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Review Article

Spinal Adaptation Following Exercise Training: Narrative Review

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ABSTRACT

Background: This article aims to investigate the possibility of adapting the spinal circuits and the spinal cord in response to various eccentric, concentric, isometric, balance, and skill exercises, whether these changes are permanent or temporary.
Methods: A narrative review of studies conducted in the field of spinal adaptation following exercise training in Google scholar, Pedro, PubMed, Science direct, Cochrane, Scopus, SID databases in the period of 2000 to 2020 with the keywords: neural adaptation, spinal adaptation, exercise training, neuroplasticity, neuro-rehabilitation, spinal plasticity, eccentric training, isometric training, and concentric training was done. An effort was made to identify and examine research linked to exercise treatment and physiotherapy in healthy and sick persons from among the different studies in this topic.
Results: From 35 recruited articles, 12 articles were critically reviewed and reported in two contents: 1-Spinal adaptation and balance exercises -2- Spinal adaptation and isometric, concentric, and eccentric exercises
Conclusion: From this review, it can be concluded that the spinal network is fully adaptable, and the manner of this adaptation is completely dependent on training and motor function. The possibility and need of therapeutic application of the spinal plasticity phenomenon in the rehabilitation program of persons with neurological diseases such as stroke are underlined in people with neurological pathologies such as stroke.

Background

As a central nervous system component, the spinal cord can develop the activity-related plasticity that results from peripheral or cerebral inputs. In fact, brain or peripheral inputs can make changes in the spinal cord that some of which are permanent [1]. This issue is very important to justify recovery after spinal cord injuries and even in designing a sports program for professional athletes [1, 2]. For example, doing several weeks of resistance training on the ankle plantar flexors can increase the excitability of the soleus H-reflex, and balance exercises on slippery surfaces for several weeks can reduce the level of H-reflex [3, 4].

The central position of spinal motor circuits carries motor commands from supraspinal centers and sensory feedback from the environment on the one hand, and regulates motor output related to sensory information during motor function on the other; in fact, these circuits ensure a proper connection of movements with the surrounding environment [5].This study was conducted to find out whether the spinal circuits and the spinal

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cord itself can be modified and adapted in response to various eccentric, concentric, isometric, balance, and skill exercises? Will these changes be permanent or temporary, and in which areas would they occur?

Methods

Narrative Review the studies conducted in the field of spinal adaptation following exercise training on the databases Google scholar, Pedro, PubMed, Science direct, Cochrane, Scopus, SID in the period 2000 to 2020 with the keywords neural adaptation, spinal adaptation, exercise training, H-reflex, neuroplasticity, neurorehabilitation, spinal plasticity, eccentric training, isometric training, concentric training were performed. Article reviews or clinical trials were written in English searching about spinal and supraspinal adaptations following various types of exercises (strength, balance, etc.) with or without study follow-up included.

The initial search was conducted by two reviewers who were experts in the field of neurological physiotherapy. From a total of 35 publications, 12 relevant studies were chosen and thoroughly assessed for any potential biases or bad technique.

Results

Section 1: Spinal Adaptation and Balance Exercises

The spinal reflex system plays an important role both to control the standing position without disturbance and create a compensatory reaction during postural disorders. H-reflex is used to measure spinal adaptive plasticity. Tibial nerve electrical stimulation at the popliteal fossa creates H-reflex of the soleus muscle. Because the tibial nerve has both sensory and motor axons, electrical stimulation causes both a reflex and a direct muscle response. H-reflex is generated by transferring the action potential of Ia afferents to alpha-motor neurons and then neuromuscular junction. M-wave moves directly from the stimulation site to the neuromuscular junction via the motor axons. Low-intensity stimulation will produce an H-reflex without M-wave because thicker Ia fibers are recalled earlier than smaller motor axons. Augmentation of stimulus intensity will cause appearance of H_{max} and then M_{max}. Calculating the ratio of H_{max} to M_{max} will eliminate the problem of getting the same EMG before and after exercise. Alteration of the H_{max} / M_{max} ratio following exercise indicates a change in the sensitivity of alpha-motorenuron in response to Ia afferent inputs. Increasing the H_{max} / M_{max} ratio indicates higher motor neuron excitability or diminished presynaptic inhibition of Ia afferent terminals. Both of these processes boost alpha-motor neuron output, which increases neural drive to muscle. This is advantageous for achieving strong muscular strength. A drop in the Hmax / Mmax ratio after exercise, on the other hand, shows inhibition of the Ia afferent route, which results in less participation of the muscle spindle in activity. This will reduce the destabilizing movements and increase the movement control of the supraspinal centers [6].

The human central nervous system generates rapid responses to changes in the supporting surface and peripheral feedback. For example, maintaining dynamic balance while walking on a narrow path will cause a lower H-reflex amplitude compared to normal walking. H-reflex is also reduced by closing the eyes while standing. Both of these instances demonstrate that in increasingly challenging activities, the transmission of Ia afferents will be decreased. The H-reflex, on the other hand, will rise when postural requirements diminish, such as when mechanical support is added. These findings indicate that the spinal reflex system in humans is extremely conformable and can respond quickly to environmental changes. People with cerebellar ataxia who cannot suppress the H-reflex, experience more unsteadiness than healthy people.

The advantage of the reduced spinal reflexes in balance tasks is probably the prevention of joint fluctuations and the transferring of motor control to higher centers. Besides, individuals can learn to change spinal reflexes in response to certain standing conditions. For example, when a person is at an unstable surface, the person learns to lower the H-reflex amplitude within 2 hours. According to recent research, training on an unstable surface reduces the H-reflex without the need of electrical stimulation. These studies make this concept clear that the balance exercises can modulate the overall spinal reflex circuits and cause a sustained decrease in

Table 1: Studies used for spinal adaptation and balance exercises

Study/Authors	Population & Intervention	Outcome
Spinal and supraspinal adaptations associated with balance training and their functional relevance/ Taube W, Gruber M, Gollhofer A 2008	Review	The sensorymotor system of adults is well able to adapt in response to balance exercises. Neural balance control can be re-taught in people with impaired reflex function. Balance exercises, along with strength and jumping exercises, are beneficial and required for patients, the elderly, and even athletes to enhance, maintain, or restore motor function. This kind of spinal plasticity is task-specific.
Activity dependent plasticity of spinal circuits in the developing and mature spinal cord/ Tahayori B, Koceja DM 2012	Review	Neural circuits can have long-term plastic changes in response to activity. However, none of these studies could explicitly state that these plastic changes occurred exclusively in the spinal cord.
Balance training and ballistic strength training are associated with task-specific corticospinal adaptations/ Schubert M, Beck S, Taube W, Amtage F, Faist M, Gruber M 2008	22 men and 15 women with no history of ankle injury or disease, seizures, any neurosurgery or metal implants in the skull / Sensorymotor training (SMT), ballistic strength training (BST) and control group (CON)	In posture and movement control, the amount of H-reflex will be activity-dependent. However, the exercises did not cause systematic changes in the H_{max} / M_{max} ratio. No significant differences were observed between groups, regardless of whether the test was taken at rest or during exercise. This might indicate that activities like pre-synaptic regulation of the Ia nerves to learn new motor abilities have a short-term impact on the spine.

H-reflex levels in people with high postural demand. Decreased H-reflex excitability in ballet dancers is justified from this perspective. However, another group of studies on balance exercises states that spinal reflex behavior is task-specific. Task-specific reflex matching has been seen in balance exercises and strength training, and jumping [7, 8]. Older people demonstrate less reflex changes in response to postural alterations. But, studies showed that older people who participated in balance training programs could adapt H-reflex to the level of younger people.

It can be said that although the sensory -motor system of adults has limitations to modulate spinal reflexes, it has a good ability to adapt in response to balance exercises. It also suggests that neural balance control can be re-trained and re-learned in people with impaired reflex function. In fact, along with strengthening and jumping exercises, balancing exercises are beneficial and important to enhance, maintain, or restore motor function, and this may be applied not just to patients or the old, but also to athletes. In addition, spinal plasticity was shown to be highly task-specific [7]. Numerous studies have shown that the level of H-reflex amplitude in professional dancers significantly decreases. This decrease is probably in terms of the long-term performance of dance-specific movements. Simultaneous contraction of the lower limb muscles, which usually occurs in ballet, increases presynaptic inhibition and decreases reciprocal inhibition. This reduction in H-reflex activity is part of the process of achieving high levels of skillful movements and maintaining balance in specific ballet techniques [8].

In Gruber et al. 2007b study, 37 participants were divided into three groups: sensorimotor training (SMT), strength ballistic training (BST), and control group (CON). The evaluation was performed before and after 4 weeks of training, including 16 sessions of 55 minutes of BST or SMT training. Finally, similar to other studies in this field, the researchers in this study stated that to control the posture and movement, the amount of H-reflex will be activity-dependent. However, the exercises did not cause systematic changes in H_{max}/M_{max} ratio. No significant differences were observed among groups, regardless of whether the test was taken at rest or during exercise [4]. This might indicate that activities like pre-synaptic regulation of Ia afferents to learn new motor abilities have a short-term impact on the spine. Naturally, the tiny number of participants in each group may be statistically successful in attaining such a result. In studies of Gruber et al. 2007b and Taube et al. 2007, a significant reduction in H-reflex and stretch-reflex amplitude was observed following sensorimotor exercises. However, a decrease in the H_{max} / M_{max} ratio in these studies was justified with supraspinal effects and not spinal. It can be concluded that the spinal effects are relatively less, and instead the control role of the direct corticospinal pathway is greater in the acquisition of new motor activity in the foot in humans [6]. A summary of the effects of balance exercise on spinal adaptation is presented in Table 1.

Section 2: Spinal Adaptation and Isometric, Concentric and Eccentric Exercises

Per Aagaard et al., in a review stated that the use of

Table 2: Studies used for spinal adaptation and isometric, concentric and eccentric exercises

Study/Authors	Type of study	Intervention	Results
Spinal and supraspinal control of motor function during maximal eccentric muscle contraction: Effects of resistance training/ Aagaard P 2018	Review	----------	Performing HLRT for long periods of time, such as weeks or months, will increase H-reflex and V-wave responses during maximal eccentric contraction along with increased eccentric muscle strength, increased spinal motor neuronal excitability, decreased presynaptic and postsynaptic inhibition, and increased motor drive from descending pathways. All of these events indicate adaptive changes in the spinal neural circuits.
Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses/ Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P 2002	14 men who had previously participated in resistance training programs	Measurement of V-wave and H-eflex amplitude in response to 14 weeks of progressive resistance training	The system's contractile demands may be met by modulating spinal stimulation and inhibitory pathways. Furthermore, evaluating the H-reflex at rest may not correctly represent neuromuscular function during muscle contraction.
Short-term plasticity of human spinal inhibitory circuits after isometric and isotonic ankle training/ Jessop T, DePaola A, Casaletto L, Englard C, Knikou M 2013	26 people without a history of orthopedic or neuromuscular problems	The isotonic training protocol includes 5 sets of 50 repetitions per set and 3 minutes of rest between sets. Isometric exercises consisted of 5 training sets with 20 5-second contractions per set and 2 minutes of rest among training sets.	The decrease in reciprocal inhibition and presynaptic inhibition observed immediately after exercise in this study indicates early activity-dependent plasticity levels in the spinal interneuron circuits. The fact that the amount of homosynaptic depression of the soleus H-reflex did not change in any of the exercise groups suggests that homosynaptic depression may depend on the duration, type, and amount of exercise, and that these factors should be considered in patients with depressed homosynaptic depression. To be considered
Spinal reflex plasticity during maximal dynamic contractions after eccentric training/ Duclay J, Martin A, Robbe A, Pousson M 2008	18 healthy male students with no history of neurological diseases	18 sessions of eccentric exercises during 7 weeks and measurements	Increased voluntary torque following eccentric exercise, depending on the type of contraction, may indicate an increase in the drive of the supraspinal centers as a result of spinal neuronal adaptations.
Changes in H reflex and neuromechanical properties of the trapezius muscle after 5 weeks of eccentric training: a randomized controlled trial./ Vangsgaard S, Taylor JL, Hansen EA, Madeleine P 2014	29 men &women	9 sessions of eccentric trapezius and shoulder exercises during 5 weeks	Trapezius H-reflex pathway excitability increases after 5 weeks of eccentric training. This might imply an increase in efferent drive, which could be explained by a reduction in motor neuron Ib inhibition.

eccentric supramaximal contraction exercises can increase the V-wave during a maximal eccentric contraction, indicating adaptive changes in the function of spinal circuits or descending paths in response to heavy resistance training occurs [9].

In a trial of 14 male volunteers who had previously participated in resistance training programs, the researchers reported an increase in V-wave and H-reflex amplitude in response to 14 weeks of progressive resistance training, indicating adaptive neurological changes including changes in irritability and an increase in neural drive in the descending corticospinal tract as well as an increase in motor neuronal excitability and a decrease in presynaptic inhibition. This study also increased the H-reflex amplitude in response to 14 weeks of resistance training, indicating an increase in alpha-motor excitability and an increase in nerve drive from the descending pathways of higher centers. Decreased presynaptic inhibition is also involved. The data obtained in this study on H-reflex show that spinal excitation and inhibitory pathways can be modulated in response to the contractile needs of the system. Besides, research data suggest that measuring resting H-reflex may not reflect neuromuscular function during muscle contraction. In fact, in this study, the H-reflex at rest did not change after 14 weeks of strenuous resistance training [3].

Homosynaptic depression (HSD), a progressive decrease in the postsynaptic potential amplitude in response to successive presynaptic stimuli, is one of the simplest examples of synaptic plasticity. None of the training protocols in Aagaard study affected the H-reflex homosynaptic depression of the soleus muscle. Other studies in this field can support the hypothesis that the difficulty of the motor task as well as the duration of training may be important factors to increase the level of homosynaptic depression. Therefore, these factors should be considered in patients with neurological lesions when the goal is to reduce homosynaptic depression.

Traci Jessop et al., stated that the amount of reciprocal inhibition depends on the level of physical activity of each person, which means that in more active people, it will be bigger. However, plasticity related to reciprocal inhibition in humans is still highly unknown and needs further study, especially during the resting phase after exercise. In the work by Traci Jessop et al., a reduction in reciprocal inhibition and presynaptic inhibition was detected shortly after exercise, indicating early activity-dependent plasticity in the spinal interneuron circuits. The fact that the amount of homosynaptic depression of the soleus H-reflex did not change in any of the exercise groups suggests that homosynaptic depression may depend on the duration, type, and amount of exercise. So, these factors should be considered in patients with depressed homosynaptic depression [10] .

In a study by Duclay et al., on healthy male students without any neurological disease, the intervention consisted of 18 sessions of eccentric exercise over 7 weeks. The H / M ratio increased solely during maximum eccentric contraction for the soleus muscle in the workout group, whereas it increased regardless of the kind of contraction for the inner head of the gastrocnemius muscle. The researchers concluded that an increase in voluntary torque following eccentric exercise, depending on the type of contraction, may indicate an increase in supraspinal drive as a result of surface adaptation [11]. Vansgaard et al., examined H-reflex plasticity in the shoulder area and trapezius for the first time, and randomly selected 29 healthy men and women in the eccentric exercise group (n = 15) and the control group (n = 14). The training program consisted of 9 sessions of eccentric training during 5 weeks. A dynamic shoulder dynamometer was used to do eccentric workouts for the right shoulder. Electrical stimulation of the C3 / 4 cervical nerves was used to record the H-reflex of the middle trapezius before and after exercise. Before and after exercise, electromyography was obtained from the middle trapezoid. In the exercise group, H_{max} and maximal voluntary contraction (MVC) and rate of force production significantly increased, while M_{max} remained unchanged in both control and exercise groups. Finally, it was reported that the excitability of the H-reflex pathway increases after 5 weeks of eccentric training. This could indicate an increase in efferent drive, which can be explained by a decrease in Ib inhibition of motor neurons [12]. Table 2 shows a summary of reviewed articles in this section.

Limitations

This narrative review does not contain articles before 2ooo and after 2020 which may have some effects on conclusion.

Conclusion

In this study, we first tried to search for the concept of spinal adaptation and how to evaluate it through H-reflex. From this review, it can be concluded that the spinal network is fully adaptable and the manner of this adaptation is completely dependent on training and motor function. For example, balance exercises can reduce H-reflex, and strength training, especially eccentric resistance training, is associated with increased H-reflex and V-wave levels. The age limit of the participants in most of these research, which makes it difficult to generalize the findings, was an intriguing problem in the evaluated publications. Researchers may be prejudiced in doubting the veracity of the data given in certain situations. The problem of spinal plasticity in patients with neurological diseases such as stroke was also addressed. By reviewing studies in cycling exercises and spinal adaptations following cross-education, an attempt was made to highlight the possibility and necessity of clinical use of the spinal plasticity phenomenon in the rehabilitation program of neurological patients.

Conflict of Interest: None declared.

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