review, see 5): some studies assumed increased spinal excitability (e.g., 1, 13) while results obtained in other experiments suggested the opposite (e.g., 4). Similarly, some authors reported enhanced corticospinal excitability following strength training (7) whereas others did not (4, 9).

These discrepancies may be due to a differential contribution of the central nervous system (CNS) in different strength tasks (static vs. dynamic, tonic vs. ballistic, etc.), may depend on the duration of the training intervention, and/or may be related to methodological reasons. In this respect it could be demonstrated that adaptations assessed at rest may differ from adaptations measured during activity (e.g., 1, 9). Furthermore, when subjects were tested during a task they had previously trained, changes of the corticospinal excitability were opposed to those observed after measurements in an unfamiliar task involving the same muscles (11).

The above-mentioned examples highlight that there is the need for further research and especially new methodological approaches in order to gain a better understanding of the mechanisms related to strength training. In this issue of the Journal of Applied Physiology, Selvanayagam and colleagues (12) provide such a new insight in their paper “Early neural responses to strength training” as they have chosen an experimental set-up in which the neural plasticity in response to one single session of strength training, could be directly observed in changes of the behavioral outcome. The experiment was designed based on a previous motor control study of Classen et al. (6) who showed that short-term practice of direction-specific thumb movements can change the direction of stimulation-evoked thumb twitches. As in this earlier study, Selvanayagam et al. (12) used suprathreshold transcranial magnetic stimulation (TMS) to induce directionally consistent movements of the forearm. After the initial test, subjects underwent three different strength training sessions involving either 1) brief contractions or 2) sustained ballistic contractions or 3) slow, sustained contractions. In all three training protocols, subjects had to perform isometric contractions to produce a force in a direction 90° away from the TMS-evoked twitch direction. Interestingly, all three training protocols caused an immediate shift in the TMS-induced twitch force toward the training direction followed by a gradual shift back toward the initial twitch direction. The strongest effect was found in response to fast isometric contractions, which had to be sustained for some seconds (training 2). As no training-related changes could be seen after electrical motor nerve stimulation, this may suggest that the strength training rapidly, and transiently, established a change in the corticospinal network representing the forearm. In contrast to the motor learning study of Classen et al. (6), subjects contracted the muscles isometrically. Consequently, the change of the twitch direction cannot be regarded as a short-term memory of the kinematic details (6) of a specific movement but can rather be seen as a facilitatory response of the neural network driving the previously isometrically activated muscles and/or as an inhibition of the neurons being responsible for the antagonistic muscles. It is remarkable that the strongest adaptations were observed when both ballistic and maximum sustained force were produced but that sustained maximal force exercises were also able to induce an immediate change in the twitch force resultant. This may point out that neural adaptation in response to “typical” strength training exercises involving slow sustained maximal contractions share considerable similarities to adaptations observed following ballistic motor skill acquisition. Based on a phenomenological approach, the study of Selvanayagam and coworkers (12) therefore suggests that strength training results in a “gain” of functional neural connectivity—or more simplistically expressed: “What trains together, gains together.” Further studies have to identify whether the adaptation of twitch direction in response to strength training is correlated to an increase in force. This could be done by identifying the neural mechanisms underlying the changes in twitch torque direction and, in the next step, inhibit their formation. As Selvanayagam and coworkers (12) have transferred a well-explored motor learning paradigm into the field of strength training, comparisons can be easily made. For instance, LTP was shown to play a role in the skill acquisition after repetitive thumb movements on the basis of pharmacological evidence (3). If LTP is involved in the early phase of strength training, too, and if LTP

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is necessary for enhancing strength, a blockage of LTP should consequently reduce or prevent the change in twitch direction as well as a (potential) increase in force.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

REFERENCES