The Biology of Physical Restoration
And Rehabilitation Science
(or The Biology of Biomechanics or The Neuropsychology of Neuromechanism)

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Introduction

Assessing outcomes for extra-corporal orthotic and prosthetic clinical and technological intervention is fairly straight forward: just ask. Of course, the resulting subjective interpretation (ratings) might not fully capture or accurately reflect the underlining biological issues involved in physical restoration and rehabilitation of individuals with desensitized or missing limbs. Further, such subjective inquisition does not represent "hard" science, and the results of this method of inquiry will doubtlessly be less than wholly convincing to third party payers. A reproducible, consistent and (most importantly) predictable method for scientific testing or proving that any one intervention modality is preferable to any other needs to be developed. To do this, we need to find answers to the following questions. What are the underlining biological issues involved in physical restoration and rehabilitation? What makes a mechanical device biological, and what is the essential role of applied or clinical biomechanical engineering in physical rehabilitation science? The answers to these questions lies in the understanding of how biomechanics and neural mechanisms interact to facilitate correlation of sensory perception skills with normal body imagery skills and the acquisition of sensorimotor skills associated with control and manipulation of the orthotic, prosthetic or robotics device.

Discussion

Physical restoration and rehabilitation of individuals with desensitized or missing limbs is an immensely complicated issue involving, among other disciplines, mechanical engineering, neuromechanics, biomechanics, neurology, neuropsychology, psychophysiology, clinical and developmental psychology, as well as innumerable medical/therapeutic intervention modalities. Linda Resnik PT PhD, director of public health research at Brown University, has recently expressed profound concern regarding the validity and reliability of current clinical outcome assessment modalities. I share her concern because subjective interpretation or rating of clinical outcomes of such a complicated issue as physical rehabilitation is indeed inherently problematic. Furthermore, the data being presented for subjective analysis and interpretation (other than mechanical) is in itself subjective, which makes valid and reliable interpretation even more difficult.

All conscious human endeavor is ultimately interpretative and analytical, and thus a personal and subjective experience. There is no way around this undeniable and inescapable fact; we all experience the outside world subjectively. But information pertaining and leading to subjective observation and interpretation must be held fully accountable to the scientific method whenever possible and to the greatest extent possible. The O&P profession is not currently providing this type of objective information leading to a more scientific assessment of clinical O&P outcomes.

If we choose to take a biocentrism approach to physical rehabilitation, we need to define the essential biological issues involved. Simply stated, an individual who is successfully physically rehabilitated think or conceive of themselves as whole and normal, they perceive or experience physical sensations of normality and they acquire sensorimotor skills that allow them to purposefully, meaningfully and voluntarily interact with their environment. The extent to which an extra-corporal orthotic-prosthetic or robotics device meets these criteria is the extent to which the mechanical device is indeed biological. In other words, the primary biological purpose of a biomechanical device is to facilitate a sense of wholeness and normality when the primary mechanical purpose of the same bioengineered device is to effectively support or replace a desensitized or missing limb. Please keep in mind that this is not strictly or even primarily a psychological issue. Rather, and in most cases, these issues are manifest in neuromechanical and biomechanical function. If we were cosmetic dentists or surgeons, elective intervention modalities inevitably entail psychological issues because the patient does not want to feel whole and normal; they want to feel like glamorous movie stars. Clinical O&P is usually not burdened with this potentially adverse psychology because orthotic-prosthetic clients would like very much just to feel whole and normal again (There are rare exceptions to this rule as pointed out by Mark Geil PhD. Director of O&P at Georgia Tech. in his case presentation entitled "Idiopathic Toe Walkers").

The question then arises: how do we physically measure how well the mechanical O&P device facilitates the essential role of applied biomechanics in physical restoration and rehabilitation? To answer this question, we need to understand the associative and acquisitive interaction between body imagery skills and sensory perception skills. The following 4 minute video illustrates how perceptual awareness of our environment is acquired. http://youtu.be/e5B5iLIHth4

To summarize, the subject learns to perceive the physical nature of the objects held in her hand by physical control and manipulation of those objects with her fingers stereo gnosis. As she manipulates the objects, she experiences sensations that imply certain features and characteristics of the object. These sensations are referred to as "implicit" sensory experiences as described by O'Regan in his 1999 paper entitled "Skill, Corporality and Alerting Capacity". These implicit sensations remain at the perceptual level of consciousness until the subject learns to predict or anticipate the interactive relationship between the image of the object with what the object feels like. When we associate an image with a sensation, we can think us this as reverse correlation. This interaction has been most recently defined as "Bayesian exploratory skills" by researchers at University of Southern California. The instant the subject can predict or anticipate how the image of the object will be affected by sensory (tactile) input and how sensory input will be affected by manipulation of the image (object) is the exact moment the subject acquires a conceptualized or "explicit" sensory awareness of the object, what neural scientists commonly refer to as "conscious perceptions". In other words, the sensation is experienced as a fully formulated, developed, conceptual and accurate kinesthetic event. However, in physical restoration and rehabilitation, it is preferable to associate (correlate) sensory input with a preconceived notion (image) of wholeness and normality.

At this point, you might ask yourself what does any of this have to do with technical and clinical O&P? It is correlation of sensory input from the O&P device with and to imagery skills or sensations that allows the wearer to conceive of themselves as a whole and normal person. Without these conscious perceptions or acquired conceptualization skills, the subject can not optimize voluntary interaction with their environment when connected to and operating the orthosis/ prosthesis or robotics device.

In essence, what the subject learns is neural correlation of sensory emanation biomechanically engineered into the supportive or replacement rehabilitation device with normal body imagery skills or sensations. The primary measurable determinate of neural correlation is anticipation of neuromechanical and biomechanical interactivity. Marcus Raichle PhD. at the Washington University School of Medicine Dept. of Neurology and Radiology in St. Louis has determined that a large fraction of the overall brain activity – from 60-80 percent of all energy used by the brain is dedicated to predictions about one's body and its' relationship to the environment in anticipation of paltry sensory input reaching it form the outside world. Terry Sejnowski PhD. at the Howard Hughes Medical Institute uses the phrase "parsimonious energy consumption" rather than "paltry sensory input" to describe basically the same thing; the "timing" of electrical spikes to encode information and rapidly and efficiently solve neurocorrelation problems. This concept of anticipatory input or timing is corroborated with the "Raise to Threshold" theory recently postulated by researchers at the Stanford University Dept. of Neuroscience and by the Merzenich dictum – "neurons that fire together wire together". In other words, if we can physically measure how well the subject can correlate perceptual skills of sensory information emanating form the O&P device with normal body imagery skills or sensations, we can physically measure rehabilitation efficacy in terms of neurocorrelation coefficients. These "hard numbers" or correlation coefficients (performance or proficiency) can then be compared with associated somatosensory capacity coefficients (degree of difficulty) and monetary expenditure to accurately determine rehabilitation productivity efficiency.

In a 1994 clinical presentation, Deanna Fish CPO FAAOP MS, director of clinical services at Hanger Orthopedic Group, stated that the dispensation of an O&P device is only 10 percent of what we need to do for orthotics/prosthetic clients, and that the remaining 90% remains to be done. She made this statement with the assumption that the mechanical properties and characteristics of the device are optimized, and that mechanically speaking, the O&P device provided adequate support or replacement of and for the user's limb. In a subsequent presentation, she also noted that the ensuing 90 percent of clinical care is equally important and significant to the optimization of mechanical design and function. I am inclined to agree with her observation and point of view. As a profession, O&P technicians and clinicians are wonderfully trained in the mechanical science of orthotics and prosthetics. We are trained and skilled in mechanical design and engineering, kinetics and kinematics and how to couple engineered mechanisms with the mechanical characteristics of the human body. We understand how to control and manipulate force and motion. But as a profession, we can also be compared to an electro-mechanical engineer trying to develop a micro-processor knee with little or no regard for sensory input and how sensory input is processed and utilized for motor (electro-mechanical) control. The human body acts very much like a MPC knee. Michael Merzenich PhD. at the University of California San Francisco Dept. of Neuroscience stated during the National Academies KECK Futures Initiative in his presentation entitled "Exploring Assistive Devices for the Body and Mind" that "we can make smarter prosthesis when we are smarter about integrating neuroscience with engineering and medical science. Researchers cannot overestimate the capacity of the human brain to restore function, to be trained, to make up what's been lost in extraordinary ways, and with the help of orthotic and prosthetic devices, sensory information can continue to flow into the brain from the peripheral system. Research shows that the brain will learn to use that information for motor control". In a 2004 lecture, Hugh Herr, PhD, director of biomechatronics at the MIT Media Lab, identified "distributed sensing and intelligence" as a key area for the future of prosthetics research. "Advances in muscle-like actuators, neuroprosthesis, and biommetric control strategies are necessary to increase the merging of body and machine to create an intimacy between the human body and prosthesis. It's our thesis that such intimacy will create a paradigm shift in this area of rehabilitation. To really push this area of medicine, we need to merge body with machine to create an intimacy between the human body and the prosthetic device".

I have termed the proposed rehabilitation science of training, measuring and recording the subject's ability to anticipate contingent sensorimotor function "Neurocorrelagraphy". The development and clinical implementation of this new science is not going to be a "solo act", but rather a concerted and concentrated effort where work and reward are shared by many gifted and dedicated individuals and institutions. I encourage all people involved in physical restoration and rehabilitation to become more interested and aware of this idea and to directly participate as much as possible in this fascinating and challenging area of rehabilitation science. This is within the professional scope of clinical O&P, and I believe this concept should be more closely associated with and integrated into the O&P profession. I think there is much to be gained by differentiating between the inherent physiological and biomechanical efficacy of the O&P device (applied technology) and the users' ability and willingness to benefit from this technology (training). As a prosthetist, I believe this would greatly simplify and clarify clinical obligations and expectations as well as promote inter-clinical communication and perhaps coalesce otherwise seemingly divergent disciplines.

Conclusion

In his introduction to a 2002 special issue of the Journal of Head Trauma Rehabilitation focused on neuropsychological technologies, Douglas Chute, PhD, wrote: "The transportability of technology should allow the bridging of research protocols to clinical practice. There is no intrinsic reason why the neuropsychologists or rehabilitation specialist cannot fully engage with the new range of neuropsychological technologies appropriate for their patients in rehabilitation". Clinical O&P is an emerging technological rehabilitation specialty, and as such, the O&P profession has the opportunity (and I believe ethical responsibility and obligation) to successfully and effectively integrate these neuropsychological technologies into daily O&P clinical practice, especially when these technologies are generated from within the O&P profession.

More to Explore

Wilson M, Sensory Substitution/Multisensory Correlation in Physical Rehabilitation Science. www. dycormfg.com (ENP/Empathy Training) 2006 or Google "Measuring Neurocorrelation Coefficients"

O'Regan J.K, Skill, Corporality and Alerting Capacity.
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Haugland M.Sinkjaer T, Interfacing the Body's Own Seeing Receptors into Neural Prosthetic Devices, Technology & Health Care 7 1999 393-399

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