Muscle Hypertrophy

The Roles of Adaptation & Variation

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Introduction

What are the requirements to stimulate or induce muscle hypertrophy? A simple answer would be to work against a sufficient load (70-85% of a 1RM) for enough work time (to create enough fatigue or inroad), and to maintain proper form as to keep momentum under control so as to sustain tension on the muscles without any noticeable unloading caused from dropping or explosive yanking. It could be argued further, when comparing methods, that dynamic activity is superior to isometric activity.

However, if that were the end of the story, the industry would not still be in a predicament of being confused about proper or, more importantly, ideal directions to develop muscles. If that was all there was to it, then we would be seeing better physiques (at the non-steroid stage) with better balance and proportions. What we have are 'experts' who uphold the above-noted general formula, but while blaming genetics, lack of intensity-of-effort, or some other factor (or combination thereof) when hypertrophy is not forthcoming.

This is the irony: Some very specific things are accepted in the exercise science community, such as strength development being joint-angle specific[1], a phenomenon apparent when limiting exercise to isometric-based training; that both the amount of muscle mass and the quality of muscle (slow twitch vs. fast twitch) have an affect on maximum force output; and that the degree of muscle type distribution can vary significantly among individuals[2]. Yet even more basic, more fundamental to exercise progression and results is the notion of adaptation to exercise and the corresponding need for variation in order to progress to a higher state of development.

As will be discussed throughout this paper, muscle hypertrophy, and what it takes for growth to transpire, is more complex an issue than simply lifting heavy weights with great effort and good form – those are immediate, at-the-time workout requirements, looked at with a monocle and narrow of sight; but when viewing and understanding effective exercise is a broader context, the needs and requirements are far more diverse. The possible reason why its complexity is not recognized more universally likely may be for the fact that hypertrophy is so quick to develop during the initial months or few years of training, simply because exercise strain is so new to the organism, and when growth slows considerably as a trainee becomes more experienced, confusion arises as to why the 'tried and true' formula no longer works. The conclusion is that "if it worked before, then it should work now," and if it no longer works, then it must be genetics, age, lack of intensity of effort, too much stress in one's life, or some other constraint holding the trainee back. Thus, people settle for mediocre results than what may be possible.

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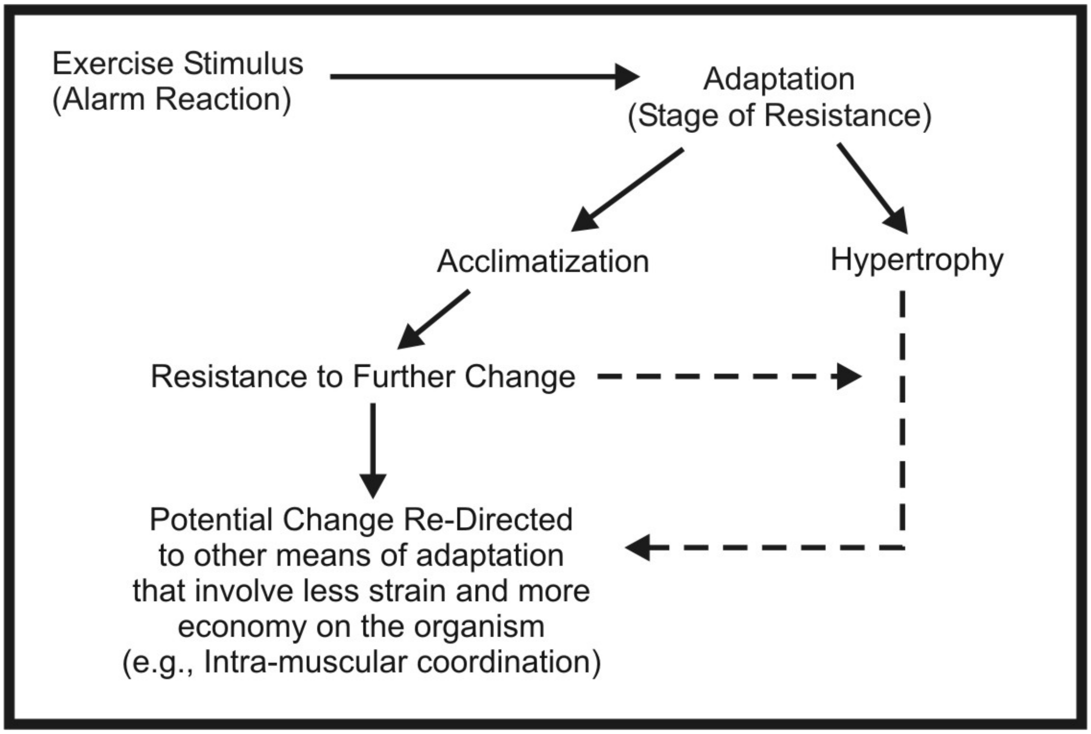
[1] Lindh, M. 1979. <u>Increase of muscle strength from isometric quadriceps exercises at different knee angles</u>. *Scand J. Rehabil Med.* 11(1): 33-6.
[2] Tesch P, Karlsson J. 1978. <u>Isometric strength performance and muscle fiber type distribution in man</u>. *Acta Physiol Scand.* May; 103(1):47-51.

As will be exposed, there is enough evidence to suggest the problem is more one of adaptation and over-familiarity than it is genetics, one's effort, etc., particularly as it concerns serious, advanced trainees who fail to think and train 'outside the box.' The scientific world is well versed of the importance of adaptation, although more in the area of evolution and Darwinism, but also when speaking of stress physiology – and if muscles adapt by becoming larger, it should be obvious that they adapt to (become used to) the strain of exercise stimuli in order to become larger. After all, if muscles did not adapt to exercise strain, they could not and would not become larger.



Having said as much, and the connection and implications are obvious, the worst thing a person can do is to avoid variation in exercise and to instill too much standardization in what is being done and how it is done. It is perplexing as to why the General Adaptation Syndrome is known in the fitness industry, and that some 'experts' claim to understand stress physiology (and the fact that muscles do adapt, as per the second stage of the GAS), and yet proclaim that there is no evidence to suggest a need for variation in exercise planning and development. Empirically speaking, those who are more 'carefree' and experimental in training, constantly trying new things in the hopes of finding the 'lost pot of gold' of muscledom, and with all other factors remaining equal, will demonstrate superior physical development – not always larger muscles, although that may be the case, but better development overall… more completeness. This paper will explore and explain why that is the case; the reader also is encouraged to cross-reference other supporting materials listed at the end.

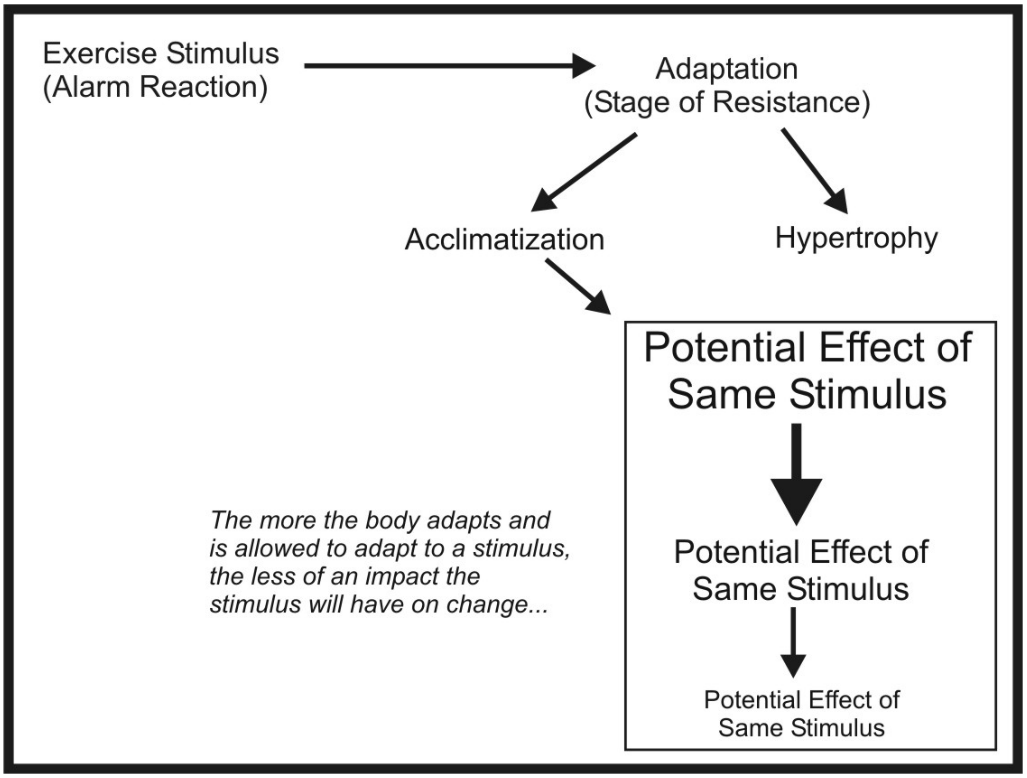
However, let's keep this simple and consider a basic premise of GAS and its affiliation to the Principle of Specificity or SAID (specific *adaptations* to imposed demands). From a very general standpoint, the body adapts and it adapts specifically, e.g., improvement of a tennis backhand in regard to skills, or aerobic exercise utilizing the aerobic energy system as opposed to the anaerobic system – or the obvious differences in training with light loads as opposed to moderate or heavy loads. Hence, if the body adapts specifically by producing specific outcomes, it must adapt (gets use) to the specific nature of the training stimulus; if not, it cannot adapt through means of producing specific outcomes. One aspect of adaptation MUST coincide with the other – nothing else makes sense.

Evolutionary Adaptation & Muscle

Every day of our lives involves evidence of evolution through adaptation. We adapt to the Sun by acquiring tans; we adapt to exercise in positive and negative ways, depending on the extent and nature of the stimulus/program; and we adapt to life in general by becoming more experienced, smarter, and physically tolerant and robust.

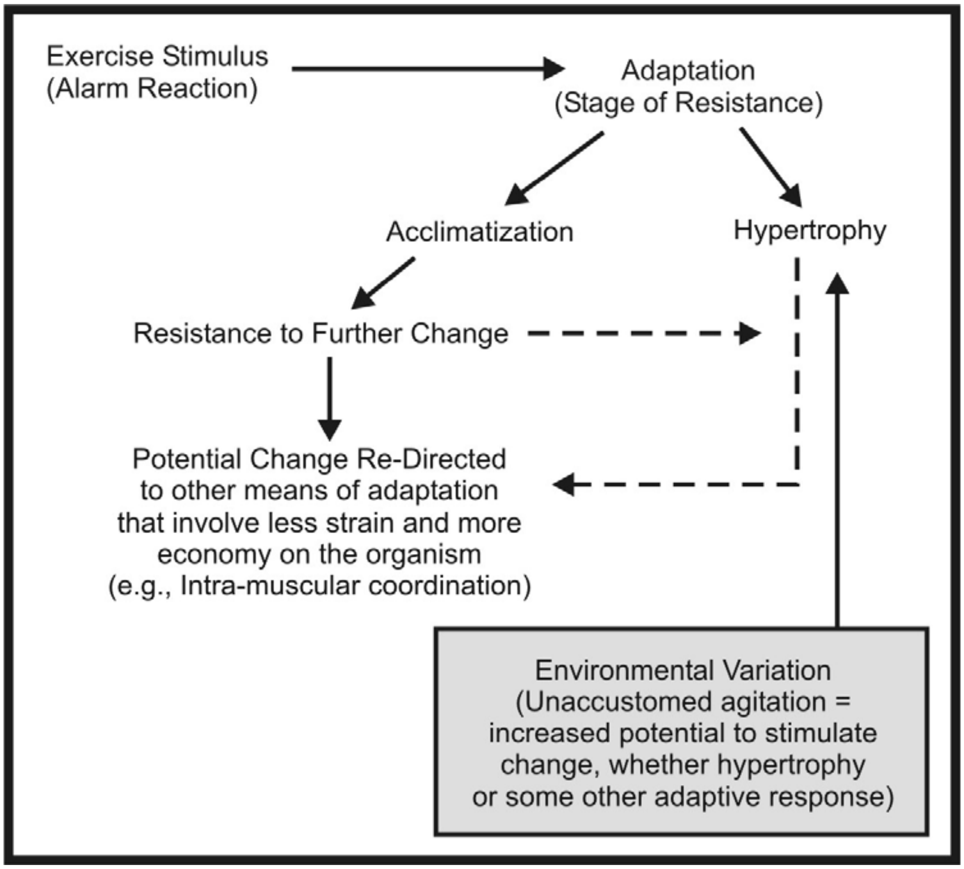
It is adaptation that is at the heart of everyday existence when viewed short-term and evolution of species when viewed long-term, and it must be understood that a synonym for 'evolution' is 'progression,' a key facet of productive strength training/muscle building exercise, viz., the Progression Principle.

But to evolve physically, to progress, there must exist variation within the environment, 'something' to trigger a higher level of adaptation to coincide with that evolution or progression – without sufficient variation (change) in the environment, such adaptation (change) cannot occur. Hence, change begets change. Thus, the more varied one's environment, the more evolved a person's physique becomes or has an opportunity to become – albeit in different ways and relative to the stressors involved. Similarly, the more varied one's exercise (while keeping in sync with the Principle of Specificity), the more evolved that person's physique and function will become.



Of course, variation must be kept within reason. It is not an issue of 'everything but the kitchen sink.' Rather, and to reiterate, one's training must be as varied as possible while adhering to the Principle of Specificity, e.g., variation with the intent to hypertrophy the muscles and in the context of a person's individuality (e.g., muscle fiber type, response to exercise, neuromuscular efficiency, etc.). There are many ways to lift a sufficiently heavy load while working the same muscle with quality form and tension, and they include exercise selection, angle of execution, and manner of lifting (e.g., cadence and rate-of-speed).

However, these are short-term variations, and more complex examinations involve the cycling of total demands, thus involving the degree to which volume, frequency, set variables, choice of exercises, etc., can be manipulated to alter overall stress levels to produce unique fingerprint expressions of exercise variation, complexity, diversity and inevitably/hopefully a higher state of physical adaptation and evolution/progression.



Not only does variation exist in nature, and need to exist to stimulate change optimally, variation has been noted in the study of human physiological responses to different classes of exercise (adaptive responses of aerobic vs. anaerobic activity), and among skill requirements of different activities. Moreover, there is variation in response to exercise among people, of how people respond to exercise strain, which response is so individualized that one research project noted that each participant, relative to him or her self, showed remarkably similar responses (unique measures of blood creatine kinase levels) between two bouts of a very specific eccentric-based exercise task spaced one year apart[3].

Thus, if variation exists so specifically in regard to one exercise protocol, there must be variation in response among individuals relative to different bodybuilding training methods. And as muscles adapt to one variation of exercise or performance, introduction of a new variation would imply a continued (better/superior) disruption and agitation (so long as the protocol is rational and applicable to the individual), and to a greater extent than re-introduction of the same variation. This not only makes sense when speaking of exercise, but it is a known factor of basic evolutionary discussions on 'organisms and change.'

[3] Chen TC. 2006. Variability in muscle damage after eccentric exercise and the repeated bout effect. *Res Q Exerc Sport.* Sep;77(3):362-71.

But before discussing further the relevancy of variation, reconsider the idea of adaptation: If one were to conduct Internet searches on 'exercise adaptation,' dozens of studies will surface – research to support the obvious notion that the body does adapt, which is a good thing… a response we want and something that has been accepted in the literature – but which response imposes a limitation for future muscle development (adaptation also means further reluctance to change). Once this is understood and accepted, then the corresponding importance of its counterpart, being *variation*, will be embraced.

To conclude this section, here are a few examples of research titles that speak of physiological adaptation.

- Regulation of immediate early gene expression by exercise: short cuts for the adaptation of immune function.
- Control of gene expression and mitochondrial biogenesis in the muscular adaptation to endurance exercise.
- mTOR signaling and the molecular adaptation to resistance exercise.
- Myocardial adaptation to short-term high-intensity exercise in highly trained athletes.
- Influence of rapid growth on skeletal adaptation to exercise.
- Role of AMPK in skeletal muscle metabolic regulation and adaptation in relation to exercise.
- Understanding skeletal muscle adaptation to exercise training in humans: contributions from microarray studies.
- Decreased PDH activation and glycogenolysis during exercise following fat adaptation with carbohydrate restoration.
- Exercise and hormesis: oxidative stress-related adaptation for successful aging.
- Adaptation of pulmonary O2 uptake kinetics and muscle deoxygenation at the onset of heavy-intensity exercise in young and older adults.

Unfortunately, research in the area of variation in exercise is scant at best; perhaps because researchers believe the need for such is common sense (as per the arguments in this paper), or because the issue has not dawned on them. Nonetheless, each study above has drawn conclusions, based on its findings, but one then needs to wonder what the studies' outcomes would have been if the protocols varied. Think about that for a moment – results of studies are based solely on manipulating/tracking one variable while applying specific, regimented exercise protocols, while ignoring every other conceivable possibility (brief reflection of the potential measures and arrangements of the fundamental principles of fitness science should give some pause for concern and awe of what is left to study). Hence, exercise research must be viewed as a means of guidance, of what to consider in prescription decisions, but not as the final word or truth as to what is best for people in general or, more importantly, specifically for one unique individual.

Adaptation at the Molecular Level

Understand that adaptation of muscle is not limited just to hypertrophy and strength, but is a diverse conglomeration of activities in the body that necessitates closer study of mycellular research in order to understand macro-changes in muscle architecture.[4] As an example, the *hormesis theory* suggests that biological systems respond with a bell-shaped curve to exposure of chemicals, toxins, and radiation; this makes sense since different organisms will respond and adapt to different extents – hence, the Bell Curve in action. A group of researchers extended the hormesis theory to include *reactive oxygen species (ROS)*, to propose: "the beneficial effects of regular exercise are partly based on the ROS generating capability of exercise, which is in the stimulation range of ROS production. Therefore, we suggest that exercise-induced ROS production plays a role in the induction of antioxidants, DNA repair and protein degrading enzymes, resulting in decreases in the incidence of oxidative stress-related diseases and retardation of the aging process."[5] In other words, "Regular exercise causes adaptation of the antioxidant and repair systems, which could result in a decreased base level of oxidative damage and increased resistance to oxidative stress."[6]

Consider another example: "Repeated acute or chronic exposure to a particular stress results in adaptation whereby the hypothalamopituitary adrenal (HPS) axis becomes less responsive to subsequent or continued exposure to that particular stress." Hence, the body gets USED TO the SAME stimulus, whereby that same stimulus has less of an effect than when introduced originally. What researchers discovered was that when comparing highly-trained ultra-marathon athletes to healthy individuals that there was "no significant overall difference in plasma cortisol levels between the athletes and the control subjects, and urinary excretion of free cortisol was similar in the two groups." Their data show that demanding and highly stressful physical training leads to "adaptive changes in basal HPA function, including a phase shift and increased pituitary in basal HPA function and increased pituitary ACTH secretion, but also blunting of the adrenal cortisol response."[7] And other research shows molecular changes in mRNAs for transfer of metabolic substrates (gene expression) as a result of exercise.[8] If this occurs in non-muscular systems, then why not in the muscular system?

[4] Blazevich AJ, Sharp NC. 2005. Understanding muscle architectural adaptation: macro- and micro-level research. *Cells Tissues Organs*. 181(1):1-10.

[5] Radak, Z., et al. 2005. Exercise and hormesis: oxidative stress-related adaptation for successful aging. *Biogerontology*. 6(1):71-5.

[6] Radak, Z., et al. 2001. Adaptation to exercise-induced oxidative stress: from muscle to brain. *Exerc Immunol Rev*. 2001;7:90-107.

[7] Wittert, GA, et al. 1996. Adaptation of the hypothalamopituitary adrenal axis to chronic exercise stress in humans. *Med Sci Sports Exerc*. 1996 Aug;28(8):1015-9.

[8] Booth FW, et al. 1998. Molecular and cellular adaptation of muscle in response to physical training. Acta Physiol Scand. 1998 Mar;162(3):343-50.

Another example of highly-acute adaptation involves Platelet Derived Growth Factor (PDGF), Transforming Growth Factor-beta (TGF-beta) and Vascular Endothelial Growth Factor (VEGF), all of which are released during exercise. These serum growth factors "could be involved in the process of adaptation of human organism to physical training. In addition, in the context of the role of inflammation in the pathogenesis of various diseases, results point to the potentially deleterious effect of strenuous physical exercise."[9] In other words, the body adapts so that exercise has less of an intrusive effect… and let it be known that forcing muscle to grow is very intrusive! Then there are hormonal changes, adaptations and effects dealing with myostatin, IGF-1, and the central role of satellite cells,[10] all which serve to regulate, control and limit muscular growth (which roles are less of a concern as the body adapts to the same exercise stimuli).

And, of course, most in the athletic/fitness industry is well aware of how chronic exercise can alter the menstrual cycle. As one researcher noted: "Exercise-related changes in the menstrual cycle can be viewed as a functionally adaptive rather than a maladaptive dysfunction. A strong case can be made that the changes in the menstrual cycle as a result of exercise are an energy conserving strategy to protect more important biological processes. This hypothesis is consistent with the theory of metabolic arrest that has been identified in lower organisms and hibernating mammals."[11]

For our purposes, we are concerned specifically with muscle hypertrophy and strength, but the point is that the body is highly diverse in how it adapts, right down to the molecule, and this is an important consideration for what is to follow. To reiterate the fundamental point of this position paper: The muscles adapt by becoming larger, but the nature of that adaptation also involves (must involve) getting used to the stimulus. If muscles were not getting used to the stimulus, then the process of growth would be shunted (and a person would enter an overtrained state, or the third stage of the GAS, the Stage of Exhaustion), since that is the process and nature of hypertrophy – getting used (adapting) to exercise. But once adapted (the second stage of GAS), there is less need for more growth – the process has been contained, controlled, and constrained. Therefore, constant change in challenges is required in order to give continual reason to adapt to the stimulus of exercise in order to adapt by way of more hypertrophy.

Consider that performing unaccustomed exercise, even among those who do exercise regularly, has a more profound impact on agitating the immune system.[12] This makes sense since strain that is different will have a greater alarm reaction (first stage of GAS) on an organism than what occurs with strain that is typical. Thus, a greater alarm reaction will stimulate greater growth potential in the stage of adaptation (so long as the stressor is within the tolerance of the organism), which means a superior and higher level of function (e.g., muscle hypertrophy).

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[9] Czarkowska-Paczek B, et al. 2006. The serum levels of growth factors: PDGF, TGF-beta and VEGF are increased after strenuous physical exercise. *J Physiol Pharmacol.* Jun;57(2):189-97.

[10] Solomon AM, Bouloux, PM. 2006. Modifying muscle mass - the endocrine perspective. *J Endocrinol*. 2006 Nov;191(2):349-60.

[11] Bonen A. 1994. Exercise-induced menstrual cycle changes. A functional, temporary adaptation to metabolic stress. *Sports Med.* Jun;17(6):373-92.

[12] Sorichter S, et al. 2006. Effects of unaccustomed and accustomed exercise on the immune response in runners. *Med Sci Sports Exerc*. Oct;38(10):1739-45.

Movement Adaptation

An example of immediate adaptation involves standing on an incline for 1-6 minutes, and then standing horizontally (flat); the change in position causes a person to lean forward slightly when stepping onto a flat surface, as to re-establish alignment that was experienced (and normal) with the inclined surface. As researchers indicated, "the transfer of a postural effect built-up during a locomotor task to a postural after-effect during a standing task is consistent with a central adaptive mechanism that adjusts the surface-referenced set point for whole body postural orientation for both gait and posture."[13]

Another example of adaptation is in the fact that "all individuals formulate an individual masticatory adaptation process to deal with the special characteristics of the food they are chewing."[14] This may seem common sense, that how we chew and mix food in our mouths is relative to the foods we eat, but it sets the groundwork when speaking of adaptation in exercise; viz., what we take for granted, as an every-day occurrence, of what "only makes sense," seems to be ignored or ridiculed when addressing a most fundamental of exercise requirements – variation.

Now, when speaking of exercise, the following is an example of very general adaptive responses at the molecular level: "in some situations when strength and endurance training are performed simultaneously, a potential interference in strength development takes place, making such a combination seemingly incompatible… there seems to be an explanation for the interference of strength development during concurrent training; it is now clear that different forms of exercise induce antagonistic intracellular signaling mechanisms that, in turn, could have a negative impact on the muscle's adaptive response to this particular form of training. That is, activation of AMPK by endurance exercise may inhibit signaling to the protein-synthesis machinery by inhibiting the activity of mTOR and its downstream targets."[15]

This has been known for some time, at least at the most basic level (that too much aerobic stimulus can hamper anaerobic responses); and authorities who are adamant about developing muscle and strength will warn against (too much) steady-state exercise, like long-distance running. Obviously they are aware of *negative adaptations* and the consequences.

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[13] Kluzik J, et al. 2007. Postural after-effects of stepping on an inclined surface. *Neurosci Lett.* 2007 Feb 14;413(2):93-8.

[14] Peyron MA, Woda A. 2006. Adaptation of mastication in response to the characteristics of the individual or the food. *Orthod Fr.* Dec;77(4):417-30.

[15] Nader GA. 2006. Concurrent strength and endurance training: from molecules to man. *Med Sci Sports Exerc.* Nov;38(11):1965-70.

The degree to which a person responds and adapts to exercise can vary significantly, which is why averaging results in strength training research offers little advice or recommendations to fitness professionals needing to individualize a training program for one specific person. Bagger, et al.[16] addressed the subject of response variation among runners (although the reader should consider the greater potential in variation when speaking of muscle fiber type and response-to-exercise of all the muscles with just one person and when trying to optimize training and maximize results):

> "To be able to identify a training induced change in a certain variable, it is necessary to know the background variation. In this study the coefficient of variation (total, between-subjects, within-subjects), the relative sources of variance (between-subjects and within-subjects), and the critical difference (within-subjects) were estimated in four categories of variables (performance and physiological variables, metabolic and hormonal variables, immunological variables, and mood state variables) in 15 moderately trained male runners measured on three different occasions over a period of 7 weeks. In the performance and physiological variables, 78.9 % of the variance was due to variation between subjects and they had the lowest critical difference (11.9 %). In contrast, the metabolic and hormonal variables had the highest critical difference (59.9 %) and 53.4 % of the variance was due to variations within subjects. The immunological and psychological variables had about two thirds of the variance arising from variation between subjects. However, the critical difference for the immunological variables was high (47.4 %), while it was relatively low for the psychological variables (26.8 %). The low critical difference and variation within subjects of the psychological and in particular the performance and physiological variables indicate that they may be beneficial as primary markers of training induced changes."

Thus, there is variation in response, which suggests further that variation in the stimulus would affect the magnitude of variation in future response.

In strength training and bodybuilding, a greater focus has been placed on neurological adaptation, or the skill factor and its role/effect. It has been suggested that neurological/skill factors are a consideration only during the beginning stages of exercise (since neural factors dominate strength training adaptation over that of hypertrophy[17]), with less impact or influence on advanced trainees.

This is not the entire story, however, since although the extent of neural factors may diminish, the nature of its role alters and becomes more finely tuned. To explain, the more muscle and strength a person develops, the more reluctant the body is to add more muscle and strength; and the more a person repeats the same exercises in the same way (same method of performance), the more honed the skills to execute those movements in a particular manner becomes.

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[16] Bagger M, Petersen PH, Pedersen PK. 2003. Biological variation in variables associated with exercise training. *Int J Sports Med*. 2003 Aug;24(6):433-40.

[17] Blazevich AJ, et al. 2007. Lack of human muscle architectural adaptation after short-term strength training. *Muscle Nerve*. Jan;35(1):78-86.

Hence, neuro-factors and muscle energetics become more pronounced, sharpened, and individualized with the advanced trainee – and this means a person simply gets better at performing the same exercises in the same manner. Skill development is more noticeable with the beginner because of the dramatic and quick adaptation to the acclimation to weight training (as one progresses from being wobbly or jerky to smooth and efficient), but it becomes improves progressively as a means of survival in the advanced trainee.

Let's look at this a bit closer. It is known that the Central Nervous System (CNS) is quick to respond, as the senses learn to compensate and become attuned to its environment as it interacts[18], acquiring knowledge of its environment so that it becomes more capable – as it progresses in its ability and evolves accordingly. An example is with runners, who will adjust mechanics in subtle ways, without knowing it, when running on various surfaces and planes.[19] The brain also has this capacity, but to a lesser extent when compared to sensorimotor adaptation.[20] However, the brain is very plastic and its architecture actually can change and adapt relative to stimuli[21,22] – as well, total force output of the muscles will increase with biofeedback (e.g., visualization and being able to see the muscle work)[23] and heightened conscious effort, e.g., aggression.

As well, there is something in the brain known as *Mirror Neurons*, cells located in the ventral sector of the premotor cortex, the part of the brain associated with selection, planning, and execution of actions. These cells fire in relation to specific goal-related motor acts, such as grasping, lifting, and holding. What is most interesting is that these cells also fire when we observe someone else performing an action, viz., the CNS establishes a pattern of response (a mapping or code of intention) to carry out an action merely by observing and without actually doing, which may suggest why many people eventually tend to lift weights in a similar manner, unless otherwise instructed – monkey see, monkey do. The reason why they are called mirror neurons is that they behave or respond as if a person is watching his or her own actions reflected in a mirror, albeit while watching somebody else's actions, to establish the groundwork for motor patterns.

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[18] Huang FC, et al. 2006. Human adaptation to interaction forces in visuo-motor coordination. *IEEE Trans Neural Syst Rehabil Eng.* Sep;14(3):390-7.

[19] Karamanidis K, et al. 2006. Adaptational phenomena and mechanical responses during running: effect of surface, aging and task experience. *Eur J Appl Physiol.* Oct;98(3):284-98.

[20] Berrigan F, Simoneau M. 2007. Is the brain able to capture a new temporal relationship between a motor action and its consequence? *Exp Brain Res.* Mar 20.

[21] Mailis-Gagnon A, et al. 2003. Altered central somatosensory processing in chronic pain patients with "hysterical" anesthesia. *Neurology*. May 13;60(9):1501-7.

[22] Juottonen K, et al. 2002. Altered central sensorimotor processing in patients with complex regional pain syndrome. *Pain*. Aug;98(3):315-23.

[23] Graves JE, James RJ. 1990. Concurrent augmented feedback and isometric force generation during familiar and unfamiliar muscle movements. *Res Q Exerc Sport*. Mar; 61(1):75-9.

Such action on a grand scale is obvious when studying *Swarm Theory*. The July 2007 issue of *National Geographic* provides an excellent, albeit general overview of this theory and how it works: "simple creatures following simple rules, each one acting on local information. No ant sees the big picture. No ant tells any other ant what to do. Some ant species may go about this with more sophistication than others. But the bottom line, says Iain Couzin, a biologist at Oxford and Princeton Universities, is that no leadership is required. 'Even complex behavior may be coordinated by relatively simple interactions,' he says."

Swarm Theory provides a vital connection to human movement. With ants, a most obvious example, it is the colony as a whole that solves problems by way of swarm intelligence, which individual ants would find unthinkable, such as determining the best and shortest routes to food. And with this in mind, humans have been applying the concept to everyday operations, such as transporting fuel, airport communications and the mass transit that takes place in either instance. As Charles N. Harper of NuTech Solutions explains: "When (Argentine) ants bring food back to the nest, they lay a pheromone trail that tells other ants to go get more food. The pheromone trail gets reinforced every time an ant goes out and comes back, kind of like when you wear a trail in the forest to collect wood. So we developed a program that sends out billions of software ants to find out where the pheromone trails are strongest for our tuck routes." The article continues: and like bees that reach a "decision by gathering information, conducting independent evaluations, and holding a kind of vote – the same practices in Chicago (help to) drive the price of soybean futures."

Think about it: ants evolved an efficient method to find the best routes, and the same happened with bees, the patterns of swimming fish, wildebeest migration, locusts, and also humans when interacting in groups ("groups can be smart" if a group's members "are diverse, independent minded, and use a mechanism such as voting, auctioning, or averaging to reaching a collective decision"[24]). Birds react similarly. For example, pigeons don't have a leader: "no pigeon is telling the others what to do. Instead, they're each paying close attention to the pigeons next to them, each bird following simple rules as they wheel across the sky. These rules add up to another kind of swarm intelligence – <u>one that has less to do with making decisions than with precisely coordinating movement</u>."

Scientists outside exercise are aware of this connection and behavior. Craig Reynolds, a computer graphics researcher, demonstrated the "power of self-organizing models to mimic swarm behavior" in motion pictures, and this helped to direct robotics engineers: "A team of robots that could coordinate its actions like a flock of birds could offer significant advantages over a solitary robot. Spread out over a large area, a group could function as a powerful mobile sensor net, gathering information about what's out there. If the group encountered something unexpected, it could adjust

[24] The National Geographic article makes a point about an important truth about collective intelligence: "Crowds tend to be wise only if individual members act responsibly and make their own decisions. A group won't be smart if its members imitate one another, slavishly follow fads, or wait for someone to tell them what to do." Likewise, fitness is an individual matter and to achieve optimum results (not mediocre or average results) necessitates intelligent thought and individual application. Nonetheless, it is obvious that most people who follow a fitness program do imitate and follow other blind sheep and expect others to make the decisions – which situation is fine if one has the coaching of a competent fitness professional, which is a rarity.

and respond quickly, even if the robots in the group weren't very sophisticated, just as ants are able to come up with various options by trial and error. If one member of the group were to break down, others could take its place. And, most important, control of the group could be decentralized, not dependent on a leader."

When contemplating and considering the above information, it only stands to reason that on a microscopic scale, when speaking of the neuro-muscular system, the interaction goes far deeper but is a form of swarm intelligence that takes control of coordinating movement (like the flashes of fireflies, "such self-organized behavior resembles the synchronized firing of heart muscle cells or the rhythmic applause of a crowd"). If we consider bees, their rules for decision-making are to "seek a diversity of options, encourage a free competition among ideas, and use an effective mechanism to narrow choices." As Vijay Kumar, professor of mechanical engineering at the University of Pennsylvania states in the article about his robotic experiments, "They don't all talk to each other. They act on local information. And they're all anonymous. To go from one robot to multiple robots, you need all three of those ideas."

The same occurs within the body, and without us being conscious of it – the neuro-muscular system always will choose the easiest and best way to execute an action among choices, and those choices become less the more basic the action (e.g., a clean and jerk as opposed to exercising on a leg extension machine), and it does so relative to the information provided from the collective whole. What occurs is "decentralized control, response to local cues, simples rules of thumb" – all of which "add up to a shrewd strategy to cope with complexity." And like ants, the more the same trail is traveled, the greater the reinforcement for repeated behavior and action when exercising.

The point being: the CNS is complex, highly diverse, and vital in human performance, and 'strength' (ability to lift more weight) can increase by means other than hypertrophy. Fundamentally, replication and continual exposure to the same actions in the same manner (method of performance), even if a few more pounds here and there are being lifted, can have a detrimental effect on overall progress in developing muscle as an organism shifts to more economical means (other than the production of more muscle) to lift heavier loads. One study[25] looked at muscle coordination and found that the body learns to constrain itself, in order to perfect movement, which we have known for some time and is a basic tenet of human energetics over the past 50 years of research. And when a person attempts to alter that movement pattern, particularly under high force or high velocity conditions, adaptation results in "an increased probability that synaptic connections will be formed" (viz., there is a relearning and reorganization of the nervous pathways).

[25] Carson RG. 2006. Changes in muscle coordination with training. *J Appl Physiol.* 2006 Nov;101(5):1506-13. Epub 2006 Aug 3.

But as per the first point, the researcher noted that "neural connectivity induced by the repetition of specific muscle recruitment patterns during training may, however, inhibit the subsequent acquisition of new skills;" thus, the body and CNS becomes locked into preferred movement patterns and will strive not to deviate from said patterns. But with "appropriate sensory guidance" (e.g., regular variation in exercise choice and how they are performed), it is possible "to promote greater subsequent flexibility in the recruitment of the trained muscles in other task contexts." And this has a bearing on muscle hypertrophy, since the more diverse and unusual training becomes, the more likely that fixed skills (physiological complacency) will not constrain the potential for further hypertrophy.

Another study makes obvious that "the organisation of the human neuromuscular-skeletal system allows an extremely wide variety of actions to be performed, often with great dexterity. Adaptations associated with skill acquisition occur at all levels of the neuromuscular-skeletal system although all neural adaptations are inevitably constrained by the organisation of the actuating apparatus (muscles and bones)."[26] The researchers further concluded: "while the extent to which skill can be acquired in isometric actions is independent of the specific combination of joint torques required for target acquisition, the nature of the kinetic adaptations leading to the performance improvement in isometric actions is influenced by the neural and mechanical properties of the actuating muscles." Hence, although exercise performance improvement is limited by certain physiological factors, we have the ability to challenge muscles in an immense number of ways, because of 'dexterity,' in order to limit adaptation of skill acquisition so as to influence (motivate) hypertrophy.

A research review summed up some of the important aspects of total body integration of strength training ability: "Indirect evidence for neurological adaptations, which encompasses learning and coordination, comes from the specificity of the training adaptation, transfer of unilateral training to the contralateral limb and imagined contractions. Changes in inter-muscular coordination appear critical. Adaptations in agonist muscle activation, as assessed by electromyography, tetanic stimulation and the twitch interpolation technique, suggest small, but significant increases. Enhanced firing frequency and spinal reflexes most likely explain this improvement…"[27] Thus, not only is the coordination of the body's physiology significant, but is directed toward the specificity of ones' training. And the more specific (standardized and routine) one becomes in how strength training/bodybuilding is executed, the more acclimated the body's physiology becomes – and the more complacent the muscles become.

[26] Shemmell J, et al. 2006. Neuromuscular-skeletal constraints on the acquisition of skill in a discrete torque production task. *Exp Brain Res.* Nov;175(3):400-10.
[27] Folland JP, Williams AG. 2007. The adaptations to strength training: morphological and neurological contributions to increased strength. *Sports Med*. 2007;37(2):145-68.

Training Adaptation and Complacency

The motor units and muscle fibers activated, and their control during a movement, are contingent upon both positioning and total force (of reaching a particular threshold to activate a particular group of motor units and fibers)[28,29], influenced in part by motor unit activation strategies.[30] As well, muscles fatigue and recover at different rates[31] depending on their position, e.g., stretch vs. full contraction,[32] and rate-of-fatigue (muscle fiber type), and the body will use strategies to accommodate fatigue best.[33] Moreover, the body will shift tension even within the same muscle group to accommodate pain – a "dynamic reorganization of the spatial distribution of muscle activity."[34] This concept is confirmed in other studies, including a 2006 research project that presents evidence that "clinical neck pain is associated with a substantial reorganization in the control strategies of cervical muscles during static and dynamic tasks."[35]

There is an enormous amount of information in the above paragraph; and in sum, the manner in which a muscle (and its parts) coordinate, activate, and fatigue are complex and always will do so specifically and relative to the environment to which they are adapting. The more simple one makes the environment, the faster muscles adapt and the more complacent they become, thereby neglecting any need for further hypertrophy.

Consider a simple example of muscle activation, and the extent of biceps brachii participation as the hand rotates from pronation to supination; the more the hand supinates, the more the biceps activate. This much is a 'given' in exercise, since it can be seen and felt with the naked eye. However, the process of human movement is more complex, in that different muscles work to different extents (depending on position) when performing a particular exercise[36], and segments within any muscle will work or hand over tension/load to other segments *within the same muscle*, influenced by

[28] Ballantyne BT, et al. 1993. Motor unit recruitment in human medial gastrocnemius muscle during combined knee flexion and plantar flexion isometric contractions. *Exp Brain Res.* 93(3): 492-8.

[29] HHwang ISH, HCho CYH. 2004. Muscle control associated with isometric contraction in different joint positions. *Electromyogr Clin Neurophysiol*. 2004 Dec;44(8):463-71.

[30] Ebersole KT, et al. 1998. The effect of leg flexion angle on the mechanomyographic responses to isometric muscle actions. H*Eur J Appl Physiol Occup Physiol.H* Aug;78(3):264-9.

[31] Kukulka CG, et al. 1986. Electrical and mechanical changes in human soleus muscle during sustained maximum isometric contractions. *Brain Res.* Jan 1; 362(1): 47-54.

[32] HPhilippou AH, et al. 2003. Angle-specific impairment of elbow flexors strength after isometric exercise at long muscle length. *J Sports Sci.* Oct;21(10):859-65.

[33] Bonnard M, et al. 1994. Different strategies to compensate for the effects of fatigue revealed by neuromuscular adaptation processes in humans. *Neurosci Lett*. Jan 17;166(1):101-5.

[34] Madeleine P, et al. 2006. Experimental muscle pain changes the spatial distribution of upper trapezius muscle activity during sustained contraction. *Clin Neurophysiol*. 2006 Nov;117(11):2436-45.

[35] Falla D, Farina D. 2006. Neuromuscular adaptation in experimental and clinical neck pain. *J Electromyogr Kinesiol.* Dec 28.

[36] Finni, T., et al. 2006. Muscle synergism during isometric plantarflexion in achilles tendon rupture patients and in normal subjects revealed by velocity-encoded cine phase-contrast MRI. *Clin Biomech* (Bristol, Avon). 2006 Jan;21(1):67-74.

changes in movement direction, mechanical line of action and moment arm.[37] In effect, what 'part' of a muscle that works in one position can be and often is different than the 'part' working in a different position – thus confirming the value and need for multi-angle, multiple-choice exercises when attempting to maximize muscular development. This concept is not unique to exercise (insofar as old-time bodybuilders reporting on their experiences), but is unknown to a large degree in the semi-academic circles; and such knowledge certainly is apparent in medicine and the study of muscle wasting diseases, e.g., as per the 'muscle compartment theory,' whereby different muscle groups, individual muscles, or muscle areas may react differently to a variety of stimuli and pathogenic factors."[38]

As previously alluded to, there is an incredibly complex relationship between mind and muscle. Not only does skill improve with advanced trainees, but the central command "causes synchronization of motor activity and muscle sympathetic activity during intense intermittent isometric exercise."[39] And rest assured that the same is true during dynamic activity, but to a more sophisticated degree, and especially if standardizing repetition performance (viz., the more usual/predictable the training experience, the easier it is for both mind and body to execute the required movement with expertise and ease). This was discovered in one study wherein "results suggest that performance gains were mediated primarily by changes in the spatial organization of muscle synergies. These changes were expressed most prominently in terms of the magnitude of activation of the monofunctional muscles."[40] In further support, researchers also found that the ability to increase the endurance time of a submaximal contraction across three sessions can be achieved by altering the level and pattern of muscle activation[41].

And consider, like the brain, that "the motor cortex and spinal cord possess the remarkable ability to alter structure and function in response to differential motor training; the corticospinal system is not only plastic but that the nature and locus of this plasticity is dictated by the specifics of the motor experience. Strength training alters spinal motoneuron excitability and induces synaptogenesis within spinal cord…" and "experiences induce changes in spinal reflexes that are dependent on the specific behavioral demands of the task. These results demonstrate that the acquisition of skilled movement induces a reorganization of neural circuitry within motor cortex that supports the production and refinement of skilled movement sequences. Increases in strength may be mediated by an increased capacity for activation and/or recruitment of spinal motoneurons; a pattern of

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[37] Brown JM, et al. 2007. Muscles within muscles: Coordination of 19 muscle segments within three shoulder muscles during isometric motor tasks. *J Electromyogr Kinesiol.* 2007 Feb;17(1):57-73..

[38] Orozco-Levi M, et al. 2006. The "oil well analogy" as a comprehensive interpretation of factors leading to muscle injury and wasting. *Ultrastruct Pathol.* Jul-Aug;30(4):247-52.

[39] Victor RG, et al. 1995. Central command increases muscle sympathetic nerve activity during intense intermittent isometric exercise in humans. *Circ Res.* Jan; 76(1): 127-31.

[40] HShemmell JH, et al. 2005. Neuromuscular adaptation during skill acquisition on a two degree-of-freedom target-acquisition task: dynamic movement. *J Neurophysiol.* Nov;94(5):3058-68.

[41] Hunter SK, Enoka RM. 2003. Changes in muscle activation can prolong endurance time of a submaximal isometric contraction in humans. *J Appl Physiol.* Jan; 94(1):108-18.

anatomic and physiological plasticity that occurs within the corticospinal system in response to differential motor experience."[42]

Researchers also studied changes in muscle size, muscle architecture, strength, and sprint/jump performances of concurrently training athletes. They concluded: "significant muscle size and architectural adaptations can occur in concurrently training athletes in response to a 5-wk training program. The adaptations (improvement in sport skills) were possibly associated with the force and velocity characteristics of the training exercises but not the movement patterns. Factors other than, or in addition to, muscle architecture must mediate changes in strength, sprint, and jump performance."[43] Again, we see an example of the importance of skill and the CNS being a prime factor when improving function and that repeating specific actions affects performance far better than non-specific actions. Certainly more muscle makes a person more functional, but regular practice to hone skills seems to be of greater importance. Why is this important? Because regular practice of the same exercises performed in the same way will place a greater burden on neuromuscular coordination (an increase in performance that deceives a person into thinking s/he is improving in the gym, to induce more muscular growth) than it will on stimulating muscular hypertrophy change.

Exercise Performance as a Factor

If the neuromuscular system gets used to a particular set of mechanics, such as swinging a baseball bat, it only stands to reason that HOW a particular set of mechanics is executed when lifting weights is part of that skill process. Consequently, doing the same exercises in the same manner decreases the potential for hypertrophy as it increases muscle complacency by way of adaptation of the same 'how.' Consider the differences in overhand vs. underhand baseball, in that being good at one does not make a person good at the other unless also practiced, and yet both involve the throwing of the same implement. The same is true of comparing a slider to a fastball or to a curve ball – all must be practiced in order to be good at each throw. If always throwing the same pitch, a person will become very good at doing so, but altering the speed and mechanics of a pitch imposes a new demand on the organism. And the same could be applied to bodybuilding.

Experienced, 'thinking' bodybuilders have known this for years, and they knew that agitation had to exist; thus, the development and implementation of stutter reps, negative-only, the 21-method, one-and-a-quarter reps, target ROM training, etc. – anything to make an exercise or workout 'different.' The same is true of altering one's cadence (which means changing speed of movement), in that changing from moderately fast movement to very slow movement, or vice versa, can have and often will have noticeable and significant changes in muscle response. And in a broader scope, successful athletes (including competitive and non-competitive bodybuilders) will alter overall exercise demands – to cycle various means and methods to keep the body guessing and on edge… to encourage a higher level of adaptation.

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[42] Adkins DL, et al. 2006. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J. Appl Physiol*. Dec;101(6):1776-82.
[43] Blazevich AJ, et al. 2003. Training-specific muscle architecture adaptation after 5-wk training in athletes. *Med Sci Sports Exerc*. Dec;35(12):2013-22.

Thus, in exercise, regular practice at a particular method of performance, or by including the same degree of demands over time, makes one good at doing so, such as those who practice explosive-style weight training will excel at that manner of weight training better than if moving very slowly, and vice versa, with evidence to suggest little or no cross-over of improvements in isometric, isotonic, and isokinetic modalities; in that regard, the body does adapt specifically to the style of training employed[44,45,46,47,48,49,50]. (As well, there are differences in how efficient ATP is utilized depending on whether experiencing concentric, isometric, or eccentric muscle action.[51])

Also, "a moderate but significant amount of hypertrophy induced by weight training does not necessarily increase performance in an isometric strength task different from the training task but involving the same muscle group."[52] In other words, development of muscle and improvement of skill performance of specific exercises/actions are two different matters, and concurrently this may explain why those who become unusually strong at choice exercise movements, often practiced in the same manner will not necessarily hypertrophy the muscles being trained.

(An obvious connection to the above is that gym performance does not dictate actual strength levels. In effect, isometric tests are most reliable since they avoid any muscular friction, stored energy, impact forces, and movement pattern skills. Isometric tests allow for exact positioning and repeatability of tests. But when compared to dynamic action, of movements that are unrelated to the positions of isometric tests, there are no correlations[53], and dynamic performance often exceed any isometric test, because of subtle changes of positioning to improve inter- and intra-muscular coordination, to make use of tissue stored energy and gravity, etc.)

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[44] Kanehisa, H, Miyashita M. 1983. Effect of isometric and isokinetic muscle training on static strength and dynamic power. *Eur J Appl Physiol Occup Physiol.* 50(3): 365-71.

[45] Behm DG, Sale DG. 1993. Velocity specificity of resistance training. *Sports Med.* 1993 Jun;15(6):374-88.

[46] Dons B, et al. 1979. The effect of weight-lifting exercise related to muscle fibre composition and muscle cross-sectional area in humans. *Eur J App Physiol* 40: 95-106.

[47] HZehr EPH, HSale DGH. 1994. Ballistic movement: muscle activation and neuromuscular adaptation. *Can J Appl Physiol.* Dec;19(4):363-78.

[48] Hammett JB, HHey WTH. 2003. Neuromuscular adaptation to short-term (4 weeks) ballistic training in trained high school athletes. *J Strength Cond Res.* Aug;17(3):556-60.

[49] Gruber M, et al. 2007. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *J Strength Cond Res.* Feb;21(1):274-82.

[50] Grubner M, et al. 2007. Training-specific adaptations of H- and stretch reflexes in human soleus muscle. *J Mot Behav.* 2007 Jan;39(1):68-78.

[51] Ryschon, TW, et al. 1997. Efficiency of human skeletal muscle in vivo: comparison of isometric, concentric, and eccentric muscle action. *J Appl Physiol.* Sep; 83(3): 867-74.

[52] Sale, DG, et al. 1992. Hypertrophy without increased isometric strength after weight training. *Eur J Appl Physiol Occup Physiol.*64(1):51-5.

[53] Murphy AJ, Wilson GJ. 1996. Poor correlations between isometric tests and dynamic performance: relationship to muscle activation. *Eur J Appl Physiol Occup Physiol.* 73(3-4):353-7.

Other research has shown that altering regularly practiced skills, such as walking, causes changes in muscle activation, coordination and electrical pulse output.[54] Since this is known, it is obvious that the more rigorous (standardized) one becomes in how a weight is lifted, the more attuned the muscles become, and the lesser the effect there will be toward hypertrophy; hence, altering how exercises are performed or a regular change of what is performed can have a beneficial influence in agitating an adaptive state.

Even when doing the same movement, when altering movement pattern and pace (e.g., performing stutter reps either while slowing or speeding movement), the degree to which certain muscles activate can change[55], and yet it 'basically' is the same movement. Thus, the complexity of possible human movement, in an enormous possibility of planes of movement and speed, necessitates complexity of adaptation as dictated by complexity of variation. This means that the body *can* adapt to and thrive on complexity of exercise application *if* one desires to maximize the complexity of such adaptation, and doing so will encourage maximum muscular development.

Complexity refers to the environment in general, such as differences in response in hot or cold climate, for example. If the body's physiology responds differently to climate and altitude (e.g., reduced muscle mass, reduction in fiber size, increased fiber capillarization and aerobic enzymes[56]), it stands to reason that it would respond differently to moving very slowly or very quickly in weight training, which it does, as per the Principle of Specificity. Hence, it also must respond (adapt) *differently* whether one performs full-range repetitions in the traditional sense, or if stutter reps or one-and-a-quarter reps are performed; thus, the more varied one's exercise selection and manner in which a weight is lifted, the greater and more complex the extent of adaptation. And since muscle adapts to exercise BOTH by becoming complacent and correspondingly by increasing in muscular size, it only stands to reason that wide variation is vital to experience both at a maximum level – viz., increasing the quantity and extent of complacency (by increasing the degree of variation), results in greater potential for hypertrophy.

Lastly, it should be noted that growth is not infinite; there are limits imposed on every individual. Consequently, is variation that important if a person is nearing or has achieved his or her growth potential? If the person is concerned with appearance, of looking muscular and developed, then what is noticed with regular change and new challenges in exercise will be fuller, more pronounced look of the muscles. The reason being is that the more the muscles are agitated and provided unique challenges, the more the muscles are on edge; even if no further growth is possible, the more responsive they remain. And this has a positive effect in how they appear in regard to fullness and hardness (tonus).

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[54] Bonnard M, et al. 2000. Adaptation of neuromuscular synergies during intentional constraints of space-time relationships in human gait. *J Mot Behav.* Jun;32(2):200-8.

[55] Neptune RR, Herzog W. 2000. Adaptation of muscle coordination to altered task mechanics during steady-state cycling. *J Biomech*. 2000 Feb;33(2):165-72.

[56] Mathieu-Costello O. 2001. Muscle adaptation to altitude: tissue capillarity and capacity for aerobic metabolism. *High Alt Med Biol.* Fall;2(3):413-25.

Muscle Memory

On December 3, 2007 I watched an episode of Daily Planet, a science news magazine. The host, Jay Ingram, spoke of an experiment whereby scientists placed a crumpled piece of Mylar paper in a glass container and placed a 2-gram weight on top. Slowly, over time, the weight pressed down on the paper and crumpled it further (presume a total compression of 50 percent over time for the sake of argument). The researchers grew tired of the experiment and stopped it – removed the weight off the crumpled piece of paper, which slowly expanded toward its original size. The crimps in the paper were the result of stored energy, which released when no longer under pressure and that allowed the paper to expand.

Shortly thereafter (days or weeks, I don't recall), they decided to replace the weight on top the crumpled paper, and very rapidly it returned to the crumpled state it achieved at the end of the experiment, after some time of being under the 2-gram weight. What happened was that it returned to the most compressed/crumpled state rapidly as a result of 'memory.'

This is vital information. If a piece of inanimate paper has memory, certainly muscles possess the same characteristic as a result of exercise. In other words, and this is well known within the exercise industry, a person can exercise hard for several months or years, stop exercise for several more months, and then resume exercise and re-gain his or her previous conditioning much faster than it originally took him to achieve – just like the crumpled piece of paper. This phenomenon is not considered unusual since muscle is dynamic with many cells and living constituents that would institute a sense of 'memory,' to improve survival if imposed by the strain of physical exertion at a later time, as opposed to non-living tissue, e.g., paper.

Now, with that being said, if muscle or any other cells within the body has a sense of 'memory,' it clearly can be deduced that the body has a sense of memory relative to the strain experienced, including exercise and the manner in which that exercise is executed. The strain of a particular weight on a particular piece of paper is very specific, and the same is true of using a particular piece of training equipment in a certain manner (viz., the Principle of Specificity, which involves not only the nature of the exercise, but a corresponding adaptation to what is being experienced). Thus, doing the same things over and over creates a means of complacency by engraining a more pronounced memory of that specific and repeatable experience. It should be obvious how this concept links closely to the idea of neuromuscular skill development, and that people get 'good' at performing the same exercises in the same ways to influence improved lifting ability without stimulating further muscle hypertrophy.

The Zone Training™ Connection

The results produced by exercise are contingent on the total demands imposed. It is not just one thing, such as intensity of effort, or load (and an associated degree of intensity of contraction). As one research paper concluded: "It follows that a thorough mechano-biological description of the loading condition is imperative. Unfortunately, the definition of (resistance) exercise conditions in the past and present literature is insufficient. It is classically limited to load magnitude, number of repetitions and sets, rest in-between sets, number of interventions/week, and training period… the current description is insufficient," and there must be "new determinants of quantitative and/or qualitative effects on skeletal muscle with respect to resistance exercise in healthy, adult humans. These new mandatory determinants comprise the *fractional and temporal distribution of the contraction modes per repetition*, duration of one repetition, rest in-between repetitions, time under tension, muscular failure, range of motion, recovery time, and anatomical definition."[57] If detailed studies were conducted on fractional and temporal distribution of the contraction modes per repetition, we may have conclusive proof as to why Zone Training™ is so effective.

In a similar vein, other research indicates that "mechanical stimuli have often been suggested to be the major determinant of resistance training adaptations; however, some studies suggested that metabolic changes also play an important role in the gains of muscle size and strength" (affected by means of time under tension and even how [the nature of] that tension is experienced).[58] The basis of Zone Training is to make equipment accommodate a muscle's force curve (and not the other way around), which factor can change as fatigue sets in – as to work 'sections' of an exercise's full range specifically and to sufficient fatigue, and in doing so there is an increase in the overall quality and extent of inroad over the full range. Thus, not only is there better mechanical stimulus when Zone Training™, but better metabolic challenges within the targeted muscle.

If we consider the issue of load, a review paper[59] looked at past literature and some new experimental results on muscle adaptation of fiber cross-sectional area and serial sarcomere number. It was concluded: "overall strain does not uniquely regulate muscle fiber size." The reason being is that strain is taken up by tissues (tendons, ligaments, outside non-targeted muscles) that hypertrophy very little if any, and this would explain why some people can become very strong through regular, heavy lifting, but with little change in hypertrophy. As I have stated many times, it is not how much weight you lift, but how you lift it. The above noted research paper further suggests: "the study of adaptation of muscle size requires an integrative approach taking into account fundamental mechanisms of adaptation, as well as effects of higher levels of organization. More attention should be paid to adaptation of connective tissues within and surrounding the muscle and their effects on muscular properties." In doing so, it will become clearer as to why heavy lifting can affect strength/performance capability to such an extent while hypertrophy remains unchanged.

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[57] Toigo M, Boutellier, U. 2006. New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. *Eur J Appl Physiol*. 2006 Aug;97(6):643-63.
[58] Gentil P, et al. 2006. Time under tension and blood lactate response during four different resistance training methods. *J Physiol Anthropol*. Sep;25(5):339-44.
[59] Huijing PA, Jasperts RT. 2005. Adaptation of muscle size and myofascial force transmission: a review and some new experimental results. *Scand J Med Sci Sports*. 2005 Dec;15(6):349-80.

Also consider the issue of intensity of contraction. It has been shown many times, through many studies, that the degree of muscular contraction is greater when induced electrically, and yet the degree of muscular strength and size achievable through those electro-muscular stimulatory means never are comparable to voluntary contractions during traditional exercise means; and this is true, although electrical stimulation may involve a higher uptake of Pi/PCr than what is possible through voluntary contractions.[60] Hence, how hard a muscle contracts does not tell the whole story. Yes, load and intense contractions are required, but obviously both are only parts of the puzzle – of the requirements of the total demands to induce hypertrophy change, and that neither element stands alone or even together as sole causes. There's more to it than simply lifting heavy weights intensely.

Now, contemplate this aspect: the metabolic cost of attaining a given force is greater (more ATP expenditure) and relative to the degree of effort required to sustain that force.[61] In effect, building up effort toward an intense contraction while under a sufficient tension, when lifting weights, causes more of an inroad than simply being at that point and sustaining an intense contraction. Consequently, it could be concluded that more repetitions per unit of time deplete ATP stores faster – and it is known that the faster you move during exercise, the quicker you fatigue – and this, too, creates a greater ATP (metabolic) inroad. And it has been speculated that the greater ATP inroad achieved (in the same anaerobic time), the greater the influence/trigger toward muscular hypertrophy, as per the ATP Deficit Theory (although, and let me make this clear that this, too, is but a small piece of the overall puzzle).

With traditional training, a person can move only so quickly to achieve so many contractions – otherwise, risk of injury increases and momentum increases, thus resulting in potential unloading or reduced quality tension. With Zone Training™, such an issue is of lesser consequence, since far more contractions can be achieved over the same period, in various combinations and at desired/required points to enhance the training effect, and while affecting an exercise's full range-of-movement.

[60] Vanderthommen M., et al. 1999. Human muscle energetics during voluntary and electrically induced isometric contractions as measured by 31P NMR spectroscopy. *Int J Sports Med.* Jul; 20(5):279-83.
[61] Russ, DW, et al. 2002. Metabolic costs of isometric force generation and maintenance of human skeletal muscle. *Am J Physiol Endocrinol Metab*. Feb; 282(2):E448-57.

But the most important consideration is that of variation and its effect on adaptation, as addressed throughout this paper. Any trainee can increase variation with different set variables, choices of exercises, and angles of pull. However, with Zone Training™, a person can alter aspects within the same exercise, such as performing close-grip dumbbell curls in one zone, shifting to a moderate width in another zone, and a wider width still in a third zone (thus making cables and free weights far more diverse in application than most people realize[62]).

Second, whether performing Zone Training or not, the degree of possible variation in cadence is quite broad, from as slow as 30-seconds up-and-down (for a 60-second set) to 1-2 seconds up-and-down. When working in zones, the extent to which a person can include a fast, moderate or slow repetition, or a static hold is easier to integrate, accommodate and control because of a reduce range in which to apply such variation.

Third, consider adding set variables such as forced reps, stutter reps, negatives, etc., within the context of various zones, all done at different rates of movement, and the potential for variation is nothing short of astounding.

Supporting Arguments and Discussions

For discussions on Zone Training™, refer to Book II of the volume Fitness Logistics.

For discussions on proper loading and the effect of human energetics in muscle accommodation, refer to the section *Proper Load Selection (Human Energetics in Exercise Performance),* Chapter 3, Book I of the volume Elemental SynerGenics.

For discussions on disrupting homeostasis, in optimizing muscular size, refer to Chapter 1, Book I of the volume Fitness Logistics.

For discussions on cycling exercise demands and contemplating exercise from a broad perspective, refer to Chapter 7, Book I of the volume Elemental SynerGenics.

For discussions on the Principle of Variation (and the influence of adaptation and Darwinism), refer to that section in Chapter 8, Book II of the volume Theoretical Foundations.

For discussions on stress physiology and the General Adaptation Syndrome, refer to that section in Chapter 10, Book I of Theoretical Foundations.

[62] The diversity of cable systems makes them the ideal choice for maximizing muscle hypertrophy. The reason being is that with machines, the angles and torque (moment arm) are fixed, which leads to quicker adaptation and fewer challenges long-term. Free weights are better because of the possibilities of variation; however, in some exercises (especially chest presses), deviation from a natural plane of movement could result in tissue strain or more serious injuries. With cables machines, the cable pulls and maintains tension without fear or abnormal strain on the tissues when moving in and out of various planes of movement, and all during the same set if desired (e.g., a person can perform a decline or high-incline chest press, or any angle between without changing body positioning).