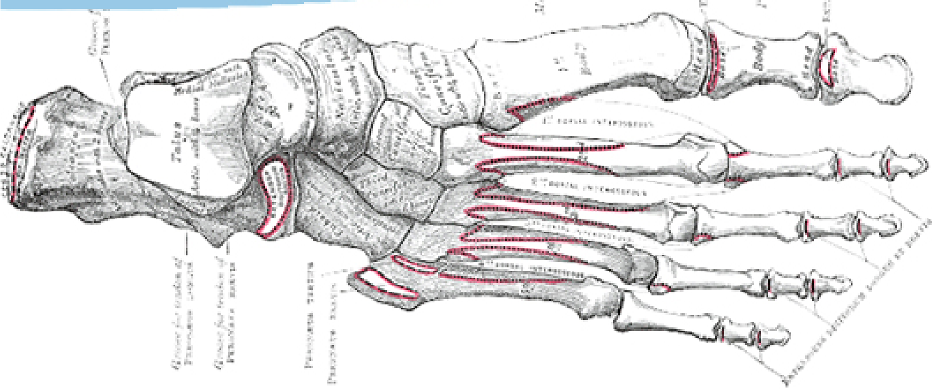

3. Revisión 1

Perceptive learning and its implications in physical rehabilitation

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Abstract: Sensory stimuli provide benefits and better results when combined with a motor treatment, both when there is a motor deficit and in the correct execution of motor patterns in healthy people.For example, the improvement of gait pattern has been demonstrated when it is accompanied of tactile and/or visual stimuli. Sensory stimuli increase the excitability of spinal motor neurons, reducing motor response time to a requested pattern. To fully understand how we can influence the treatment by sensory stimuli to improve a specific motor pattern, we must use neuroimaging to know the centres and structures that are activated for each type of sensory stimulus in the nervous system and to discover the relationship that these structures keep to each other. Besides, it is also important to make clear the theoretical bases that currently support this type of treatment, i.e., sensory substitution, cross-modal, sensory integration, cognitive learning, etc. Today, sensory stimuli are mainly used to learn about and intervene in sensory disorders such as visual impairment. Nowadays, different interventions are known from occupational therapy and physiotherapy in which applying proprioceptive or vestibular stimuli are starting to be applied to improve motor performance patterns. A greater knowledge of the neural processes that connect the sensory associative cortexes with the ones in charge of executing a motor response would allow a qualitative leap in [the] interventions [of the professionals], as well as in [the achievement of the]results of the rehabilitation programs.

Resumen: Los estímulos sensoriales proporcionan beneficios y mejores resultados cuando se combinan con un tratamiento motor, tanto cuando existe un déficit motor como en la correcta ejecución de patrones motores en personas sanas, por ejemplo, se ha demostrado la mejoría del patrón de la marcha cuando se acompaña de estímulos táctiles y/o visuales. Los estímulos sensoriales aumentan la excitabilidad de las neuronas motoras espinales, reduciendo el tiempo de respuesta motora a un patrón pedido. Para entender completamente cómo podemos influir mediante el tratamiento por estímulos sensitivos para mejorar un patrón motor concreto debemos conocer por neuroimagen los centros y estructuras que se activan para cada tipo de estímulo sensorial en el sistema nervioso y qué tipo de relación guardan todas estas estructuras entre sí. Y además dejar claras las bases teóricas que actualmente respaldan este tipo de tratamiento tales como la sustitución sensorial, cross-modal, la integración sensorial, aprendizaje cognitivo… La principal aplicación de los estímulos sensoriales en la actualidad se dirige al aprendizaje y la intervención en trastornos sensoriales como problemas visuales. Actualmente se conocen diferentes intervenciones desde la terapia ocupacional y la fisioterapia en las que se está empezando a aplicar estímulos propioceptivos o vestibulares para mejorar patrones de ejecución motores. Un mayor conocimiento de los procesos neuronales que conectan las cortezas asociativas sensoriales con las encargadas de ejecutar una respuesta motora permitiría dar un salto de calidad en las intervenciones de los profesionales y en la consecución de los resultados en los programas de rehabilitación.

Keywords: Neurodevelopment, sensory stimulation, physiotherapy, occupational therapy, learning, motor pattern.

Palabras clave: Neurodesarrollo, estimulación sensorial, fisioterapia, terapia ocupacional, aprendizaje, patrón motor.

Objetives

The following article/revision aims at:

- Knowing the approaches and frameworks that currently support the actions of physical therapists and occupational therapists and their implications for physical rehabilitation.
- Delving into different theoretical models of neuronal plasticity and sensory processing.
- Knowing the importance of a sensory intervention both previously and during physical treatment in order to know the advantages of doing a combined treatment.

Introduction

In transdisciplinary teams, when we deal with people who have some kind of functional diversity or disability of physical origin, we try to achieve that a particular person reaches the highest degree of independence in daily life activities using techniques that focus on joint ranges, muscular power, etc. However, we do not consider that many problems are caused by poor sensory processing, and we rely on theoretical models that do not take into account the evolution and the state in which the patient obtains sensory stimuli which, if the state of function is normal, are not perceived since all its processing is automatic.

From the approaches of neurodevelopment and neuro-rehabilitation, we can obtain theoretical models and techniques of treatment based on the use of sensorial stimuli, such as the Bobath model. This model establishes that motor learning is necessary for the correct accomplishment of tasks, establishing a feedback between the sensory cortex that learns the sensation of movement and the motor cortex that, after several repetitions, is able to perform the required task. Another approach is the one developed by Jean Ayres. His model of sensory integration explains the ability of the central nervous system (CNS) to organise the sensory information that allows us to respond to the problems we may face. Nowadays, different stimuli are used during the treatment. For instance, we can mention the use of Kinesio tape, the use of Kabat diagonals, the use of TENS (transcutaneous electrical nerve stimulation), etc. We do not only apply corrective elements, nor do we extend the joint range of the shoulder, hip or any other joint, but, at all times, the brain does not stop receiving different proprioceptive, vestibular, tactile stimuli. The problem is that this information is not used in an orderly way or directed towards a specific objective. Would the results improve in the intervention of professionals/interventions? Yes, either qualitatively or quantitatively. A proof of the aforementioned is found in the change in protocols of action in cases of/in processes of traumatic origin, where proprioceptive treatment, for example, in sprains has become essential and mandatory if we want to not reach chronicity of the lesion and avoid relapses.

There are several theoretical models that attempt to explain what happens in the cerebral cortex and how processing occurs. These are sensory integration, sensory substitution, cross-modal plasticity and metamodal processing theory. When we study these models, we can obtain information on which stimulus or sensory modality is the most adequate to get a particular response. We can also get to know whether, alternatively, working with several stimuli at the same time produces better cortical effects; know if there are specific areas that are repeated in people that are concretely stimulated by each sensorial modality, forms of sensorial learning, how to use the stimuli to generate to improve in the motor responses ... Examples of the use of sensory modalities for improvements in specific motor activities are:
Marchese, R et al found that patients with Parkinson's disease improve their autonomy in daily life activities significantly when, in addition to following a rehabilitation protocol, sensory stimuli are applied during training. (1) Studies such as that of Rao N. et al studied the postural improvement in people with diabetic neuropathy, who may have between 1.6 and 35% more chances of falling (2) The study of Rao N. et al and other studies aim to demonstrate changes in posture improvement, reduction of postural oscillation, the speed of movement, etc. when we apply proprioceptive, tactile and vestibular stimuli. These studies defend and try to demonstrate that, independently of the area where the sensory stimulus is applied, the individuals studied are able to improve the motor activity more than those that do not receive the stimulus (3-10). When we pursue improvement of balance and gait in patients with diabetic neuropathy, it is not necessary to apply a tactile stimulus to the lower limbs, but it could be applied to the upper limbs. The place of application is not essential, but the existence

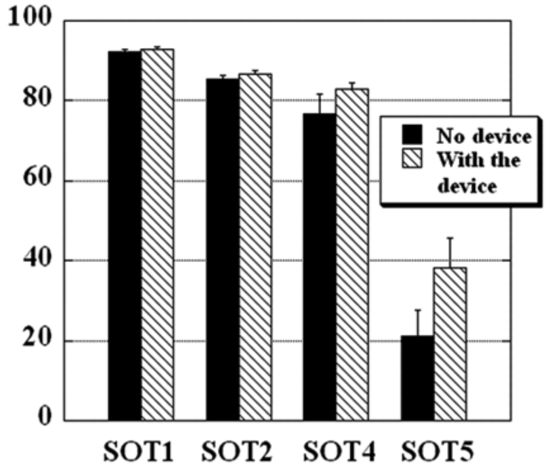

Figure 3.1: La barra oscura indica los resultados obtenidos por sujetos sin estimulación eléctrica y la barra a rayas marca los resultados de sujetos que han sido sometidos a un estímulo.
Rao N, Aruin AS. Auxiliary sensory cues improve automatic postural responses in individuals with diabetic neuropathy. Neurorehabil Neural Repair. United States; 2011 Feb;25(2):110–7

of a stimulus.

In neurological pathologies such as balance disorders, it is interesting to provide sensitive information to achieve a more effective physiotherapy treatment. As it has been proven, sensory information is currently being combined with motor therapy in pathologies such as Parkinson's, diabetic neuropathy, spinal cord injury or hemiparesis (11-15).

Review/Revisión

This review/revision gathers ideas from several approaches to obtain potential benefits for motor-based disorders. For such purpose, several theories explaining the processes that take place in the CNS in response to sensory stimuli, as well as works based on these models, have been reviewed, being the following: sensory integration, sensory substitution, cross-modal plasticity and the metamodal theory.

The sensory integration model by Jean Ayres. (16, 17)

Sensory integration is a neurodevelopmental model of occupational therapy that explains the capability of the CNS to interpret and organise the data inputs received by the sensory organs. This information is analysed and used by the brain and lets us respond correctly to certain environmental demands.

The works of J. Ayres are mainly based on learning and behaviour disorders. His theory establishes several consecutive levels, the last of which results in the correct development of ADL. The functionality of each level requires an adequate performance of the previous one.

- -Level 1: Tactile, vestibular and proprioceptive experiences.
- -Level 2: Movement planning, attention, body image.
- -Level 3: Eye-hand coordination, object manipulation, gross motor control, language.
- -Level 4: Abstract reasoning, behaviour, ADL.

This theory aims to account for the relationship between difficulties in academic learning and difficulties in interpreting the sensory information from the body and the environment in individuals with general learning disorders or clumsiness.

When the information enters the brain, it must be processed. To do so, 4 steps take place:

- -Registration: consciousness of each stimulus.
- -Modulation: regulation of the intensity of the stimulus
- -Discrimination: interpretation, the distinction of the relevance of the stimulus.
- -Integration: Connection of the stimuli to interpret the environmental demands.

Once these steps have been followed, it is possible to provide an adaptive response to overcome a certain obstacle or environmental demand. If the whole sensory processing is correct, an adaptive response will be carried out. This happens because all the sensory stimuli are properly integrated. Nonetheless, if any intermediate process fails, a "sensory indigestion" (in the author's words) will happen. This "indigestion" means that our brain is not able to process all the information from the environment because there are too many stimuli or because these are insufficient. If the disorder is located at the registration level, the stimulus is insufficient to induce a response (hyporesponsive patient). Consequently, if the stimulus has a normal intensity (for other people), the patient perceives it as an excessively powerful stimulus and responds exaggeratedly (hyperresponsive patient). Finally, the disorder may be located at the integration level, leading to difficulties in motor planning, sequencing, temporal-spatial organisation, etc. The treatment proposed by the Sensory Integration Model is based on providing sensory experiences of at least two of the three types of sensory inputs. The presentation of sensory inputs aims to regulate the patient's alertness, permitting subsequent challenges on posture control, coordination, laterality, ocular control, etc.

Sensory substitution

This model offers theoretical support to understand how a tactile stimulus may improve the neuronal network, eventually leading to an improved balance through a huge processing network. This network includes the vestibular, proprioceptive and visual systems, as well as their associated areas of sensory processing, the cerebellum, etc. For example, tactile sensitivity can be used to specifically stimulate the cortex that processes vestibular information in order to improve balance and/or walking. In the same vein, an artificial device can be used to provide tactile information, thus stimulating the visual cortex (18). Briefly, sensory substitution consists in producing a neuronal response from a specific type of sensitivity by stimulating another sensory modality with an artificial device. "'If a subject without functioning eyes can perceive detailed information in space, correctly localise it subjectively, and respond to it in a manner comparable to the response of a normally sighted person, I believe it is fair enough to apply the term 'vision'" (Bach-y-Rita, 1972)".
Although the majority of cases reported in the literature about/on sensory substitution are based on vision substitution, there are more examples, such as the vestibular-tactile system.

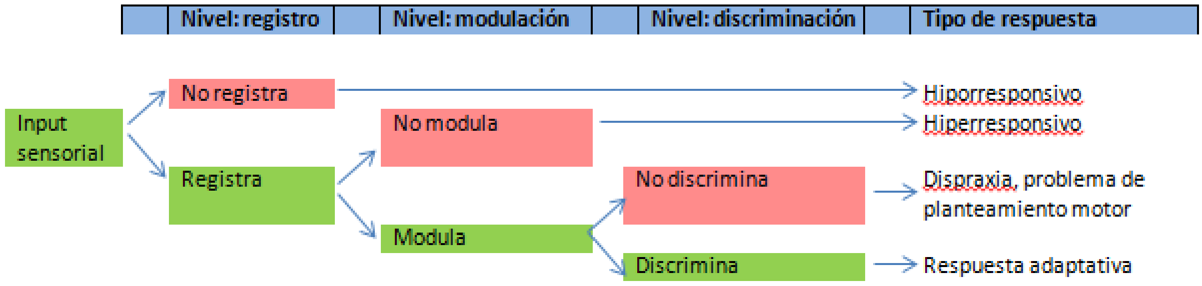

Figure 3.2: Del Moral Orro G., Pastor Montaño MA, Sanz Valer P. Del marco teórico de integración sensorial al modelo clínico de intervención. TOG (A Coruña) Vol 10. Num 17. May 2013

This theory is supported by the neuroplasticity observed in the brain (including that of adults) following perceptual learning. The study of perceptual learning mainly aims to understand how the repetition and practice of a given task lead to an improvement in other tasks, as well as to an increased efficiency and plasticity in the cortex, both in particular areas and in general (19).

Figure 3.3: Proulx MJ, Brown DJ, Pasqualotto A, Meijer P. Multisensory perceptual learning and sensory substitution. Neurosci Biobehav Rev. United States; 2014 Apr;41:16–25

The Sensory Substitution Model explains how a sensory stimulus is able to activate a particular area of the cortex that regulates a different sense, on the basis of the reverse hierarchy theory of perceptual learning. Any sensory modality can activate its corresponding area in the cortex, but its subsequent processing requires afferent information towards the associative cortex, where the sensory modalities converge. The reverse hierarchy theory of perceptual learning establishes that the flow of information is not only ascending. Instead, when a task learning process is involved, the flow goes downwards in the hierarchy, leading to a larger recruitment of the sensory cortex.

Cross-modal plasticity and the metamodal theory During many perceptive and cognitive processes, transmodal connections have been observed. This means that perceptual learning may take place through different sensory modalities. For example, an auditory influence has been observed in visual movement tasks, and visual influences have been observed in auditory learning. In the same vein, connections between taste and audition, or between somatosensory discrimination and audition, have been observed. (19-31). It has been proved that, when a subject lacks the main entry of a sensory modality (i.e. vision), the cortex area that processes that modality does not cease its normal activity. The metamodal hypothesis was developed to account for evidence that the same brain regions normally responsive to visual categories maintain such response selectivity in the absence of visual experience. For example, the lateral occipital area is involved in the perception of object shape and identity. When a blind person uses tactile stimuli to recognize objects, this region is still activated for shape and object discrimination and, therefore, must have supramodal properties since it is able to be activated and carry out its function despite not receiving information from the main sense modality (in this case, the shape perception in the visual cortex). These results have been supported by evidence in the auditory domain: an area once thought to be visual, as it is the lateral occipital complex, and to be involved in shape recognition, was activated during an auditory stimulation (19, 32-41).

The cross-modal theory aims to account for cortical activations on the basis of the strengthening of specific connections among different cortex areas through specific stimuli in the absence of a particular sensitivity (31-41). However, this theory has not been demonstrated. Per-

Figure 3.4: Proulx MJ, Brown DJ, Pasqualotto A, Meijer P. Multisensory perceptual learning and sensory substitution. Neurosci Biobehav Rev. United States; 2014 Apr;41:16–25

ceptual learning according to the reverse hierarchy model proposed by the metamodal organisation. In this diagram, the visual input (red) has been eliminated. The visual cortex is in charge of the spatial processing, but in the absence of a visual stimulus and in the presence of an auditory stimulus, this cortex area does not cease its function, resulting in the perceptual learning of the visual areas. The visual cortex areas detect, process and differentiate visual patterns, and even when the main stimulus is auditory, this area induces visual representations, also in blind subjects.

Conclusions

The input of sensory information might be used to improve motor patterns. Nowadays, it is known that working on proprioception is effective to improve trauma lesions such as sprains and fractures. Furthermore, sensory information is currently being combined with motor treatment in disorders such as Parkinson's disease, diabetic neuropathy, spinal lesions, hemiparesis, etc.

Every task requires the correct integration of sensory stimuli and the activation of various areas of the cortex. Several sensory modalities need to be used in order to increase the cortical recruitment and thus obtain a correct motor performance. The different models of neurodevelopment support the sensory integration theory and provide its practical framework with a theoretical background. For example, [they support] the need to offer different sensory modalities (vestibular, proprioceptive and tactile) to obtain the right alertness that let us improve the ADL.

We consider that the current treatments used in occupational therapy and physiotherapy should include both sensory assessments and treatments as a key goal.Considering that the patient will require to automatically process all the sensory inputs after discharge, and a bad processing would lead to a non-adaptive response.
In order to know the specific stimulus that must be applied to obtain the target response, it is essential to know and understand the learning and sensory stimulation pathways, the associative centres, and how each sensory modality influences the ulterior motor responses. Further research is warranted to determine if the results depend on the sensory modality.Moreover, it will determine whether the simultaneous stimulation on several sensory modalities results in better outcomes in comparison with stimulation alone or not. Theories of intervention from occupational therapy and physiotherapy need to be reviewed/revised, updated and adapted. This is especially important in the domain of neurodevelopment, in order to improve the current interventions and obtain better outcomes.

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