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A CRITICAL ANALYSIS OF THE NATIONAL STRENGTH AND CONDITIONING ASSOCIATION'S OPINION THAT FREE WEIGHTS ARE SUPERIOR TO MACHINES FOR INCREASING MUSCULAR STRENGTH AND POWER

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Abstract

A significant portion of a recent review on the development of research-based strength training in the National Strength and Conditioning Association focused on their opinion that free weight strength training is superior to machine training for increasing muscular strength and power. The purpose of this critique is to challenge that widely held belief, trace that belief to its probable genesis, and show that it is based primarily on a plethora of unsupported opinions and one highly flawed training study rather than science-based research.

Key words: *Resistance training, free weights, machines, burden of proof*

Introduction

Shurley and colleagues [1] recently documented the chronological history of the National Strength and Conditioning Association (NSCA), which included the genesis and development of the Association's publications. Because the authors specifically stated that for several years there was a raging debate about free weights versus machines and dedicated a significant focus of their manuscript to the specific topic of free weight and machine strength training, this critical analysis will challenge the authors' and the NSCA's opinion that free *weights* are superior to machines for increasing strength and power. There are some legitimate arguments for advantages and disadvantages of all strength training equipment such as cost, space requirements, safety, friction, degree of learning difficulty, etc., which are not the focus of this commentary. The purpose is to challenge the widely held belief that free weights are superior to machines for increasing muscular strength and power.

Free weights are freely moving objects such as barbells, dumbbells, kettlebells, body mass etc. that are used to provide resistance for strength training. Strength training machines use a weight stack, plate loader, pneumatic, hydraulic, or electronic devices to provide resistance. Science dictates that the entire burden of proof is on those who claim superiority of one mode of training over another and that proof must consist of peer-reviewed well-controlled strength training studies—not books, opinions or anecdotal testimony.

Elder Viewpoint (1979)

Shurley and colleagues [1] cited a 1979 NSCA Viewpoint article by Elder entitled *Machines: a viable method for training athletes?* [2]. Elder stated unequivocally that no strength training machine could even approach the strength gains or muscle size achieved with free weights, and that his athletes actually lost strength after training exclusively on machines for 12 weeks. He did not report the training protocol, any data, and most importantly, the type of machines that the trainees used. Shurley and colleagues mentioned that Elder tested his trainees strength only with barbells. However, they did not reveal that it was only one exercise (bench press) that was tested and the study involved only six subjects. Elder noted that all his subjects showed a marked improvement in muscle hypertrophy but did not attempt to explain why their larger muscles did not elicit strength gains. He cited no credible evidence to support his claim regarding the superiority of free weights and admitted he had only his personal observation to support his opinion. Elder also claimed that free weight training enhances an athlete's ability to handle freely moving objects in a specific sport; however, he failed again to cite any evidence to support that opinion.

Shurley and colleagues [1] stated that it was increasingly clear to the NSCA Research Committee that they needed to preserve their academic objectivity by testing the claims of equipment advertisers who were closely affiliated with the Association. If the Research Committee would have applied a similar challenge to the coaches who were closely affiliated with the NSCA, perhaps the coaches' Viewpoints, Roundtables and studies published in the NSCA journals would have had some validity and provided a greater benefit to their readers. Shurley and colleagues could have attempted to explain to their readers the concept of mechanical specificity as it relates to the modality used for training and testing for strength, which was inherent in Elder's Viewpoint [2]. A study by Boyer [3], which was published in one of the NSCA's journals, would have been a good example.

Mechanical Specificity, Boyer (1990)

Boyer [3] randomly assigned 60 previously untrained females (19-37 years) to one of three progressive resistance-training programs. All subjects performed 3x10RM, 3x6RM and 3x8RM weeks 1-3, 4-6 and 7-12, respectively, on 2 lower-body and 5 upper-body exercises 3x/week for 12 weeks. They exercised similar muscle groups using free weights, Nautilus, or Soloflex machines. There was a significant pre – to post-training decrease in thigh, arm and iliac skinfolds and a significant decrease in percent body fat, with no significant difference among the groups for any anthropometric variable. The free-weight group showed significantly greater strength gains than the Nautilus group when tested on the equipment used for training: 1RM bench press (24.5 and 15.3%), behind-the-neck press (22.3 and 10.9%), and leg sled (15.5 and 11.2%), for free-weight and Nautilus groups, respectively. The Nautilus group showed significantly greater strength gains than the free-weight group when tested on the Nautilus machines: bench press (47.2 and 23.3%), lateral raise (46.8 and 19.4%), and leg press (28.2 and 17.1%), for the Nautilus and free-weight groups, respectively. Overall, the average strength gain in the free-weight group was 20.4% (Nautilus and free-weight equipment combined), while the Nautilus® group increased 26.6% (Nautilus and free-weight equipment combined). The Soloflex group significantly increased strength by an average 29.5% when tested on the Soloflex machine, an average 15.1% when tested on the Nautilus machines, and 11.7% with the free weight exercises. Boyer concluded that although the strength gains were significantly greater when each group was tested on their specific training modality, all the groups produced comparable gains in muscular strength and improvements in body composition.

Pipes (1978)

In another study, Pipes [4] randomly assigned 36 young males to a Universal or Nautilus training group, and a control group that did not train. The two training groups performed 3 sets of 8 repetitions with 75% 1RM on four exercises 3x/week for 10 weeks. The 1RM was reassessed every two weeks. They used the leg press, pull-down, seated military press and biceps curl machines by the respective Universal and Nautilus machine manufacturers. All the groups were tested on the four machines from both manufacturers. The anthropometric values (lean body mass, percent fat, skinfolds, circumferences) significantly improved in both training groups, with no significant difference between those groups. When tested on the Universal machines, the group that trained on the Universal machines showed significantly greater strength gains than the Nautilus group on all the exercises (leg press: 28.9 vs 7.5%, pull-down: 25.4 vs 9.5%, military press: 21.9 vs 9.4%, biceps curl: 25.5 vs 9.1%). Conversely, when tested on the Nautilus machines, the group that trained on the Nautilus machines demonstrated significantly greater strength gains than the Universal group on all the exercises (leg press: 27.0 vs 7.5%, pull-down: 24.5 vs 10.5%, military press: 27.3 vs 12.3%, biceps curl: 23.2 vs 7.8%). In summary, the strength gains were approximately 2 to 3½ times greater when the trainees were tested on the specific machine used for training compared with a similar machine from a different manufacturer. This study was another remarkable example of the specificity of training and testing modalities.

It is worth noting that Pipes (4) mistakenly referred to Universal machines as *constant resistance* exercises compared with the variable resistance Nautilus machines. However, Universal machines also provide *variable resistance* exercise, which is discussed in detail later. Pipes' study was published a year before Elder's Viewpoint (2), so it could have been cited by Elder and more importantly by Shurley and colleagues (1) to inform readers about the mechanical specificity of training and testing modalities.

Nautilus Viewpoint (1979)

In response to Elder's Viewpoint [2], Nautilus expressed a Viewpoint [5] that challenged Elder's claim that his athletes lost strength after training with machines. At this point in the debates there was no specific author listed for the Viewpoints from Nautilus Sports/Medical Industries. Nautilus noted that many strength coaches, who have a background in Olympic weightlifting or powerlifting, confuse strength training with skill training. Skill training requires the practice of the specific movement with the specific implement of that physical activity or test. The six subjects in Elder's group did not practice the specific skill of bench pressing a free weight barbell for 12 weeks. Elder, or any other football coach, would probably not consider having their athletes train with free weights throughout the off-season and not practice football skills until opening day of the regular season. The team must practice the specific skills involved in playing football.

Nautilus [5] noted that when used properly, free weights are certainly a viable tool for building strength. They manufactured and sold both machines and free weights. Nautilus machines incorporated a cam that provided a variable external torque. The irregularly shaped cam changed the length of the external moment arm as it rotated through a range of motion. Their rationale was to provide a greater resistance (external torque) for each machine in the range of motion where the muscles produced a greater internal torque, and apply less resistance where the muscles produce a lower internal torque. However, as noted by Shurley and colleagues [1], Nautilus cited no evidence to support the efficacy of the cams and their variable external torque.

It is important to recognize that free weights and most strength training machines are variable resistance exercises. The amount of mass that is lifted does not change throughout the range of motion with any of those modes of exercise. However, the external resistive torque changes throughout the range of motion [6]. Free weights have a naturally occurring, constantly changing external moment arm with single joint exercises and multiple changing external moment arms in multiple joint exercises. Nautilus machines use a mechanically designed and engineered eccentrically shaped pulley known as a *cam* that varies the external moment arm [7], and Universal machines incorporate changing lever and pulley systems [8]. As an external moment arm changes, so does the external torque (the effective resistance). Free weights and plate loading or selectorized machines all use a mass to provide resistance, which remains constant through the range of motion. And they all provide an external torque, which is variable throughout the range of motion.

Yessis Viewpoint (1980)

Shurley and colleagues [1] reported that Yessis [9] took exception to the Nautilus discussion of strength in his own Viewpoint. However, the Yessis Viewpoint was actually a response to a different Nautilus Viewpoint [10]. Shurley and colleagues neglected to cite this second Viewpoint (part II) by Nautilus. It was clearly noted at the beginning of the Yessis article that this was the Viewpoint Yessis was challenging—not the article that Shurley and colleagues cited. Nautilus [10] pointed out that an athlete can train explosively with almost any exercise tool available, including Nautilus machines. However, they believed that explosive resistance exercises may be more dangerous than slower well-controlled movements and that the higher forces generated with explosive movements can be shown graphically with a force plate.

Behm and Sale (1993)

Nearly a quarter-century ago, Behm and Sale [11] resistance trained 8 male and 8 female young university physical education students 3x/week for 16 weeks. All the participants performed 5 sets of maximal effort ankle dorsiflexion exercise. One limb was restrained and therefore restricted to an isometric muscle action. The contralateral limb was opposed by a Cybex II isokinetic dynamometer and was permitted to move through the entire range of motion at its maximal possible velocity (5.23 rad/s, 300°/s). The duration of muscle actions was similar (~0.5s) for both limbs. The dominant limb was randomly assigned to either concentric or isometric muscle actions and the contralateral limb was trained using the mode of exercise not assigned to the dominant limb. At a given session, trainees would perform the concentric exercises first and then the isometric muscle actions first in the next session. This within-subject training protocol was the researchers' attempt to ensure a common neural intent to execute rapid movements and similar motor commands to both limbs. They assessed isometric and concentric peak torque at 8 velocities (0, 0.26, 0.52, 1.04, 1.55, 3.02, 4.19, and 5.23 rad/s). There was a significant increase in peak torque at all the velocities tested in both limbs. Both limbs showed a similar increase in isometric rate of force development (26%) and relaxation (47%), decreased evoked twitch time to peak torque (6%) and half-relaxation time (11%). All of these resistance training responses in both limbs were produced by a training program that prevented actual rapid movement in one of the limbs. Behm and Sale stated that most rapid movements are pre-programmed in the central nervous system and once the central command is discharged to the motor neurons, that discharge cannot be modified by proprioceptive feedback. The study they cited by Desmedt and Godaux [12] in support of their statement concluded that the ballistic command mode can also operate under isometric conditions and the recruitment of motor units appear to be similar under isometric and isotonic conditions. Therefore, when the intent is to move rapidly, the motor unit discharge is the same whether the limb actually moves rapidly, very slowly (e.g., with a heavy resistance or when muscle fatigue is making the exercise more difficult), or no movement occurs. These results suggest that the principle stimulus for a high velocity training response is the intent to perform a rapid muscle action, rather than the actual velocity of movement.

The recommendation by Nautilus [10] for a slower, more controlled speed of movement is not without merit. Their philosophy was that movements are purposely slow only at the beginning of a set. As the muscle fatigues toward the end of a set and after a very slow turnaround from an eccentric to concentric muscle action, the trainee is actually attempting to move the resistance as fast as possible. However because of the increased level of fatigue, the resistance is still moving slowly. This could minimize any potential benefit from the stretch/shortening cycle that would make the exercise easier. Their rationale was that making the exercise more difficult would increase the intensity of effort, and subsequently result in a greater stimulus to increase strength and power. Winter and colleagues [13] have recommended the term *intensity* be adopted to categorize the trainee's perceived challenge and Winter and Fowler [14] noted that the phrase *intensity of exercise* should be used during the performance of exercise to indicate the physiological, psychological or biomechanical demand on the trainee, rather than the amount of resistance.

Fisher and Smith (2012)

Regarding the concept of exercise *intensity*, Fisher and Smith [15] have noted that reporting the percentage of 1RM only represents the amount of the resistance lifted relative to the maximal amount of resistance for a specific exercise. Although an increased load may increase the effort, it is not an accurate measure of the level of effort or intensity exerted by the trainee. When a specific group of trainees complete the same range of repetitions (e.g., 4-7, 8-12, etc.) at the same percentage of the 1RM (e.g., 80%), the relative load is similar among the trainees. However, it is incorrect to assume that they are exercising at a similar level of effort (intensity). The authors cited studies [16-18] that reported very large variations in the number of possible repetitions executed at a specific percent of the 1RM between individuals who are previously untrained or trained, between males and females, and among different exercises within an individual. Fisher and Smith discussed the study by Shimano and colleagues [18]. The next paragraph is a brief summary of the studies by Hoeger and colleagues [16-17].

In two cross-sectional studies by Hoeger and Colleagues [16-17], they evaluated 40 untrained females, 26 resistance trained females, 35 untrained males, and 25 resistance-trained males. Experience in the resistance trained subjects ranged from two months to four years. The maximal number of repetitions was recorded on seven Universal machine exercises at 40, 60, and 80% 1RM in random order for each exercise. Hoeger and colleagues noted that with a given percent of the 1RM subjects will differ from one another by one to several repetitions at the point of muscular fatigue for a specific exercise, as well as differ from one exercise to another within an individual. For example, at 80% 1RM (a load commonly used for increasing muscular strength and hypertrophy), untrained females performed ~12, 6 and 10 repetitions for the leg press, thigh curl and bench press exercises, respectively. Trained females performed ~22, 5 and 14 repetitions for the leg press, thigh curl and bench press exercises, respectively. There was no significant difference between untrained and trained females for the thigh curl but significant differences in the leg press and bench press. For the same three exercises, untrained males executed ~15, 6 and 10 repetitions while trained males performed ~19, 7 and 12 repetitions, respectively. There was no significant difference between untrained and trained males for any of those exercises. Hoeger and colleagues cautioned that trainees should not assume that a given number of repetitions is always associated with the same percent 1RM for all exercises. A similar caution is that if a group of subjects is assigned to train with a specific percentage of the 1RM (e.g., 80%) with a specific range of repetitions (e.g., 8-10), some trainees may not be able to complete 8 repetitions (good effort/intensity but below the prescribed range of repetitions) and some trainees may need to perform 12 or more repetitions to achieve a similar level of effort/intensity. And some individual trainees may experience significantly different levels of effort/intensity that are dependent of the specific exercise. Based on the prevailing evidence, Fisher and Smith [15] concluded that the misuse of the term *intensity* is responsible for several potential complications and inadequacies in research and that the use of the term *load* could resolve those complications. Within the context of resistance training, *intensity* is simply the level of effort applied to a given load.

Nautilus [10] believed that specificity of training means that *specificity* is a superlative. That is, there are no degrees of specificity. A movement is either specific or it is not. They acknowledged that although it is true that free weights require a greater element of balance compared with most machines, free weight balancing skills are required only by Olympic weightlifters and powerlifters. And those athletes must specifically practice the skill of lifting heavy weights.

Another important point Nautilus [10] stressed was the direct relationship between muscular strength and anaerobic muscular endurance. As the muscle fibers within each motor unit become stronger with training, fewer motor units are required to perform a specific submaximal task. Therefore, there are a greater number of motor units in reserve, which results in an enhanced anaerobic muscular endurance. Training for muscular strength directly enhances muscular endurance. The submaximal test should be similar for pre – and post-testing assessments; that is, at the same percent of the pre-training and new post-training 1RM. It should be noted that Nautilus did not cite any references to support their training philosophies. Nonetheless, Shurley and colleagues [1] failed to discuss or even cite this thought provoking article from Nautilus. However, they did cite the response to that article by Yessis [9].

As noted, Shurley and colleagues [1] mentioned briefly that there was a rebuttal to the Nautilus Viewpoint [10] by Yessis [9] but they did not address any of the comments by Yessis. He claimed that Nautilus machines were useful only for building strength but not power. However, his statement can be easily refuted. Power is the result of the work produced (force x distance) in a specific time. For a given range of motion on a Nautilus machine or with a barbell when the force (the external resistance) is moved through that range of motion in a specific time, the result is power. When trainees enhance their ability to increase the amount of resistance throughout the range of motion in the same amount of time, the power generated is greater as well—on a Nautilus machine or with free weights. Yessis erroneously concluded that when a trainee increases strength on a Nautilus machine, the movement time increases and the result is either no increase or a loss in power. Even if his statement was true, and he provided no evidence for support, it would also be similar with free weights.

Yessis [9] mistakenly claimed that a trainee could not quickly transition from the eccentric to the concentric phase of the movement on a Nautilus machine. This type of rapid transition (stretch/shortening cycle) may enable greater force production; however, the momentum created by the rapid transition unloads the muscle for the remainder of the repetition. Consequently, the repetition becomes easier to complete and results in a decreased intensity of effort. If this were the intended—but perhaps misguided—training protocol, it would be equally possible to execute with a Nautilus machine or free weights. Shurley and colleagues [1] did not mention any of these erroneous unsupported claims by Yessis and because they failed to site the correct reference (10) that Yessis challenged, it would be difficult for many readers to understand the basis for the conflict of opinions or draw their own conclusions about the debate.

Wolf Viewpoint (1980)

Wolf [19] responded to the Yessis critique [9] with his own Viewpoint. One of his main points was that because the larger motor units are capable of generating the greatest forces, they contribute to the greatest expression of power, and those motor units can be recruited at relatively slow speeds of movement and a high intensity of effort. Harman [20] has stated: "*It is incorrect to associate strength with low speed and power with high speed*" (p. 20). Wolf noted that because a strength trained athlete can exert greater power than an untrained person, they can generate even more dangerous rapid movements. He also strongly supported the previously discussed muscular strength-endurance relationship noted by Nautilus.

Yessis and Wolf Viewpoints (1981-1982)

Shurley and colleagues [1] reported that Yessis [21] and Wolf [22] had another exchange of Viewpoints, and that there was another article from Nautilus [7]. These are a few examples of those exchanges:

- Yessis attempted to explain how Nautilus machines were built for strength development and not power. He claimed that if a 200 pound resistance is moved 2 feet in 2 seconds, 200 watts (formerly known as foot-pounds) of power are produced. If the time is cut in half to 1 second, 400 watts of power are produced with only a small change in time.
- Wolf noted correctly that watts were not formerly foot-pounds, but foot-pounds per second. He also pointed out that a watt is not equal to 1 foot-pound per second, but is .74 foot-pounds per second. Consequently Yessis' previous and subsequent calculations were approximately 26% in error throughout his article. The small change in time that was referred to by Yessis was actually a rather large decrease of 50% in his example.
- Yessis claimed that a trainee who increases strength with slow speed, high intensity training will decrease the time it takes to execute the lift with the heavier resistance and therefore would not enhance power.
- Wolf pointed out that Yessis probably meant to state that the time would increase—not decrease. However, Wolf noted that there was no evidence to suggest that as trainees get stronger, they get slower.
- Yessis admitted that when athletes perform explosive, ballistic power movements, they become susceptible to injury. However, he claimed that explosive lifting is required because of the danger inherent in their sport. Regarding explosive movements, Winter and colleagues [13] stated: "*Of particular, concern is use of the word "explosive". This is not a physics term and of course nothing actually "explodes" in the human. We recommend that the term "explosive" no longer be used to describe human movement*" (p. 296).
- Nautilus and Wolf were vehemently opposed to exposing athletes to this type of unnecessary so--called explosive training (forces more dangerous than the forces in their sport activities) to supposedly prepare them to withstand other potentially detrimental forces.
- Yessis claimed that a trainee could not perform rapid movements or a quick transition from an eccentric to a concentric muscle action on Nautilus machines (Yessis called it a *speed of switching phenomenon*).
- Wolf noted that if a rapid transition were desired, it could be executed equally as well on Nautilus machines and free weights.

The accompanying article from Nautilus [7] was simply a brief tutorial on the concept of variable resistance exercise. As noted correctly by Shurley and colleagues [1], none of the aforementioned articles and Viewpoints [2, 5, 7-10, 19, 21-22] cited any evidence (strength training studies) to support their opinions about free weights or machines.

Manning and colleagues (1990): Testing the Validity of the Nautilus Cam

Manning and colleagues [23] recruited 22 males and 27 females to participate in a progressive resistance training program for the knee extensors. The subjects were assessed for maximal isometric knee extension torque at 8 angles of knee flexion on a Nautilus knee extension machine. The researchers randomly assigned the participants to one of three groups: a group that trained with variable resistance (VR), another with constant resistance (CR), or a control group. The same Nautilus machine used for the pre – and post-training training assessments was used for training. The VR group exercised with the variable resistance cam supplied with the machine. The cam was replaced with a circular sprocket for the CR group. Therefore, the only difference in training between groups was the pattern of resistance offered by the machine. The training groups performed 1 set of 8-12RM full range of motion knee extensions 2 or 3 times a week for 10 weeks. Each repetition was executed in a slow controlled manner (2s concentric, 4s eccentric). Both groups significantly increased isometric knee extension torque at all the angles tested with no significant difference in strength gains between groups at any angle. The pre – to post-training percent change in the resistance used for training was almost twice as great for the VR group (45.9%) compared with the CR group (23.7%). Manning and colleagues speculated that because the males and females in the CR group were significantly stronger (~29%) than the VR group prior to training, the VR group may have had a greater potential for strength gains. Despite their contention that the constant resistance training should result in significant strength gains only at the weakest point in the range of motion, they concluded that either variable or constant resistance is sufficient to elicit full range of motion strength gains when the exercise is performed slowly and includes an eccentric muscle action.

Stone and Garhammer Viewpoint (1981)

Shurley and colleagues [1] claimed that the lack of evidence supposedly changed in 1981 when Stone and Garhammer [24] joined the debate about free weights and machines with their own Viewpoint on strength and power. Stone and Garhammer claimed that there was little doubt that free weights produced greater gains in strength and power than Nautilus and other machines. They cited only one training study by Stone and colleagues [25] and one study by Wathen [26]. Wathen compared free weights with training on a Mini-Gym Leaper, which did not provide resistance for eccentric muscle actions and is therefore irrelevant to the discussion of free weights versus Nautilus or other machines such as Universal that did incorporate an eccentric component at that time. Dating back over a quarter century, the evidence strongly suggested that strength training protocols with a combination of concentric and eccentric muscle actions are superior to those using concentric-only muscle actions for increasing muscular strength and hypertrophy [27-29]. The study by Stone and colleagues is discussed in great detail below.

Stone and Colleagues (1979)

Stone and colleagues [25] recruited 34 young males who had enrolled in a university beginning weight training class and initially received 4 weeks of training both with free weights and Nautilus machines. Subjects were then randomly assigned to progressively train on 8 Nautilus machine exercises or with 9 free weight exercises 3x/week for 5 additional weeks. The Nautilus group performed 1 set of each exercise and had a target number of repetitions (from 2 to 15) to reach muscular exhaustion. They performed each repetition with a slow controlled movement and 1 day each week trained with negative accentuated repetitions (by alternating limbs to lower the bilateral resistance). The free weight group varied the number of sets from 1 to 5, and repetitions varied from 3 to 12. Unlike the Nautilus group, they trained at their greatest possible speed of movement. The authors did not report the intensity of effort for the free weight group.

Stone and colleagues [25] claimed that the results of their study showed that free weight training was superior to Nautilus training. The free weight squat and vertical jump showed a significantly greater increase for the free weight group. However, there was no significant difference between groups in leg press strength, power (the Lewis formula), or body mass. Stone and colleagues did not report any absolute pre-training data or percent change in strength for any of the 17 exercises. Consequently, it is not known if the increase or the difference in squat strength and vertical jump had any meaningful clinical or practical application to any other activity. The authors did not cite any references to show any carry-over from the squat or vertical jump exercises to any other physical activity—other than squatting with a barbell or vertical jumping.

Stone and colleagues [25] did not have a control group and there were several potential uncontrolled independent variables such as a different number of exercises, sets, repetitions, rest between sets and exercises, different speed of movement and degree of effort in the free weight group, which Stone and colleagues failed to report. It is not known if the free weight group performed each set to fatigue or simply executed a given number repetitions at a specific percent of 1RM.

Stone and colleagues [25] attempted to use the Lewis formula, which combines body mass and jump height to estimate power. In retrospect, it is unreasonable to transfer the height of a jump into some meaningless estimate of muscular power. Harman and colleagues [30] reported that compared with force-platform determination, the Lewis formula underestimated peak power by 70.1% and average power by 12.4%. They concluded that the validity of the Lewis formula has never been supported in a scientific peer-reviewed journal. Consequently it is not a valid method for estimating average or peak power generated by a subject performing a jump. They recommended that the Lewis formula be discontinued. Lower body power estimates are not accurate because the movement has variations in technique, muscle actions and body mass and a weak association between jump height and power [31]. Stone and colleagues believed that power was the most important component for enhancing athletic activities. However, there is very little evidence that attempting to maximize power is related to or is meaningful in most physical activities [31].

Stone and colleagues [25] claimed that one reason the Nautilus machine leg press was not as effective as free weight squats was that each plate on the machine weighed 25 pounds and consequently the trainees in that group could not progress in resistance similar to the free weight group in 5, 10 and 15 pound increments. However, even if the Nautilus 2½, 5 and 7½ pound add-on plates were not available to Stone and colleagues, they could have simply pinned one or more 2½, 5 or 10 pound plates to the weight stack.

Stone and colleagues [25] also criticized the mechanics of the Nautilus machine. They noted that trainees have different limb lengths that create different moment arms. Therefore, the Nautilus machine was not likely to vary the external torque to match each individual. That was a valid point because Nautilus never published any information disclosing how they estimated the strength curve on their machines. However, during the performance of a barbell squat the external torque (the effective resistance) is arbitrarily variable and may not match the optimal internal torque of each individual. Free weights produce a variable resistance but it is a random variation that is determined by constantly changing internal and external leverage factors throughout the range of motion. Consequently, the resistance is too light in some portions of the range of motion and too heavy in other areas—the sticking zone. The trainee is limited to using the amount of resistance that can be handled in the sticking zone. Accordingly, the muscles are being properly overloaded (stimulated) in the sticking zone but not in the stronger positions.

Stone and colleagues [25] claimed that fatigue on the Nautilus machine was likely to occur near the completion of the concentric phase of the rep and consequently limit movement and work output. They claimed that these factors may limit or impede progression and thereby reduce the training effect. However, they cited no evidence to support their claims or why failing at any specific point in the range of motion would significantly influence outcomes.

Footnote

The Nautilus Leg Press machine in the era (circa 1980) of the study by Stone and colleagues [25] incorporated a cam whose radius was ~19 cm from the axis of rotation to the chain's point of contact at the beginning of the concentric muscle action and ~25 cm at the end of the stroke—a steady increase of ~33% for external effective resistance. The Nautilus Duo-Squat, which was also a leg press machine, had a negative cam that unwinds as it moves through the positive stroke. It is connected to a circular sprocket ~15 cm. Depending on the distance from the adjustable seat to the footpads, the radius on the negative cam is ~6 cm at the beginning of the concentric muscle action. At the end of the positive stroke the radius is ~1 cm, which increases the external torque by ~5-6 fold (unpublished personal observations). Both leg press machines provided the greatest amount of resistance in the range of motion where the trainee is the strongest.

Contrary to the previous comment by Stone and colleagues [25] that fatigue occurs near the completion of the concentric muscle action, it is well known that there is an internal biomechanical and musculature advantage toward the end (~last third) of the range of motion in multiple joint free weight exercises such as the squat and bench press. The use of elastic bands or chains may compensate for that advantage with a greater or variable resistance by attaching elastic bands or chains to the barbell. Elastic bands provide increasing resistance throughout the range of motion, whereas chains only add resistance as they are uncoiled from the ground. In order to avoid additional resistance in the sticking zone of multiple joint movements such as the squat and bench press, one could attach a cable or rope to the chains and a barbell. The cable should be long enough to move through the sticking zone for squats and bench presses with just the weight of the barbell and the cable, which is negligible. Once through the sticking zone (~2/3 of the accent or lift), the chain will begin coming off the floor and completely off the floor at the end of the lift. The extra resistance from the chains would be applied gradually only in the mechanically strongest portion of the range of motion.

A recent meta-analysis by Soria-Gila and colleagues [32] included seven studies with 235 young male and female trainees that compared groups training with free weights combined with elastic bands or chains and groups that followed the same training protocol with free weights only. There was no significant difference in strength gains between groups of previously untrained participants. However, there were significantly greater upper body and lower body strength gains (bench press and squats) in experienced trainees (>2 years weight training). Soria-Gila and colleagues concluded: "*This meta-analysis provides research-based data supporting the benefits of VRT* [variable resistance training] *using chains or elastic bands as an effective strategy to increase strength (1RM) in athletes of different sports disciplines*" (p. 3268).

One example from that meta-analysis [32] is a study by Anderson and colleagues [33] who recruited 44 young males and females with at least two consecutive years of organized weight training experience and were Division I-A university athletes. All the participants performed 2-3 sets of 2-10 reps at 72-98% 1RM for 11 upper and lower body exercises including the free weight bench press and back squat 3x/week for 7 weeks. They were randomly assigned to a group that used free weights only (FWR) or a group that used free weights combined with elastic bands (CR) on the back squat and bench press exercises. Both groups significantly increased bench press strength; however, the CR group had a significantly greater increase compared with the FWR group (8% and 4%, respectively). Both groups significantly increased back squat strength with the CR group producing significantly greater gains than the FWR group (16% and 6%, respectively). Anderson and colleagues concluded that using heavy elastic bands to alter the free weight resistance (bench press and squats) resulted in greater strength gains in an already well-trained group of athletes.

Jones (1973)

The idea for attaching chains to a barbell is nothing new. Forty-four years ago Jones [34] noted that for a specific exercise, people are stronger at some points in their range of motion. If they use resistance that they could handle in the strongest position, then it would be too heavy in their weakest position. Jones recalled that 25 years prior to his writing, he first approached this problem by using a weight that was suitable for the weakest position and then attached chains to that weight. As the weight was lifted, the chains were gradually uncoiled from the floor, which steadily added the weight of the chains to the barbell. Therefore, the concept of adding chains to a barbell has existed for at least 69 years.

Jones' [34] solution was to design a machine with an eccentrically shaped cam to vary the external moment arm and hence the effective resistance throughout the range of motion. His hyperbole when he wrote and spoke about his Nautilus machines may have offended or frightened some people and perhaps his statements were the genesis of the continuous unsupported machine criticisms. However, in sharp contrast to the machine haters, Jones noted in the same article: "*The barbell was (and is) a tool capable of producing outstanding degrees of muscular strength—eventually; but it is obviously not the ideal tool*" (p. 52). In the same year [35], he stated: "*Used properly, the barbell is capable of safely producing very worthwhile results….the problem arises from the fact that very few people use a barbell properly. But even when it is used properly, a barbell has certain definite limitations*" (p. 4).

In a book authored by Stone and O'Bryant [36], they noted that studies comparing machines and free weights support the theoretical and empirical data concerning strength and power; and noted: "*These studies include those in which exercise selection and/or repetition schemes were made as similar as possible in comparing modes*" (p. 155). Obviously and unfortunately, their excellent recommendations for study design and control were not included in the study by Stone and colleagues [25].

In their study, Stone and colleagues [25] did not indicate if the people who performed the pre – and post-test evaluations were blinded to the mode of training (free weights or machines). Studies with lack of blinding tend to exaggerate intervention effects compared with adequately blinded studies [37]. There is an inherent difficulty conducting double blind studies with resistance training. For example, trainees would obviously know if they were exercising with free weights or machines, one set or multiple sets, shorter or longer repetition durations, etc. However, it is feasible to blind the assessment of outcomes. Poor internal validity such as not controlling the accuracy of 1RM assessments and the numerous potential confounding variables such as speed of movement and the consequential differences in momentum may confound the practical application of the results to different populations. Perhaps it should be mandated that the assessors are blinded in all resistance training studies.

Shurley and colleagues [1] claimed that the study by Stone and colleagues [25] "…*demonstrated greater improvements in strength and power in a barbell trained group than in a Nautilus-trained group*" (p. 523). However in contrast to the statement by Shurley and colleagues, Stone and colleagues actually concluded: "*There was no significant difference between groups in power*" (p. 160). Consequently, the statement by Shurley and colleagues was misleading at best.

Garhammer (1978)

Stone and colleagues [25] made several other unsubstantiated claims in their Discussion section and they cited an article by Garhammer [38] from *Track*

Technique seven times in two paragraphs. For example, they claimed that as a muscle shortens, the ability to produce force is reduced and with free weights the lever systems in the body will compensate for this limiting factor. They cited only the article by Garhammer in an attempt to support those statements. In fact, Garhammer made a similar claim and in addition he claimed that this so-called compensation would "... *permit efficient continuation of the movement*" (p. 2297). Garhammer failed to cite any references in his article to support those claims. If the compensation really did permit an efficient continuation of movement, why do most free weight exercises have sticking zones?

Stone and colleagues [25] claimed that under heavy workloads, fatigue is more likely to occur with machines near the completion of the concentric muscle action rather than at the beginning of the movement. They cited the article by Garhammer [38] again. Garhammer had stated: "*It is possible that an athlete will be unable to continue some movements to complete joint extension*" (p. 2297). He cited no references to support his opinion. These examples clearly demonstrate that when the claims by Stone and Colleagues are traced to the references they cited for support, it is obvious that their claims are without any scientific merit.

Garhammer [38] made several more unsubstantiated claims. For example, he claimed that there is a preferential recruitment of fast-twitch muscle fibers with very rapid limb movements; if an athletic event requires rapid limb movement, one must train with predominantly explosive movements; and free weights are far superior to expensive machines. He failed to cite any scientific evidence to support his claims. After he asked what sporting event would an athlete lie on a bench or sit in a chair and exert force against an object that offers increasing inertia, he then advocated the power clean exercise because it involves muscle groups acting across the ankle, knee and hip joints, large muscles of the back and shoulders, is fast and explosive, and is performed in the standing position. He did not cite any evidence to support a carry-over from the power clean to any athletic event. One might ask how many sporting events besides Olympic weightlifting involve explosively lifting off the floor heavy discs attached to a seven foot bar and then catching it on your chest. As with the previously discussed study by Stone and colleagues [25], Garhammer's article was devoid of any scientific support for his opinions regarding strength training.

Stone and Colleagues (1979) and Berger (1962)

The consistent long term citing of a highly flawed study such as Stone and colleagues [25] is analogous to the consistent long term citing of the study by Berger [39] regarding single and multiple sets, which was also cited by Shurley and colleagues [1]. The study by Berger went unchallenged for 40 years. Carpinelli [40] challenged the validity of the study and shortly thereafter an exchange between Berger [41] and Carpinelli [42] was published. Berger's study was also cited in previous work by two authors (Todd and Todd) of the current article by Shurley and colleagues, but never challenged. Todd and Todd [43] reported Berger's results, quoted his conclusion, and they commented: "*It is beyond the scope of this article to address the various tasty nuggets found within Berger's famous study*" (p. 277). Unfortunately, Todd and Todd never challenged any part of Berger's study, which is not unlike their failure to challenge anything in the study by Stone and colleagues in their most recent NSCA publication [1]. Readers can read the *tasty nuggets* in the exchange between Carpinelli and Berger and have the opportunity to decide on the validity and relevance of the studies by Berger and by Stone and colleagues.

In the book by Stone and O'Bryant [36], they listed a few studies that compared different machines such as Nautilus and Universal and they incorrectly referred to Universal machines as *non-variable resistance* machines. In fact, Universal machines vary the external torque by changing the position of the fulcrum relative to the point of application of force as the weight-bearing roller arm moves further from the pivot point at the end of the lever. That shift of the fulcrum increases the resistance to the trainee throughout the range of motion [8]. The article by Smith described the variable resistance of the Universal machines and was published in an NSCA journal two years before the book by Stone and O'Bryant. Nevertheless, the only studies they cited that compared machines and free weights were the previously mentioned studies by Stone and colleagues [25] and Wathen [26], and a study by Silvester and colleagues [44] that will be discussed shortly.

Not only did Shurley and colleagues [1] fail to mention the article on Universal machines by Smith [8] when discussing free weights versus variable resistance Nautilus machines but they did not cite another variable resistance machine article in the NSCA's invited series of articles. Keiser [45] described in detail how a compressor supplied air pressure to each of their pneumatic resistance machines providing instantaneously variable resistance for concentric and eccentric muscle actions. The resistance is varied by a piston compressing a pre-selected amount of air in a cylinder and by differences in leverage as the machine's linkage changed throughout the range of motion. Perhaps Shurley and colleagues' omission of the two articles on strength training modes by Smith and by Keiser was another indication of an unfounded bias against resistance training machines and their favorable unsupported opinions of free weights.

Recently, Frost and colleagues [46] compared training with free weights or Keiser pneumatic resistance on bench press strength in 18 males with 3-15 years of resistance training experience. After they were matched for 1RM bench press, one group trained with free weights and the other group with pneumatic resistance. All the trainees followed a similar whole body progressive resistance routine, including the bench press exercise 3x/week for 8 weeks. Both groups significantly increased bench press 1RM when assessed with free weights (10.4 and 11.6%) and pneumatic resistance (9.4 and 17.5%), free weight and pneumatic resistance training groups, respectively. Frost and colleagues noted that despite performing the bench press with one specific type of resistance (free weights or pneumatic) throughout the training, the pre – to post-training increase in 1RM was not significantly different between either group on both modes of exercise.

Although it is beyond the scope of this critique, it should be recognized that there is also a constantly variable internal torque. Some of the many elements that affect internal torque vary within a specific repetition such as a change in the angle of muscle insertion and hence a change in the internal moment arm, length of the muscle, velocity of shortening, etc. Other internal (muscular) elements may vary as a result of resistance training such as muscle cross-sectional area and force production. Thus, the variable external (resistive) torque at any particular point in the range of motion may not match the variable internal (muscular) torque with free weights or machines. As previously noted, the claims by machine companies that their machines are designed to provide an optimal variable resistance are without scientific support.

Shurley and colleagues [1] stated that Stone and Garhammer [24] concluded: "*There is little doubt that free weights, properly used, can produce greater gains in power and strength than Nautilus and other machines*" (p. 24), and they cited the two aforementioned training studies [25-26]. Shurley and colleagues failed to report that Stone and colleagues [25] reported no significant difference in power. Although the title of the article by Shurley and colleagues includes the words *The Emergence of Research-Based Strength and Conditioning*, they failed to note any of the several discrepancies between the claims by Stone and Garhammer, the data from Stone and colleagues, and the actual results. Shurley and colleagues also neglected to inform their readers of all the potential confounding variables in the highly flawed study by Stone and colleagues. One indication of good historical journalism is to challenge the prevailing narrative or belief. That challenge and any research-based evidence are conspicuously missing from the narrative by Shurley and colleagues.

Garhammer (1981-1982)

Shurley and colleagues [1] stated that the article by Stone and Garhammer [24] was followed by a 2-part article: part I by Garhammer [47] and part II by Stone [48]. Garhammer (part I) wrote extensively about how athletes must exhibit *precise* coordinated movements in their competitive events and referred to how the body adapts to *specific* demands of athletic competition. He claimed that there are neuromuscular similarities of free weight exercises and the neuromuscular demands of athletic performance. However, he did not cite any training studies to demonstrate that free weight training has a superior carry over to any specific physical activity other than perhaps powerlifting and Olympic weightlifting. Similar is not the same as specific.

Garhammer [47] claimed that some variable resistance machines, including machines with a cam, restrict acceleration and others permit excessive momentum. He believed that the resulting velocity profile is significantly different from what is common to athletic movement. However, he failed to cite any evidence to support those claims. He noted that if a trainee moves too fast on a machine, the resistance will move for a short distance on its own. Of course because of momentum, that is also true with most free weight exercises.

Arandjelovic [49] stated: "*The greater the momentum of the load lifted, such as a weighted bar or dumbbell, the longer the load will sustain motion against gravity even in the absence of any additional force exerted against it by the trainee*" (p. 136). Thus, the momentum may be used to overcome biomechanically weak points in a lift. A compound movement such as a barbell squat involves coordinated action of several separate muscle groups. The momentum generated from the full squat position can be used to overcome a potential biomechanical weakness at the midpoint of the concentric portion of the lift. A similar technique can be used in the bench press. This phenomenon is practiced by strength and power athletes such as powerlifters and Olympic weightlifters and is often used during competition to demonstrate strength and power in a specific lift. While actually training to build muscular strength, power and hypertrophy, the use of momentum to complete a repetition is commonly known as cheating [50]. Perhaps coaches, trainers and trainees should try to stress the difference between training for strength/power and demonstrating strength/power.

When trying to understand the difference between building muscular strength/power and demonstrating muscular strength/power, coaches and trainees could focus on the distinct differences between the desired outcomes. The goal of the former is primarily chronic; that is, to safely, effectively and efficiently as possible apply a stimulus (resistance training) that will elicit an optimal response—an increase in strength/power. The goal of the latter is primarily acute; that is, to move some specific form of resistance from point A to point B. For example, a powerlifter or Olympic weightlifter moving the heaviest possible resistance from point A to point B, or an offensive lineman moving a defensive lineman from an effective position to an ineffective position, etc. As with any other demonstration of strength/power, trainees must specifically practice the desired skill.

Garhammer [47] expressed his opinion about the importance of a counter movement (stretch/shortening cycle) in resistance training and the ability to utilize it with free weight training. However, he neglected to mention that all Nautilus machines and free weights provide resistance for the stretch/shortening cycle of muscle actions.

Garhammer [47] claimed that as a barbell is moved through the range of motion and optimal internal leverage produces the greatest internal torque, the barbell perfectly accommodates the increased internal (muscular) torque by accelerating at a greater rate. In fact, the barbell responds to the larger internal force with a greater acceleration. The greater the applied force to a given mass, the greater the acceleration. During the execution of some multi-joint free weight exercises, such as the squat, bench press and military press, greater torque can be generated during the last third of the concentric muscle action as compared with the middle third, which is usually the sticking zone. When a trainee attempts to accelerate the barbell throughout the range of motion, the greater acceleration in the first third of the repetition produces greater barbell momentum, which was discussed in a previous paragraph. The momentum helps the athlete move the resistance through the sticking zone and makes that part of the repetition easier and the last third of the repetition—where the athlete is the strongest—the easiest. The result is a reduced intensity of effort throughout most of the repetition. This technique however, is a great asset for athletes who are demonstrating the specific skill of powerlifting or Olympic weightlifting but perhaps it should be minimized while building strength thereby increasing the intensity of effort for each repetition.

Garhammer [47] emphasized the importance of eccentric muscle actions and correctly referred to the insufficiency of isokinetic machines because they did not have an eccentric component at that time. However, all Nautilus machines have always provided resistance for concentric and eccentric muscle actions. Shurley and colleagues [1] claimed that Garhammer stated that the constant velocity of Nautilus machines were unlike sport movements. However, Garhammer specifically stated that constant velocity was inherent in isokinetic machines. He did not refer to Nautilus machines, which are not nor have ever been isokinetic machines. For a group of authors who have previously written extensively about strength training history [43, 51-53] in the NSCA's *Journal of Strength & Conditioning Research*, Shurley and colleagues (Todd and Todd) should have known how Nautilus machines function. Ironically, the Editor-in-Chief of the aforementioned journal recently claimed that Todd and Todd were the best resource for the study of resistance training history and physical culture [54].

Garhammer [47] consistently attempted to use the testimony of other coaches and weightlifters as evidence to support his own training philosophy; that is, he used other opinions to support his own opinions. He stated that some physiologists and medical doctors attempt to support a specific training philosophy based on hypothetical concepts but have little or no evidence to support their philosophy. Ironically, there was an absence of evidence to support any of Garhammer's philosophies.

Stone (1982)

Stone [48] authored the 2nd part of the 2-part article. He stated that his intention was to inform readers how and why free weights produce superior results compared with machines. He began with a brief tutorial on neuromuscular physiology and emphasized that the timing of the firing of specific patterns of motor units is critical for most sport activities and that the acquisition of skill is an integral part of strength training. He claimed that there was little doubt from motor learning studies that similar training activities augment performance. Stone cited four references in an attempt to support those statements: three books, and one study on motor skills and physical fatigue [55] that did not involve strength training. That study compared climbing a Bachman ladder during fatigued and non-fatigued conditions. Stone did not cite any strength training studies to support his opinions.

Stone [48] stated that some authors have recommended purposefully slow movements but that type of slow training would result in a smaller training effect. His rationale was that fewer fast twitch motor units would be recruited and the lower force level would reduce the need to increase motor unit firing frequency and synchronization. Stone's explanation contradicts what is perhaps the most supported principle in neurobiology—the size principle [56]. The size principle states that motor units are recruited in an orderly manner proceeding from to smaller slow twitch motor units to the larger fast twitch motor units, and that recruitment is based primarily on the intensity of effort. At the end of a maximal effort set of repetitions, all the motor units in a specific motor unit pool are firing at maximal capability—regardless of the speed of movement [57].

The only strength training studies cited by Stone (48) that compared free weights and machines are the previously discussed unrelated study by Wathen [26] and the previously discussed deeply flawed study by Stone and colleagues [25]. Nevertheless, Stone's concluding comment, which was quoted by Shurley and colleagues [1]: "*Clearly, free weights have numerous advantages over machines*" (p. 523), is without any scientific merit.

Shurley and colleagues [1] claimed: "*Mike Stone* [48] *refuted the Nautilus claims nearly point by point, citing research for each contention*" (p. 523). Shirley and colleagues devoted an entire paragraph to describe how Stone allegedly refuted the claims by Nautilus. However, a careful reading of Stone's article, and checking the references he cited, reveals that Stone failed to cite any research (strength training studies) to support his attempt to refute the claims by Nautilus. This does not imply that the claims by Nautilus were valid, but simply that Stone's refutations were unfounded. Apparently, Shurley and colleagues failed to check the validity of Stone's references.

In another article, Stone and colleagues [58] stated: "*The authors' observations and those of others strongly suggest that LBM may well be the most important factor contributing to strength-power gains*" (p. 38). Although the authors may have really believed that lean body mass is the greatest contributing factor to increased strength and power, they neglected to challenge the Viewpoint by Elder [2]. Recall that Elder reported that as a result of strength training with machines, his athletes increased muscle size but antithetically claimed that they lost strength.

Stone and Borden (1997)

Almost twenty years later, Stone and Borden [59] claimed that studies have consistently indicated that free weights produce superior strength gains. They cited only four references in an attempt to support their assertion: the previously discussed studies by Boyer [3] and Stone and colleagues [25], and studies by Wathen and Shutes [60] and Jesse and colleagues [61]. Similar to the previously discussed study by Wathen [26], Wathen and Shutes compared barbell squat training with training on the isokinetic concentric-only Mini-Gym Leaper in 24 collegiate football players for 8 weeks. There were two groups of Leaper trainees; one group executed a lower number of repetitions and the other group a higher number of repetitions. The authors did not report the number of sets, repetitions, intensity or frequency of training. The group who performed—and practiced—the squat exercise for 8 weeks showed a significantly greater increase in 1RM barbell squat compared with the two Leaper groups. None of the groups produced a significant increase in vertical jump or 40 yard dash. As noted in the previously discussed study by Wathen, the free weight group practiced the barbell squat for 8 weeks and a major potential confounding variable was the lack of an eccentric component on the Mini-Gym Leaper.

Jesse and Colleagues (1988)

Jesse and colleagues [61] randomly assigned 47 subjects to one of four training groups. Two groups trained on a Nautilus leg press machine and two groups performed barbell squats 3x/week for 7½ weeks. One of the two Nautilus groups used a Nautilus protocol (one set of the exercise performed purposely slow to exhaustion) and the other followed a so-called *periodized* protocol of progressively decreasing volume and increasing intensity throughout the study duration. Repetitions, sets, intensity and speed of movement were not reported. Similarly, one of the free weight groups performed one set of squats to exhaustion, while the other group progressed with decreased volume and increased intensity for the 7½ weeks. All groups significantly increased 1RM barbell squats, with both barbell squat groups producing significantly greater gains than the Nautilus groups. The four groups significantly increased 1RM leg press, with no significant difference in strength gains among the groups.

Kompf and Aradjelovic [62] have noted that the squat is a complex exercise from a biomechanical and neuromuscular aspect. Given that the ascent from the full squat position involves concentric actions of muscle groups with antagonist functions (e.g., the quadriceps and the hamstrings at the knee and hip), perfecting the squat requires practice to fine tune the timing and recruitment of the different contributing muscles. In the aforementioned training program by Jesse and colleagues [61], the free weight group had an inherent advantage in the free weight 1RM squat assessment because that group used the same equipment for training and assessment, while the Nautilus machine group did not use free weights for 7½ weeks.

The study by Jesse and colleagues [61] was published only as an abstract with limited data and limited information on the methodology. Consequently, details of the progressive training protocols are unknown and the only logical conclusion drawn from the abstract is that it was more effective to practice the barbell squat for 7½ weeks than to not squat for 7½ weeks. The authors did not report any statistical analysis between the single set groups and the *periodized* groups. However, the strength gains reported for those groups in the leg press and the barbell squat were similar and within a couple of percentage points. Any reference to those similar strength gains in the single set and *periodized* groups was conspicuously missing from the abstract.

Stone was a co-author of the abstract by Jesse and colleagues [61] and one of 17 authors and the corresponding author with the editor of a journal who published a Correspondence [63] regarding single versus multiple sets of strength training. That group of authors desperately attempted to discredit a review by Carpinelli and Otto [64]. One of their criticisms was that Carpinelli and Otto used an abstract of a study as a reference in their review. Stone and his colleagues [63] proclaimed: "*Abstracts rarely contain all the pertinent data, a factor well known by most exercise and sports scientists*" (p. 409). It appears that Stone's negative opinion about citing abstracts was not applicable to his own article because Stone and Borden [59] cited the abstract by Jesse and colleagues.

It is also worth noting that in the aforementioned Correspondence [63], Stone and 16 of his colleagues boasted about their over 300 years of combined weight room experience and that Carpinelli and Otto [64] ignored the experience of the majority of strength athletes and coaches in their review. Perhaps their extensive experience in the weight room of observing common strength training practices was more of a liability than an asset to critical thinking because many weight room practices have absolutely no foundation in physiology. Those statements about experience in the weight room underscored their preference to be influenced by common practice and opinions rather than science based resistance training studies.

Stone and Colleagues (2000)

Three years later in a similar article by Stone and colleagues [65], they referred to *mechanical specificity* and claimed: "*The more similar a training exercise is to the actual physical performance, the greater the probability of transfer*" (p. 66). They cited three references in an attempt to support their claim; two books and one peer reviewed article on the neuromuscular aspects of resistance training by Behm [66]. When Behm referred to movement specificity, he cited one study by Rasch and Morehouse [67] and stated that those authors reported larger strength gains when trainees were tested in a familiar position or exercise versus a test not specific to the training mode. Briefly, Rasch and Morehouse reported that one of their groups of young male trainees performed 3x5RM standing dumbbell curls 3x/week for 6 weeks. They reported the post-training data for three different isometric strength tests: standing with a cable tensiometer at 100° elbow flexion (familiar position), supine at 100° elbow flexion (unfamiliar position), and supine at 80° elbow flexion (another unfamiliar position—the Martin test). Rasch and Morehouse concluded: "*It will be observed that the increases in strength following isotonic training* [dumbbells] *were considerably larger when the subject was tested in the position in which he practiced the exercises (erect) than when tested in a position (supine) or by a technique (modified Martin) unfamiliar to him*" (p. 33).

In the study by Rasch and Morehouse [67], simply changing the position of the torso significantly affected the test outcome. For example, the strength gain in the erect position was ~4 times greater than the supine test and ~3 times greater than the Martin test. Rasch and Morehouse never mentioned any transfer of strength gains to sports performance or any other specific physical activity. They were referring to the difference of testing trainees either *specifically* the way they were training or in some slightly unfamiliar position. Readers may have been misled and inferred from Stone and colleagues' statement [65] that strength gains after training with a barbell squat are more effective on the performance of a football lineman, tennis player, hockey player, shot putter, etc. than the strength gains produced after training on a leg press machine. That inference is not supported by Behm's article or the study by Rasch and Morehouse. In fact, most of the strength training research showed that strength gains are specific to the mode of testing and cited no evidence to support a superior carry-over of mechanical specificity to any particular sport or physical activity.

Stone and colleagues [65] noted that only three studies in the scientific literature used previously trained subjects: the highly flawed previously discussed study by Stone and colleagues [25], and the studies by Wathen [26] and Wathen and Shutes [60] who compared free weights with training on a Mini-Gym Leaper. As previously explained, the Mini-Gym Leaper lacks the capability to provide resistance for eccentric muscle actions. None of these three studies with previously trained subjects supported the superiority of free weights over machines such as Nautilus that provide resistance for concentric and eccentric muscle actions.

Buckner and colleagues [68] explained that the use of the word *trained* or the phrases *recreationally trained*, *well-trained*, etc. are not well defined in the literature. Some authors define trained participants based on a specific period of training (e.g., 6 months, 2 years, etc.); others may use either absolute or relative strength levels as criteria or perhaps a combination of months/years of training and strength levels. These inconsistences make it difficult to differentiate responses between previously untrained and so-called trained populations [68].

Stone and colleagues [65] stated that when comparing free weight with machine strength training, equal workloads are rarely prescribed because researchers often use the machine manufacturer's recommended training protocol. They referred to the previously discussed study by Stone and colleagues [25] as an example of using one set to failure for the Nautilus group and multiple sets in the free weight group. Valid research should require minimizing potential confounding variables and assign similar training protocols for a free weight versus machine training study, with the mode of training (free weights or machines) the only independent variable.

The same year as the article by Stone and colleagues [65], the NSCA published a roundtable discussion of machines versus free weights [69]. Neither Stone nor the other contributing participants cited any additional strength training studies that reported the superiority of free weights over Nautilus machines.

Stone and Colleagues (2002)

Two years later, Stone and colleagues [70] claimed again in a section entitled Machines vs Free Weights that free weights produce superior strength gains. They cited four studies: Boyer [3], Jesse and colleagues [61], Stone and colleagues [25], Wathen & Shutes [60]. None of these previously discussed studies supported their claim.

Stone and Colleagues (2007)

In a 2007 book by Stone and colleagues [71] under a section entitled Machines versus Free Weights, they claimed that studies have consistently shown that free weights produce superior results. They cited only the previously discussed studies [3, 25, 60-61]. Those four studies are apparently all they had in an attempt to support their opinion.

Omission Bias

Shurley and colleagues [1] quoted Stone [48]and Stone and colleagues [25] who claimed the superiority of free weights compared with machines. Objective journalism should have compelled Shurley and colleagues to report other studies that compared free weight and Nautilus training, especially a study by Silvester and colleagues [44] that was published at around the same time as the study by Stone and colleagues [25]. Studies such as the ones discussed below are conspicuously missing from the narrative by Shurley and colleagues.

Silvester and Colleagues (1981)

Silvester and colleagues [44] reported the results of two experiments comparing free weights and machines. In experiment #1, 60 previously untrained college-age males were randomly assigned to one of three groups who performed 1x4-16RM for Nautilus knee extension and leg press exercises, 2x7-15RM Universal leg press, or 3x6RM free weight squats 2-3x/week for 11 weeks. Vertical jump height showed a similar significant increase for the Universal, and free-weight groups. The authors noted that the increases were relatively small (~1 cm) and they were not sure if the changes had any meaningful practical application. There was a significant increase in lower-body strength (isometric knee extension and hip extension combined) of 8.6, 9.7, and 12.5 %, for Nautilus, Universal, and free-weight groups, respectively. However, there was no significant difference in strength gains among the groups.

In experiment #2, Silvester and colleagues [44] randomly assigned 48 previously untrained college-age males to one of four groups. Two groups performed barbell curls for either 1x10-12RM or 3x6RM, and two groups performed Nautilus machine curls 1x6RM or 3x6RM with approximately 80% 1RM. All the groups trained 3x/week for 8 weeks. The four groups significantly increased isometric elbow-flexion strength (average of the four angles tested) after training with 1 set of barbell curls (23.0%), 3 sets of barbell curls (33.0%), 1 set of Nautilus machine curls (26.2%) or 3 sets of machine curls (19.5%). There was no significant difference in strength gains among the groups at any of the four angles tested. Silvester and colleagues concluded that "…*variable resistance* [Nautilus] *and free weights were equally effective at developing strength throughout the complete range of motion*" (p. 32).

Rossi and Colleagues (2016)

Rossi and colleagues [72] randomly assigned 26 young males to one of three resistance training groups. One group performed 6 sets of barbell squats for lower body training, a second group used a leg press machine for 6 sets, and a third group combined 3 sets of squats and 3 sets of leg presses. All the trainees followed an 8-10RM progressive resistance protocol 2x/week for 10 weeks. There was a significant increase in fat free mass, balance test performance, vertical jump height, and 1RM leg press, with no significant difference among the groups for any of those outcomes. The squat group and the combination squat+leg press group showed significantly greater increases in 1RM squat than the leg press group (31.5, 19.8, and 7.9%, respectively). Rossi and colleagues noted that during the squat exercise the knees flexed to ~120° and the hips to ~20°, while to only ~90° knee flexion and to ~45° hip flexion on the leg press machine. They speculated that the differences in range of motion for these two exercises could explain the greater increase in 1RM squat for the two groups who had practiced squatting for 10 weeks compared with the leg press group who did not squat for 10 weeks. The authors concluded that the three training protocols had a similar significant positive effect on all the functional outcomes including the vertical jump and balance tests.

Wirth and Colleagues (2016)

Wirth and colleagues [73] randomly assigned 78 young male and female athletes with at least six months resistance training experience to a squat, leg press or control group. Both training groups performed 5x8-10RM, 5x6-8RM and 5x4-6RM weeks 1-3, 4-6 and 7-8, respectively. Subjects trained 2x/week and performed each set to momentary muscular failure. The only difference in training protocol between the groups was the selected exercise (barbell squat vs leg press). The squat group significantly increased vertical jump performance but there was no significant vertical jump increase in the leg press group. The authors concluded that the squat exercise was more effective in enhancing jump performance. Both the squat and leg press groups significantly increased maximal isometric and dynamic strength (1RM), with no significant difference between groups for those outcomes.

Sanders (1980)

Sanders [74] randomly assigned 22 college students to a free-weight (bench press and behind-the-neck seated press) or Nautilus (chest press and shoulder press machines) training group. Both groups performed 3x6RM 3x/week for 5 weeks. Strength tests (isometric) were conducted with a load cell fastened to a table. Elbow extensor strength significantly increased in the free-weight (~22%) and Nautilus (~24%) groups. Shoulder flexor strength significantly increased following free weight training (~12%) and Nautilus training (~13%). There was no significant difference in strength gains between the free weight and Nautilus groups. Sanders concluded that free weights and Nautilus machines were equally effective for developing muscular strength.

Langford and colleagues (2007)

Langford and colleagues [75] trained 49 healthy young males 2x/week for 10 weeks. The subjects had novice to intermediate resistance training experience. All the trainees performed the bent-over row, shoulder press, and biceps curl exercises with dumbbells. Three groups each used a different type of resistance for the bench press exercise: barbell, log bar or weight stack machine. The relatively unstable log bar was partially filled with water to 50 kg and they added free weight plates to determine each trainee's 3RM and the resistance used for training with the log bar. All trainees were assessed for 3RM with the barbell, log bar and on the machine bench press as well as isokinetic peak force on a Biodex dynamometer. They trained the bench press using only the specific mode of exercise assigned to their group. The bench press progressive resistance protocol varied and ranged from 3-5 sets and 4-12 repetitions. All three groups significantly increased peak force and 3RM on the three modes of exercise, with no significant difference in strength gains among the groups when tested with the barbell (12.9, 11.2 and 11.3%), log bar (10.5, 16.9 and 14.7%), and machine (8.8, 11.0 and 15.8%), for the barbell, log bar and machine training groups respectively. Langford and colleagues stated: "*Although the exercises included for training in this study appear to differ in the demand to control the load [log bar>barbell>machine], the data indicate that similar strength improvement occurs after short-term training with the 3 types of bench press exercises*" (p. 1065).

Langford and colleagues [75] stated: "*In a roundtable discussion* [reference 69]*, investigators could not reach a consensus because of the lack of research data to determine which mode of isotonic training, machine versus free weights, better transfer strength when subjects are tested on a mode not used during training*" (p. 1065). And perhaps most importantly: "*The degree of specificity for a resistance exercise to most effectively enhance sport performance and prevent injury is yet to be determined*" (p. 1065).

Balachandran and colleagues (2016)

Balachandran and colleagues [76] randomly assigned 29 previously untrained but independently-living older males and females (~69 years old) to either a standing Cybex Bravo Pro cable machine (SC) or seated Cybex VR2 machine (SM) resistance training protocol. The participants in the SC group executed all cable exercises in a standing position while the SM group performed similar exercises seated in traditional exercise machines. All participants performed 3 sets of 12 repetitions for 6 upper body and 4 lower body exercises 2x/wk for 12 weeks. The assessors of all functional outcomes were blinded to the group assignments. There was a similar session rating of perceived exertion, volume of exercise, repetition duration, and intensity of effort in both groups. The authors reported similar results in both groups for most of the primary and secondary outcomes. Balachandran and colleagues concluded: "*The primary finding of the study was that both seated machine (SM) and standing cable (SC) training showed clinical and statistical improvements in physical performance, but there was no statistically significant difference between the groups*" (p. 136).

Fisher and colleagues (2012)

Fisher and colleagues [77] randomly allocated 36 young males with at least two years of resistance training experience, which included a non-specific variation of the deadlift exercise, to one of three groups: MedX lumbar extension machine (LUMX), Romanian (stiff-legged) deadlift with wrist straps (DL), or a control group. The researchers assessed maximal isometric lumbar extension torque at 12^{o} intervals from lumbar flexion (72^{o}) to full lumbar extension (0°) and tested the Romanian deadlift 1RM. The LUMX and DL groups performed 1 set of 8-12 repetitions with ~80% of the tested functional torque/1RM at a repetition duration of 2s concentric and 4s eccentric muscle actions to volitional fatigue 1x/week for 10 weeks of supervised progressive training. The Romanian 1RM deadlift significantly increased in the DL (~16%) and LUMX (~8%) groups. The DL group did not increase maximal lumbar extension strength at any angle; however, the LUMX group significantly increased lumbar extension torque at 6 of the 7 angles in the range of motion. The authors acknowledged the specificity of training as related to the exercise tested but noted that although each group may have had the disadvantage of not using the specific exercise of the other group, the DL group showed a significant strength gain only when tested in the deadlift and did not improve in lumbar extension strength; whereas the LUMX group showed significant gains in lumbar extension strength and deadlift 1RM as well. Given the propensity of injury to the lumbar area its debilitating effects, Fisher and colleagues recommended that if strengthening the lumbar extensors is desired, coaches and athletes should include isolated lumbar extension exercise at least once a week in a resistance training program.

Manual Resistance: Dorgo and colleagues (2009)

Dorgo and colleagues [78] recruited 84 undergraduate males and females for participation in a resistance training program and randomly assigned them to a free weight training group (WRT) or a manual resistance training group (MRT). About half the subjects were currently engaged in a resistance training program. The manual resistance group used a spotter to provide resistance to the lifter with limited equipment such as PVC pipe, rope, straps, etc. and a chair or bench. Traditional weight training equipment such barbells and dumbbells were not used. The spotter was positioned to have a mechanical advantage over the lifter, which allowed the spotter to control the resistance throughout the range of motion and for a weaker spotter to apply the required resistance to a stronger lifter. The researchers developed a training program with exercises as similar as possible for free weight trainees and manual resistance trainees. All the trainees performed a progressive resistance protocol of 2-4 sets for 8-12RM that included 6-9 large muscle group exercises such as the bench press, shoulder press and squat at each session 3x/week for 14 weeks. All the trainees performed a similar number of exercises, rest intervals, sets and repetitions. Both groups significantly increases 1RM bench press (9.8 and 7.4%) and squat (32.9 and 26.8%), WRT and MRT groups, respectively. There was no significant difference in strength gains between the WRT and MRT groups. Both groups significantly increased bench press and squat muscular endurance (repetitions to exhaustion with 70% of pre-training 1RM), with no significant difference between groups. Dorgo and colleagues concluded: "*The WRT group had an apparent advantage in the free weight 1RM testing because the same equipment was used for training and assessment, whereas the MRT group did not use free weights or exercise machines during the 14 week program. Therefore, it may be inferred that the slightly greater strength improvements* [although not statistically significant] *observed for the WRT group compared with the MRT group are attributable to training-testing specificity rather than differences in the effectiveness of the training modalities*" (p. 302).

Muscle Hypertrophy

It should be emphasized that Shurley and colleagues [1] did not cite, nor is this author aware of any resistance training studies with supporting evidence to suggest that free weights are superior to machines for enhancing muscle hypertrophy.

Integrity

Dankel and colleagues [79] have noted that if the percent increase in strength is recorded for each individual within a study, the individuals with lower baseline values respond to a greater extent than those with higher baseline values. For example, if two trainees each increase strength by 10 kg and one had a starting strength of 100 kg and the other 200 kg, the strength gains would be 10% and 5%, respectively. The authors concluded: "*The wide range of trainability in response to resistance training makes taking the percentage change an inappropriate way to analyze the data obtained within the same study in which all individuals undergo the same training protocol and testing procedures*" (p. 448).

With the exception of the one study by Balachandran and colleagues [76], none of the aforementioned resistance training studies discussed in this critical analysis controlled for blinded outcomes assessments. Consequently, all those studies were potentially subjected to some degree of confirmation bias.

Many of us have experienced delusional expectations regarding one specific training protocol or mode of exercise over another and we should be careful not to fool ourselves and attempt to translate those beliefs into the scientific literature without strong supporting evidence. We find ways to fool ourselves and even an honest person can be a master of self-deception [80]. When writing about scientific integrity, the Nobel Prize winning theoretical physicist Dr. Richard Feynman [81] stated: "*The first principle is that you must not fool yourself—and you are the easiest person to fool. So you have to be very careful about that. After you've not fooled yourself, it's easy not to fool other scientists*" (p. 343).

Conclusions

It is apparent from their extensive writing over several decades that the NSCA, Stone, Garhammer and many others including Shurley and colleagues [1] sincerely believe that strength training with free weights is superior to machines for increasing strength and power. However, belief is not necessarily synonymous with validity. Those beliefs must be supported with well-controlled resistance training studies. The study by Stone and colleagues [25] has been consistently cited for almost four decades in support of free weights over machines. With the exception of that one highly flawed study, all the references from that era of the NSCA are simply unsupported opinions expressed primarily in NSCA journals.

Shurley and colleagues [1] boasted that the NSCA's *Journal of Strength and Conditioning Research* has swelled to more than 400 articles in its most recent volume and noted the NSCA's 40-year history and 38 years of NSCA journal publications. Considering the plethora of opinions about free weights and machines, there should be a preponderance of strength training studies just in the NSCA's journals that would support their belief in the superiority of a specific training mode. If those studies existed, Shurley and colleagues could have cited some of them to support their opinion and the opinion of the NSCA that they emphasized in their article**.** Practical application of any claim for a specific mode of exercise would require the replication of results in males and females across different age groups in populations who train for general fitness, health, strength and muscularity, as well as competitive athletes.

Shurley and colleagues [1] noted that the pioneers in the strength and conditioning profession (in the 1970s) relied on anecdotal evidence and quasi-scientific assertions. Unfortunately, not much has changed over the last 40 years.

Science dictates that the burden of proof lies entirely on the claimant. An extraordinary claim such as the NSCA's claim for the superiority of free weight training, which has prevailed throughout the NSCA literature for the last 38 years, requires a preponderance of extraordinary scientific evidence for support. In the article by Shurley and colleagues [1] there is a conspicuous absence of scientific evidence to support the superiority of any specific mode of exercise for increasing muscular strength, power, or hypertrophy, rendering their opinion and the NSCA's opinion simply unsupported opinions.

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The author declares no conflict of interest and has never had a financial or corporate affiliation with Nautilus Sports/Medical Industries or any other machine or free weight enterprise. He has been training safely and productively with free weights and Nautilus machines for decades.

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