Scientific Support For The Point Of View That

# STRENGTH CHANGES EVERYTHING®

**Brian Cygan**
*B.Sc.*

**James P. Fisher**
*PhD*

**Matt Essex**
*M.S.*

**Jeremy Bourgeois**
*PT, DPT*

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# THE IMPACT OF MUSCLE LOSS ON AGING AND SOCIETY

## In the Beginning: Our Genetic Programming

Our DNA has shown little evolution from that of our early ancestors, and yet our lifestyles are vastly different. Hunter-gatherer tribes did not know when or from where their next meal would be coming. As a result, our bodies became highly efficient with energy and essential nutrient storage. Carbohydrate energy sources were often converted and stored as fat to overcome prolonged periods without nourishment, and daily activity consisted of continued light movements with intermittent periods of high-intensity exercise (Sisson, 2012). Genetically speaking therefore, we are well-suited for periods of continued light activity such as walking, interspersed with short, intense high-effort exercise (MacArthur & North, 2007).

Modern lifestyles in the US, in contrast, have devolved and are now misaligned with our biology. All too often, as people age, the data suggests that they are spending considerable hours in inactive states, particularly in seated positions, which limits skeletal loading and hinders posture. With transportation that removes much of the physical activity that used to be commonplace (Mandal, 1981). Furthermore, our food sources are plentiful, accessible upon demand and without exertion, and are rich in carbohydrates. This lack of physical activity has been established as the leading causal factor for the rise in chronic diseases seen in our modern society (Booth, Roberts, & Laye, 2011).

## A Public Health Crisis

There has been a consistent and steady decline in the health of the US population at large, evidenced by the growing prevalence of medical conditions and diseases. According to the National Centre for Health Statistics, in 2018 it was estimated that the prevalence of obesity among US adults was 42.4%, an increase from 30.5% in 2000 (NCHS, 2020). These data suggest the US population has the highest prevalence of obesity in the world (Preston & Stokes, 2011). Additionally, obesity is a significant risk factor of Type 2 diabetes, cardiovascular disease and strokes, and is associated with a multitude of other medical conditions including cancer, osteoarthritis, liver disease, sleep apnea, and depression, all of which affect morbidity, quality of life, and mortality (Chu et al., 2018; Rippe & Angelopoulos, 2012).

Fundamentally, these chronic conditions are most often driven by poor lifestyle habits that are perpetuated by the ever-demanding US culture, including fast-food diets, high-stress environments (workplace and home), substance abuse, lack of general physical activity, and misguided understandings of exercise. As we age, the habits that we have adopted throughout the course of our lives become more pronounced. It used to be that a person might retire in their 50s, experience a chronic, non-communicable disease in their 60s, and die in their 70s. Today, we are more likely to begin experiencing a chronic disease in our 40s, retire in our 60s or 70s, and die in our 80s or 90s. By age 65, which is still considered young in our new culture, approximately 85% of Americans have been diagnosed with a chronic disease and 60% are suffering with multiple chronic conditions (Centers for Disease Control and Prevention, 2021). So, although the population is living longer in the US, it is not healthier, and, many more years are being lived in a state of disease after age 40. In this sense the World Health Organization (WHO) suggests that life-expectancy (mortality) does not provide a full picture of the state of US population health, and has introduced the concept of *disability-adjusted life years*, as a model for measuring the universal goal that most people hope to achieve in aging—high quality of life—not just living longer.

## Societal and Individual Economic Implications

This public health crisis has serious financial implications for both the individual and society. For example, data from 2008 suggests that each overweight or obese individual spent $266 and $1723 that year on healthcare, respectively.

In the same year, the combined cost of overweight and obesity amounted to $113.9 billion. By 2010, expenditure had risen to $2646 for an obese male and $4879 for an obese female (Chu et al., 2018). Unfortunately, the cost of poor/ill health does not cease with the individual. It is estimated that societal or indirect expenses as a result of absenteeism (absence from work) and preabsenteeism (attendance at work but less than normal productivity) cost each country incalculable amounts each year (Gianino et al., 2019; Kang et al., 2011; Stromberg et al., 2017.

## Healthy Aging

Human chronology results in physical decline; however, the degree to which this occurs and whether or not the decline will become disease is influenced to a large extent by key choices that are made throughout the aging process. Most notably is the decision of whether or not to place a priority on physical activity, and what type of physical activity to perform (i.e., the type of physical activity that best attenuates age-associated decline).

The National Health Interview Survey of 2020 was a longitudinal US population cohort study that examined 7 years of physical activity and mortality data of 479,856 adults. Both cause specific mortality (cardiovascular disease, cancer, chronic lower respiratory tract diseases, accidents and injuries, Alzheimer's disease, Type 2 diabetes (mellitus), influenza and pneumonia, and nephritis, nephrotic syndrome, or nephrosis) were analyzed. The researchers' published conclusion was, "Adults who engage in leisure time aerobic and muscle strengthening activities at levels recommended by the 2018 physical activity guidelines for Americans show greatly reduced risk of all cause and cause specific mortality" (Min Zhao, Sreenivas P Veeranki, Costan G Magnussen, and Bo Xi, 2020).

The vast majority of the US population, however, is not choosing to remain active as they age. Indeed, of persons age 65-74 and over 75 years, only 37% and 24%, respectively, were generally active enough to receive any kind of health benefit; and only 17% and 12% of the same age groups, respectively, were engaged strength building activities (NHIS, 2012). The reason strength building activities are being singled out is that these specific types of activities (described in detail below) are required to prevent significant losses in bone mineral density (osteopenia/osteoporosis), muscle mass (sarcopenia), muscle strength (dynapenia), and physical function. This negative progression has been correlated to increased risk of metabolic disorders, such as insulin resistance and sarcopenic obesity, and most of the other so called "age-related" chronic conditions and disabilities (e.g., neurological and cognitive disorders, falls and hip fractures). (Janssen, Heymsfield, & Ross, 2002; Warming, Hassager, & Christiansen, 2002). When skeletal muscle is not prioritized in the same manner as other vital organs such as the heart, in aging, muscle mass will decrease by approximately 1-2% each year after the age of 50 (Von Haehling, Morley, & Anker, 2010) and strength declines at a rate of approximately 1.5% each year starting between age 35 and 40 (depending on genetic and lifestyle factors). The gradual nature of muscle mass and strength loss is often not significant enough to cause concern in the fourth and fifth decades of life; however, as it compounds year-over-year by the time most people reach age 60, they have unknowingly lost up to 30% of their adult strength. Worse yet, the rate of muscle mass and strength loss accelerates around age 60 to up to 3% per year, effectively doubling the rate of decline every decade thereafter. Of perhaps greatest concern is that muscle mass and strength loss dominantly affects Type IIAB ("fast-twitch") muscle fibers which are together both fatigue resistant and high force

> There is, however, an interesting paradigm relating to overweight and obesity, and muscle mass and fitness as we age.

producing (Lee et al., 2006). Loss of Type IIA/B muscle fibers is associated with a loss of motor neurons— the signaling pathway which innervates muscle fibers and predominantly higher threshold motor units, associated with higher force, Type II muscle fibers (Piasecki et al., 2016). In summary, this causes a deterioration in muscle quality (strength per unit of mass) and overall reductions in physical capabilities, which is devastating to one's overall health and ability to maintain independence and autonomy, in aging.

## Shifting Paradigms

In spite of the evidence above, it is still common and acceptable practice for healthy body mass (weight) and obesity to be determined using the body mass index (BMI). This is an assessment based on mass and stature (mass / height2). For example, a person weighing 200lbs at a height of 6ft (72inches) would have a BMI of 200/722 (x conversion factor of 703) = 27.1. However, this does not consider the degree of muscle mass or fat mass with any level of precision, and as such has been deemed unreliable for specific populations. In the landmark National Health and Nutrition Examination Survey of 1994, 3659 participants aged 55 years were assessed and reported that persons in the highest quartile for BMI (females = 29.6, males = 29.7) also had the highest quantity of muscle mass (i.e., the "muscle mass index (MMI)" as so termed by the authors). They then considered mortality after a 20-year follow-up and reported that the highest quartile for BMI and MMI in older adults was correlated to a significantly lower mortality (n=372; death rate of 40.8%) compared to the lowest quartile for BMI and MMI (n=530; death rate of 58%) (Srikanthan & Karlamangla, 2014). With older adults therefore, it is inadequate and potentially dangerious to rely upon BMI alone as a measure of body composition, whereby "overweight" or "obese" classifications represent an unhealthy excess of fat, since this could lead to a prescription for weight loss that in turn might also result in muscle loss and increased risk of frailty and mortality.

This relationship has been further supported by reviewing the relationship between knee extensor strength, overweight, obesity, C-reactive protein levels, and all-cause mortality. Further data from NHANES for 2740 adults aged >50 years were reviewed, and participants were classified as (ia) normal weight and unfit, (ib) normal weight and fit, (iia) overweight and unfit, (iib) overweight and fit, and (iiia) obese and unfit, and (iiib) obese and fit. Analyses revealed "no difference in CRP levels between normal weight and unfit participants (ia) and overweight and fit (iib) participants" and "compared to normal weight unfit (ia) adults, overweight fit (iib) adults had a lower hazard rate for all-cause mortality" (Buckner, Loenneke, & Loprinzi, 2015). Essentially, this means that being strong negated any degree of being overweight.

### SUMMARY

There is unquestionably a growing economic and public health crisis that appears at first glance to be stemming from obesity, chronic disease and the aging of the global populace. The implications are extensive and time is of the essence for meaningful and sustainable change. While nutritional habits are important, there is too much resistance to make that the primary focal point and doing so would not get to the root of the problem entirely. A more representative solution for both all-cause mortality and quality of life is to slow the decline of muscle mass and improve muscle quality and strength with the most effective and efficient exercise we can engage in as we age. The following section will explain how strength training can impact the systems of the body, improving functionality and longevity, as well as quality of life.

1 C-reactive protein (CRP) is a substance produced by the liver that increases in the presence of inflammation in the body. An elevated C-reactive protein level is identified with blood tests and is considered a non-specific "marker" for disease.

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There is abundant evidence demonstrating how strength training can mitigate many of the potential health issues outlined. With strength training, a person can improve their strength (Fisher et al., 2011), muscle mass (Fisher et al., 2013), cardiovascular fitness (Fisher et al., 2011), metabolic health (Holloszy, 2005), bone mineral density (Kelley et al, 2001), and neurological functioning (Nagamatsu et al., 2012), each of which will be discussed herein. Furthermore, strength training results in strengthening of joints, tendons, and ligaments which leads to a reduction in the potential for strains, sprains, and injuries (Lauersen, Bertelsen, & Andersen, 2014; Stone, 1990).

## Current Physical Activity Guidelines

Despite extensive, ample research supporting the efficacy and importance of strength training for quality of life and longevity, it is often considered an afterthought in physical activity guidelines (Strain, Fitzsimons, Kelly, & Mutrie, 2016). Indeed, strength training is mentioned in physical activity guidelines across the world (O'Donovan et al., 2010; Piercy et al., 2018; Tremblay et al., 2011); however, it is felt that this element of the recommendations should have a more prominent place and greater urgency placed upon it (Phillips & Winett, 2010; Westcott, 2012; Winett & Carpinelli, 2001). In addition to the lack of focus in public health policy, we have raised concerns over the current state of these recommendations, particularly from the perspective of strength training as a higher effort mode of exercise (Steele et al., 2017).

## Muscular Response to Strength Training

### Strength

The reality is that strength training represents perhaps the most comprehensive form of exercise available. A reduction in strength has been shown to be a significant risk factor for all-cause mortality independent of muscle mass (Newman et al., 2006). However, evidence suggests that "2 decades of age-associated strength loss can be regained in 2 months of resistance exercise" (Hurley & Roth, 2000). Other studies have reported a reversal in mitochondrial deterioration to the extent that participants with an average age of 68 years showed mitochondrial characteristics similar to persons with a mean age of 24 years following only six months of strength training (Melov et al., 2007). Independent studies have shown large increases in strength following brief (<15 minutes), infrequent (2 x / week) strength training. A group of males and females (mean age = 55 years) performed only 5 exercises (pull-down, chest press, seated row, overhead press, and leg press) over a 10-week duration and showed increases ranging from 40-90% in maximal strength (Fisher, Steele, McKinnon, & McKinnon, 2014). More recently, a review of the health benefits of strength training summarized that a minimal dose approach need only include three exercises (chest press, seated row, and leg press) for a single set of each exercise once or twice per week (Fisher, Steele, Gentil, Giessing, & Westcott, 2017). The caveat to these exercise types, and perhaps the most important element of strength training, is that of intensity of effort. When instructed, our bodies send neural impulses to recruit only the muscle fibers necessary to complete a task. As that task becomes more difficult due to fatigue, we recruit higher threshold motor units and the corresponding Type II muscle fibers; this is called the size principle (Denny-Brown & Pennybacker, 1938; Henneman & Olson, 1965). Based on this sequential recruitment of muscle fibers, when strength training is performed to a high intensity of effort, a person recruits their higher threshold motor units and the corresponding Type II

> 2 decades of age-associated strength loss can be regained in 2 months of resistance exercise

muscle fibers for growth, and hence reduces the risk of age associated loss. This is fitting with the high intensity of effort exercise expected in our genetic blueprint. As we practice this recruitment of higher threshold motor units, so our bodies become more efficient in delivering neurological impulses and thus our strength increases.

Increasing muscular strength also plays a key role in maintaining and improving balance as we age (Rezmovitz, et al., 2003). Furthermore, strength training and improvements in lower body strength have shown a reduction in fear of falling in older adults (Yamada et al., 2011a), which might be as important a marker in maintaining an active and healthy life from a psychosocial perspective as balance itself. Other reviews have suggested that strength training of the lower body alone might not be the key marker for improving balance (Orr et al., 2008), but rather that lower back strength is also crucial to maintaining postural stability and balance as a whole as we age (Behennah, Orr et al., 2018).

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## Strength and Longevity

Finally, without diminishing the other important health benefits attainable, we should note that there is a myriad of research supporting the relationship between strength, independent of other health markers, and longevity. Long term data has repeatedly shown that elevated lower limb (typically the quadriceps) and hand grip strength in mid-life predicts against old age disability (Rantanen et al., 1999; Rantanen et al., 2012) and mortality (Artero et al., 2011; Newman et al., 2006; Ruiz et al., 2008). Of course, it is not necessarily lower limb or hand grip strength, per se, which provides resilience in aging, but rather that these two measurements are simple, objective assessments which can be measured using isometric or isokinetic testing devices and are representative of whole-body strength and function. Indeed, it has been suggested that a simple lower limb strength assessment was at least as effective in predicting health outcome measures (e.g., balance, functional mobility and falls) as more expensive and time-consuming measures (Menant et al., 2017).

## Muscle Mass

In addition to neurological adaptations which promote strength increases, the recruitment of muscle fibers during strength training results in the sensing of mechanical tension, which in turn catalyzes molecular pathways for both neural and morphological adaptations called, "mechanotransduction" (Hornberger & Esser, 2004). As such, strength training also results in an increase in muscle protein synthesis, the anabolic building or rebuilding of muscle (McGlory, Devries, & Phillips, 2017). This serves to counteract our bodies' natural catabolic processes associated with aging. Typically, we see a number of morphological adaptations associated with resistance training, all of which might lead to strength increases; these adaptations include changes in the angular direction of the muscle fibers within a muscle (i.e., pennation angle) (Aagaard et al., 2001), a tighter packing density of muscle fibers within a muscle (Aas et al., 2020) which might be a result of an increase in muscle fiber size at the cellular level (Fisher, Steele, & Smith, 2017; Haun et al., 2019), and an increase in whole muscle cross-sectional area (Fisher et al., 2017; Haun et al., 2019). It's important to differentiate between these adaptations since an often-desirable goal of strength training is the increase in whole muscle size. However, we cannot preferentially increase muscle size, and given that muscle hypertrophy is metabolically very demanding, our bodies will naturally try to limit whole muscle growth. In this sense, a person should not be disheartened when they fail to see their muscles grow bigger because the reality is that morphological adaptations are occurring "beneath the surface" which are serving to increase strength, quality of life, and longevity.

## Lower-Back Health

Low back pain is one of the most endemic musculoskeletal problems within Western society as lifetime prevalence rates are estimated to be around 80-90% (Hoy et al., 2010). As such, it is one of the most common reasons for healthcare consultation (Jöud, Petersson, & Englund, 2012) and has significant societal impact resulting from time off work and the inability to return to usual function (Hoy et al., 2014). However, it is important to remember that low back pain is a symptom, not a diagnosis (Bono, 2004). This distinction, coupled with the fact that weakness of the lumbar muscles appears to be related to low back pain (Mayer et al., 1999; Risch et al., 1993), should cause an emphasis to be placed upon the benefits of muscle strengthening exercise. It is worth acknowledging that many people seek manual therapies in the form of manipulation, mobilization, or soft tissue treatment; however these should only be considered as an adjunct to exercise strategies. Indeed, massage and pharmacological interventions are considered passive treatments that serve only to remedy the resultant symptoms (e.g., pain) but not the cause (Shipton, 2018).

The well-established theory of the deconditioning hypothesis asserts that a reduction in muscular size and strength of the lumbar extensors (possibly due to gluteal and hamstring dominance for trunk extension movement) is a causal factor in low back pain which, in turn, results in disuse of these muscles leading to further deconditioning (Steele, Bruce-Low, & Smith, 2015). It is noteworthy that this is not necessarily a product of typical muscular deconditioning with age but is exaggerated as a result of the specific disuse of the lumbar muscles. Furthermore, people presenting with low back pain often have coexisting reductions in a range of physiological impairments including: reduced cardiovascular capacity (Smeets, Wittink, Hidding, & Knottnerus, 2006), diminished lumbar strength (Graves et al., 1990), reduced spinal mobility (Thomas, Silman, Papageorgiou, Macfarlane, & Croft, 1998), reduced muscular endurance (Kankaanpää, Taimela, Laaksonen, Hänninen, & Airaksinen, 1998), and reductions in balance and proprioception (Behennah et al., 2018).

Lumbar exercise is specifically recommended since it treats the cause of the pain. Based on the deconditioning hypothesis, exercising the lumbar extensors and spinal stabilizers at an intensity of effort high enough to improve muscular strength and function can serve to reduce the severity and recurrence of low back pain, as well as improve mobility, muscular endurance, and motor control (Carpenter & Nelson, 1999; Risch et al., 1993; Steele et al., 2015).

## Cardiovascular Response to Strength Training

Current physical activity guidelines prioritize typical forms of aerobic exercise (e.g., walking, running, swimming, and cycling). In some cases "muscle strengthening activities" are mentioned, but these typically include heavy gardening, yoga, and using resistance bands, which might not provide enough musculoskeletal loading to attain the possible and desired health benefits in all but the most unfit of persons. The reality is that strength training has been shown to produce similar acute responses and chronic adaptations in the cardiorespiratory system when

> Resistance training is at least as effective as aerobic endurance training in reducing some major cardiovascular disease risk factors.

compared to traditional forms of aerobic exercise (e.g., running and cycling) (Steele et al., 2012; Steele et al., 2018). A recent review suggested that strength training where rest intervals between exercise was minimized, demonstrated considerable increases in cardiovascular fitness (measured as maximal volume of oxygen; VO2max). In fact, 12-weeks of strength training, performed twice weekly for up to 30 minutes each session, showed close to a 10% increase in aerobic capacity in previously untrained people (Muñoz-Martínez, Rubio-Arias, Ramos-Campo, & Alcaraz, 2017).

Furthermore, a literature review from 2011 concluded that, "resistance training is at least as effective as aerobic endurance training in reducing some major cardiovascular disease risk factors" (Strasser & Schobersberger, 2011). The authors noted strength training's ability to improve body composition, mobilize visceral and subcutaneous abdominal fat (thereby reducing resting blood pressure), improve lipoprotein-lipid profiles, and enhance glycemic control. Specifically, this reduction in blood pressure as a product of exercise is of particular importance since 1/3 of American adults have high blood pressure (hypertension), which is a major risk factor in cardiovascular disease (Ong, Cheung, Man, Lau, & Lam, 2007). Studies with samples as large as 1600 adults aged 21-80 years old have shown reductions in resting systolic and diastolic blood pressure from as little as 20-minutes of strength training twice per week for 10-weeks (Westcott et al., 2009). In summary, large reviews have concluded that strength training is effective for reducing resting blood pressure, with average reductions being 6.0 mm/Hg systolic and 4.7 mm/Hg diastolic (Cornelissen & Fagard, 2005; Kelley & Kelley, 2000). Notably, these adaptations were comparable to those associated with aerobic activity.

## Skeletal Response to Strength Training

In addition to the muscular and cardiovascular benefits, strength training also imposes appropriate stress on our skeletal system sufficient to maintain or improve our bone mineral density (Kelley et al., 2001). Throughout our life we have continued remodeling of our skeletal structure; we are building and breaking down bone by cells called osteoblasts and osteoclasts, respectively. However, a product of aging is that the anabolism (building of bone) lessens while catabolism (breaking down of bone) begins to dominate (Eriksen, 2010; Rachner, Khosla, & Hofbauer, 2011). This can lead to osteoporosis (literally "porous bones") which can lead to fragility and greater risk of fracture due to structural deficiency in the microarchitecture (Rachner et al., 2011). While osteoporosis is particularly common in post-menopausal females, a recent publication suggested that 1 in 3 females and 1 in 5 males over the age of 50 will experience osteoporotic fractures in their lifetime (Sözen, Özışık, & Başaran, 2017). Appropriate strength training can apply the minimal essential strain to encourage osteoblasts to lay down new collagen fibers, all the while previously dormant osteoblasts migrate to the area. This results in the collagen fibers becoming mineralized and an increase in bone density.

A further product of aging is osteoarthritis which occurs when cartilage at the end of the bones where a joint occurs, breaks down and wears away. Osteoarthritis results in pain and stiffness at the joint, as well as swelling of articular structures, and as a result of the pain and diminished movement, muscle weakness and atrophy ensue (Ronai, Sorace, & LaFontaine, 2008). In this sense, strength training is particularly important to retain muscular strength and muscle mass in persons with osteoarthritis who might have limited mobility and daily activity. Furthermore, strength training has also been shown to reduce self-reported pain associated with osteoarthritis (Jan, Lin, Liau, Lin, & Lin, 2008; Lange, Vanwanseele, & Fiatarone singh, 2008; Latham & Liu, 2010). This reduction in pain in persons living with this condition can significantly improve mental health and overall wellbeing from a psycho-social perspective (O'Connor, Herring, & Caravalho, 2010).

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## Metabolic Response to Strength Training

Further benefits of strength training, in addition to the externally obvious factors such as improved strength and muscle mass, are the internal, hormonal responses. This section will consider primarily cortisol and insulin, which are considered to be two of our stress hormones and ultimately are the metabolic causes of overweight and obesity, as well as their negative effects on our emotions, mood, and cognitive function.

## Cortisol

Cortisol is considered the primary stress hormone, often thought of in conjunction with our "fight or flight" response. Cortisol speeds up our heart rate, promotes the release of glucose into our blood to provide a fuel source, and suppresses our digestive system. While this chain reaction is extremely beneficial in an emergency, cortisol is also triggered by our consistently stressful and busy modern lives. It suppresses our immune systems, and a lack of physical activity causes cortisol levels to build up in the blood with negative and degenerative effects upon the body. Strength training to a sufficiently high intensity of effort, performed infrequently can serve to help our bodies better cope with cortisol release and to reduce the amount of cortisol in our bloodstream, leading to a reduction in the symptoms of stress (Kraemer et al., 1999).

## Insulin

As a result of the release of glucose into our blood stream, elevated cortisol can also catalyze problems with our insulin response, and in fact cause insulin resistance (Rizza, Mandarino, & Gerich, 1982). In brief, the role of insulin is to allow cells of the body to take in glucose to be used as a fuel or stored as body fat (Reaven, 1988). If there is an excess of sugar in the blood as a result of continued release or consumption, then our bodies respond with continued insulin releases to attempt to overcome this, even when blood sugar decreases. Thus, we have chronically elevated insulin levels which result in lethargy, hunger, and cognitive dysfunction. This often leads to other health problems, including weight gain and high blood pressure, and if prolonged, can ultimately lead to Type 2 diabetes (Rask-Madsen & King, 2007; Shepherd & Kahn, 1999). Strength training can reduce our insulin resistance and improve our insulin action. By performing high intensity of effort exercise, we reduce the amount of sugar in our blood by using it as an energy source, as well as by the activation of GLUT-4 vesicles which transport glucose into the cells (Bird & Hawley, 2017). Studies suggest that even a single bout of strength training can acutely improve insulin sensitivity and chronic adaptations and can reduce or reverse insulin resistance after 8-weeks of training (Bird & Hawley, 2017).

## Myokines

For a long time, strength training has been hailed as a metabolically advantageous method of sustaining bodyweight and reducing fat mass. This is, at least in part, because muscle mass is metabolically advantageous in that it has higher calorie expenditure than fat mass (Zurlo, Larson, Bogardus, & Ravussin, 1990). However, researchers have continuously sought a link between muscle contraction and some of the exercise-induced metabolic changes in other organs (Pedersen, Akerstrom, Nielsen, & Fischer, 2007). A growing area of research is the study of myokines, which are cytokines[2], peptides, and proteins released by skeletal muscles in response to muscle contraction. From them we learn that not only is muscle a metabolically valuable organ, but that it is also essentially an endocrine organ. Muscle fibers are now known to produce and release peptides and proteins which exert either paracrine or endocrine effects (Pedersen, 2011). In this sense, there is accumulating epidemiological evidence that a physically active life plays an independent role in the protection against Type 2 diabetes, cardiovascular diseases, cancer, dementia, and even depression through the release of myokines (Pedersen et al., 2007; Pedersen, 2011).

## Implications

The stimulus of properly performed strength training can result in a far more balanced hormonal and metabolic profile in a healthy individual. Ultimately this leads to a reduction in risk factors such as diabetes and systemic inflammation. Essentially, strength training provides the high intensity of effort exercise required by our genetic blueprint to provide a homeostasis in our bodies' functioning. In addition to the aforementioned benefits of preventing the onset of health impairments, strength training can also counter unwanted weight gain and accelerate fat loss.

Typical strategies associated with weight loss are one-dimensional, prescribing a reduction in calories and an increase in aerobic exercise (e.g., running, cycling, swimming). This approach can produce meaningful decreases in fat mass, but unfortunately it is all too often accompanied by a loss of muscle mass. Aerobic exercise serves to burn calories while we exercise, but that's all. In contrast, strength training has a similar calorie expenditure during exercise, but also serves to increase the metabolism, continuing elevated caloric expenditure for up to 72 hours after training has ceased (Hackney et al., 2008; Heden et al., 2011). Notably, this is also the case following a single set, high effort strength training protocol (Heden

2 Systemic inflammation is a result of the release of pro-inflammatory cytokines which might result from conditions such as overweight or obesity, diabetes, chronic stress, and chronically elevated cortisol and/or insulin levels. Systemic inflammation is a key contributor to more severe medical conditions such as coronary heart disease.

et al., 2011). In addition to the calorie expenditure during and after a bout of exercise, strength training can serve to attenuate the muscle loss typical of persons on a calorie-restricted diet. Ultimately strength training assumes a more multidimensional approach to body recomposition (Sardeli et al., 2018). In the earlier sections we have highlighted the importance of both muscular strength and muscle mass independent of body composition, as well as the relationship between muscle mass index, body mass index, and all-cause mortality. In light of these factors, we should now recognize that just as body composition is important for health and longevity, muscle mass increase and retention should be imperative to improving body composition while reducing body fat.

## Neurological and Psychological Response to Strength Training

In addition to numerous physiological benefits, strength training also results in improved cognitive function (Nagamatsu et al., 2012). Other psychological health benefits include reduced fear of falling (Yamada et al., 2011b), improved sleep quality (Singh et al., 2005), reduced anxiety (Cassilhas et al., 2007), reduced depression (Singh et al., 2005), and improved self-esteem (Tsutsumi et al., 1998).

Cognitive function is a major health care issue in persons 65-years and older, and mild cognitive impairment is a well-recognized risk factor for more serious health conditions such as dementia (Petersen et al., 1999). Studies now support that strength training, even at a low volume and frequency (i.e., once per week), may limit age-associated cognitive decline, and even enhance cognitive function (Liu-Ambrose et al., 2010). A six-month strength training intervention using only six exercises for the major muscle groups, performed 3x/week showed improved memory performance and verbal concept formation among seniors (Cassilhas et al., 2007). A further study reported improved selective attention/conflict resolution, associative memory, and regional patterns of functional brain plasticity in senior women (Nagamatsu et al., 2012). In summary, it is well recognized that strength training can play an important role in cognition in older adults and should be recommended as part of a healthy aging program (Liu-Ambrose & Donaldson, 2009).

### SUMMARY

Science/research strongly suggest that Strength training reverses aging in skeletal muscle, both at a cellular and functional level (Hurley & Roth, 2000; Melov et al., 2007). In that sense it is not an unrealistic goal to "have a biological age equal to, or lower than, our chronological age" (Fisher et al., 2014), and indeed strength training has been referred to as "the prophylactic to aging" (Fisher et al., 2017). However, the benefits of strength training extend far beyond our aesthetics or physical abilities. Strength training improves our bodies' physical functioning through a healthier management of hormones and release of myokines (Bird & Hawley, 2017; Pedersen, 2011), improving cardiovascular fitness (Steele et al., 2012), metabolic health (Holloszy, 2005), bone mineral density (Kelley et al., 2001), and neurological functioning (Nagamatsu et al., 2012). The evidence supports that the resulting increased strength and muscle mass reduces the risk of all-cause mortality (Artero et al., 2011; Ruiz et al., 2008) and ultimately concludes that "strength training is medicine," serving to reduce risk of all-cause mortality as well as to improve quality of life (Westcott, 2012).

# FUNDAMENTAL REQUIREMENTS FOR EFFECTIVE STRENGTH TRAINING

Having identified and discussed the current state of global health, age associated human deterioration, and the potential health benefits of strength training, this chapter will identify and discuss the variables within, and summarize the fundamental requirements for, effective strength training.

A long-held perception exists that productive strength training requires hours of commitment to the gym, the lifting of heavy weights and complex equipment and/or exercises. The reality is that this couldn't be further from the truth. Even large organizations such as the American College of Sports Medicine (ACSM) and National Strength and Conditioning Association (NSCA) advocate time-consuming and overcomplicated strength training programs (American College of Sports Medicine, 2009; Haff & Triplett, 2015). Typically, for example, strength training has been prescribed based on desirable outcomes – that a person should train using different loads, repetitions, sets and rest intervals dependent upon their desire to optimize strength, muscle hypertrophy, or muscular endurance/weight loss (American College of Sports Medicine, 2009). However, this simply perception simply is not accurate, as the preponderance of research suggests otherwise (Fisher et al., 2011; Fisher et al., 2013; Fisher et al., 2017).

## Volume of Training

An ongoing debate has been that of the required number of sets for optimizing muscular adaptations in strength and hypertrophy (Carpinelli, 2012; Fisher, 2012; Krieger, 2010; Otto & Carpinelli, 2006). However, more recently a consensus has been reached that strength increases are equivocal between single- and multiple-set training protocols (de Sousa et al., 2020; Schoenfeld et al., 2019), and differences in hypertrophy are negligible but might favor higher volumes of training (de Sousa et al., 2020; Schoenfeld et al., 2019). However, there are some inherent issues with the body of literature that should be acknowledged. First, volume of training has historically meant the number of sets per exercise, but it is now used to refer to the number of exercises per muscle group (Schoenfeld et al., 2017; Schoenfeld et al., 2019). It is myopic to consider only one exercise, when, in fact, we could see a more accurate picture if we consider the response to multiple exercises which target the same muscle and even multiple exercises which stress our fatigue centrally rather than peripherally. Second, any potential increases in muscle hypertrophy which favor multiple set protocols are limited by study duration. It is much more likely that, at best, a higher volume of training might attain more rapid responses in hypertrophy compared to lower volume protocols. However, as our bodies inevitably plateau in response to strength training, it is almost certain that a lower volume protocol would "catch-up" and ultimately attain the same muscle growth that our nutrition, genetics, and rest/recovery permits (Counts et al., 2017). Given that time constraints are the most commonly cited barrier to exercise (Trost, Owen, Bauman, Sallis, & Brown, 2002), encouraging persons to engage in low volume (i.e., single set) strength training is a more attainable and practical approach. This paradigm shift also accommodates additional variables such as intensity of effort, which will be discussed.

## Required Load

Along with volume of training, we must also consider the load being lifted. There is often a perception that strength training, as well as the related desirable adaptations it produces, requires the use of very heavy weights or, furthermore, that lifting heavy weights stimulates one adaptation (i.e., maximal strength) more so than lighter weights (which has been thought to augment muscular endurance). This is simply another long-standing fallacy of traditional strength training dogma (Fisher et al., 2020; Schoenfeld et al., 2021). Interestingly this principle, often referred to as the strength-endurance continuum, is often credited to Captain Thomas DeLorme and his seminal work

3. Although, of note, it was DeLorme who first suggested the 3 sets of 10 repetitions of an exercise. However, once again this is misrepresented; DeLorme actually suggested that a first set of 10 repetitions be performed using 50% of a 10-repetition maximum (RM), a second set of 10 repetitions be performed with 75% of a 10RM, and following these warm-up sets, a single set of 10 repetitions be performed to momentary failure with a load permitting only 10 repetitions (DeLorme & Watkins, 1948). For clarity, the recommendation of a single set to momentary failure dates to the 1940s.

rehabilitating veterans returning from WWII (DeLorme & Watkins, 1948; DeLorme, 1945).[3] In fact, DeLorme was researching the comparative muscular adaptations of strength training compared to aerobic training.

The reality is that physiological adaptations are almost identical irrespective of the external load being lifted (Fisher et al., 2017), with a single exception. Bone mineral density increases require a minimal essential strain to stimulate adaptation. Research has identified increases in bone mineral density from the impact of running (Rector, Rogers, Ruebel, & Hinton, 2008) and other similar activities which involve high impact forces, as well as from the lifting of heavy weights (i.e., >80% of 1-repetition maximum) (Vincent & Braith, 2002). Notably, other athletes such as cyclists, who do not have impact forces or load the skeletal system and often do not participate in strength training, have shown very poor bone mineral density (Rector et al., 2008). As such, a strong recommendation would be for all persons, including these athletes, to engage in strength training with sufficient load to stimulate increases in bone mineral density.

## Isokinetic Exercise

Isokinetic strength training has many advantages compared to traditional strength training. Primarily, when using an external load, a person is subject to several submaximal repetitions before the load begins to stimulate any adaptations, and further, the person must cease exercise when their force production drops below that of the external load, as a result of fatigue. When using isokinetic technology, a person can choose how hard to press against the movement arm, and from the initial repetition can work hard enough to stimulate adaptations. Essentially – every repetition can be maximal. Furthermore, as the trainee's strength decreases due to fatigue, they are not subject to having to cease exercise because their strength drops below the external load; the movement arm can still be moved. In addition, isokinetic technology is not subject to some of the limitations of typical strength training mechanics. A muscle and/or movement typically has biomechanical angular positions where a person can produce a high force, and other angular positions where the maximal force is considerably less; this is referred to as the strength curve. If using a typical strength training device, a trainee is subject to their personal physiological strength curve not aligning to the resistance curve of the external load, and thus, at certain positions in an exercise, it might feel comparatively easy or difficult. With isokinetic technology, there is no sticking point because the external resistance essentially adapts to the force applied by the participant. Finally, during the eccentric phase of an exercise, where the muscles are around 40% stronger, when using a typical external load, a trainee's output is almost always submaximal through this phase of the exercise. In other words, the eccentric phase is limited to what can be lifted concentrically, even though, again, the same muscles are generally able to handle 40% more weight in the eccentric phase. However, with isokinetic technology the external resistance can be maximal throughout every phase of a repetition. It is perhaps the perfect accommodating resistance. Ironically, while isokinetic technology has been favored by exercise scientists in laboratory-based research for more than 50 years, the expense has typically made this technology unviable in commercial exercise facilities and thus inaccessible to their clients.

> Isokinetic strength training has many advantages compared to traditional strength training.

## Contraction Type

It is perhaps noteworthy to differentiate between isometric, isotonic and isokinetic contraction types. Isometric contractions are best defined by there being no change in the joint angle and thus effectively no shortening or

4 For example, consider a person who can lift 100lbs for 10 repetitions; the initial repetitions are relatively easy, and only by the 6th or 7th repetition does the trainee begin to work hard enough to stimulate adaptations through stressing the human organism. However, at the 10th repetition the trainee is forced to cease exercise since they are no longer able to lift the load.

lengthening of a muscle. Isometric muscle actions are typically used for testing of muscular force or torque around a joint, but can also an represent efficacious method to train a muscle, notably if injury prevents movement. In contrast, isotonic muscle action can be experienced when using a traditional free-weight or weight stack resistance machine. Safe and efficacious use of these types of machines relies somewhat on the user's experience and knowledge as they must appreciate how forces might change throughout a range of motion and be in control of the external load throughout the duration of the exercise. Finally, isokinetic exercise is effectively computer controlled; movement velocity is pre-set and controlled by a server allowing the movement arm and load to continually and effectively adapt to the resistance applied by the user. Isometric and isokinetic testing and training represent valid and reliable ways to test the muscular system, and isokinetic training, due to its very nature, can accurately provide constant data collection and holistic performance evaluation.

## Progressive Overload

When using typical free-weights and/or resistance machines, a trainer or trainee should keep detailed records of the load lifted, repetitions performed, and time-under-load for each exercise in order to identify progression. This also helps with programming of progressive overload where a load can be increased in subsequent sessions for time efficiency, as well as to maintain sufficient load to optimize all adaptations. In contrast, when using isokinetic technology, where maximal effort is applied through both concentric and eccentric muscle actions, maximal force data is recorded by the computer. This means that progressive overload occurs naturally through the increasing force production by a trainee when exercising at maximal effort. The data also allows instant feedback as to how a person is performing physiologically, which might be subject to fatigue from a previous workout or other physiological or psychological stresses, which can negatively impact exercise performance.

## Intensity of Effort

Perhaps the most important controllable variable within strength training is that of intensity of effort, or how hard the trainee works. The body of literature is very clear on this subject; the primary stimuli for adaptation is the recruitment and mechanical tension of muscle fibers and the resulting metabolic stress as a product of energy production and muscular contraction (Schoenfeld, 2010). These are optimized when a person reaches momentary failure (Steele, Fisher, Giessing, & Gentil, 2017). Given that all other variables are at best secondary, neither external load, number of repetitions, nor volume of training appear to impact adaptations where exercise is performed close to momentary failure (Morton et al., 2019; Morton, Colenso-Semple, & Phillips, 2019). In this sense, and as highlighted, isokinetic exercise is not subject to cessation when a person can no longer overcome the external load, but rather can be terminated when a trainee's force drops below a desired threshold or when a chosen time-under-load has been reached.

## Time-Under-Load

In continuation of the above, it is worth highlighting that evidence does not categorically support a specific time-under-load for optimal adaptations to strength training. In considering the mechanisms for muscular adaptations noted above, both mechanical tension and muscle fiber recruitment can be optimized in relatively brief times (e.g., <30 seconds) when exercise is of maximal intensity of effort. However, metabolic stress, which might be more necessary for increases in muscle hypertrophy, requires longer time-under-load to produce the biological byproducts associated with energy production (e.g., 60-90 seconds) (Schoenfeld, 2010). Empirical studies have suggested that neither repetition duration nor the number of muscle actions impacts strength and muscle size increases, again with the caveat that intensity of effort is maximal (Carlson et al., 2019).

An additional factor for consideration is that of discomfort. More and more research has identified that lighter-load exercise, which is performed to momentary failure, produces greater degrees of discomfort when compared to heavier loads (Fisher et al., 2018; Fisher & Steele, 2017; Stuart et al., 2018). The longer time-under-load and corresponding greater number of muscle actions produce metabolic stress, such as increased blood lactate, cortisol, inorganic phosphate (Pi), and hydrogen ions (H+), the result of which is an increase in muscle acidity (or decrease in pH) (Genner & Weston, 2014; Schott, McCully, & Rutherford, 1995). Due to this, a trainer should provide sufficient exercise to stimulate positive adaptations, but not for such a duration that causes unnecessary discomfort for the trainee. A recommendation would be for a time-under-load of 60-90 seconds.

## Equipment Selection

Reviews published in 2011 and 2013 highlighted with glaring clarity that a muscle does not know what it is contracting against, it simply contracts or relaxes (Fisher et al., 2011; Fisher et al., 2013). Throughout these review articles, the authors compared the plethora of external resistance methods available, including free-weights, selectorized resistance machines, hydraulic and pneumatic resistance forms, isokinetic technology, bands, and manually applied resistance. There is no evidence to support one modality over another for the physiological adaptations attainable where exercise is performed to a sufficiently high intensity of effort (Fisher et al., 2011; Fisher et al., 2013).

## Exercise Selection

The growing body of research supports that a minimal dose approach to resistance training can be performed. There isn't a need for direct stimulation of every muscle group using single-joint movements, but rather a handful of multi-joint exercises which target multiple muscle groups is sufficient for adaptations in strength and muscle mass (Fisher et al., 2017; Gentil, Fisher, & Steele, 2017). As expected, there exists a caveat to this guidance. Due to biological factors, the muscles of the lower back appear not to get sufficient stimulus from multi-joint exercises. Specifically, where trunk extension exists, that is rotation of the pelvis and extension of the lumbar spine, the gluteal and hamstring muscles appear to dominate the exercise. This means that the lumbar extensors do not receive enough stimulus to adapt. In this sense, while a minimal dose approach to strength training might include an upper body multi-joint pressing movement, an upper body multi-joint pulling movement, and a lower body multi-joint exercise, due to the unique nature of the spine, as well as the aforementioned prominence of back issues in aging populations, additional exercises should likely include lumbar extension and potentially neck flexion and extension (Fisher et al., 2017).

## Repetition Duration and Movement Velocity

Now we will consider whether there is need for high movement velocity within strength training. While many persons and organizations have previously advocated the use of explosive lifting for muscular adaptations (American College of Sports Medicine, 2009), this lacks empirical support and therefore unnecessarily increases risk of exercise injury. In fact, studies show little difference in forces generated or experienced where repetitions are performed at varying controlled repetition durations that maintain muscular tension [e.g., 10s:10s, 5s:5s, and 2s:4s (concentric: eccentric)] (Johnson, 2005). Nevertheless, when attempting to move the load explosively, forces increased by as much as 45% initially but then decreased by 85% for the majority of the repetition. Physics provides a likely reasoning for this; the initial force needed to overcome the inertia results in excess momentum which carries the weight through the rest of the range of motion. Indeed, empirical studies have reported greater decrement in force production and rate of force development where exercises are performed with a longer repetition duration/slower movement velocity (Tran, Docherty, & Behm, 2006). This larger decrease in force production suggests greater recruitment and fatigue, the driving stimuli for adaptation. Further research has shown that intent of movement is more important than explosive movements (Behm & Sale, 1993a; Behm & Sale, 1993b). When we reach fatigue and attempt maximal effort contractions irrespective of external movement velocity, we stimulate neural adaptations might include activation of our Type II motor units and corresponding muscle fibers. Our attempt to move fast, even when we cannot due to fatigue or external factors, might further stimulate motor unit synchronization and possible adaptations in the frequency of motor unit discharge; both of which are mechanisms for strength increases. While we see that intervention studies have shown no difference in strength increases between different repetition durations/movement velocities, we should note that perhaps the most important element of increasing muscular strength is to maintain muscular tension throughout a movement (Carlson et al., 2019).

## Frequency

The accepted wisdom has been that strength training should be performed multiple times per week for a sufficiently long duration to stimulate adaptations in muscular strength and hypertrophy. However, this belief is likely predicated upon the anecdotal experience of bodybuilders and the desire to break plateaus by transitioning from full-body workouts to split-routines (whereby only a couple of muscle groups are trained each workout, but with a greater volume of exercise per muscle group). The preponderance of academic research supports that strength training need only be performed once or twice per week to optimize adaptations in strength and hypertrophy (Grgic et al., 2018; Grgic, Schoenfeld, & Latella, 2019; Schoenfeld, Ogborn, & Krieger, 2016), as well as attain the numerous health benefits (Fisher et al., 2017).

# Recovery

While some authors have suggested that frequency might be an often-overlooked variable for optimizing hypertrophy (Dankel et al., 2017), perhaps as a product of more regularly increasing muscle protein synthesis, this is highly dependent upon the volume of exercise being performed in a workout and the recovery between workouts. In fact, frequency is a variable that might be the most self-selectable; some people need not train more than once per week for positive adaptations, but might not negatively impact their adaptations when training at a slightly higher frequency (i.e., two or three times per week), depending upon training volume. Certainly, some people will recover very quickly from even high-volume eccentric strength training sessions, where others might take up to nine days to completely recover from a single, high-volume session of eccentric dominant training. (Chen & Nosaka, 2006).

For clarity, physiological response to a bout of strength training follows a sine wave form. As we perform a workout, our strength decreases, and only after the workout does our body begin to recover when afforded the proper rest (sleep) and nutrition. Given appropriate stimuli, our strength progressively increases over time and provided adequate recovery, the body will supercompensate, that is, increase in strength which can result in progressive increases over time. This is true of almost all systems of the body, albeit that they might respond over differing time scales. Furthermore, there is almost certainly a heterogenous recovery time following an acute bout of strength training based on individual genetics and other lifestyle factors.

If we repeatedly exercise before our bodies have adequately recovered from the previous bout of exercise, then we will fail to make progression and might attain a state referred to as overreaching,  a short-term state preceding overtraining. Overreaching might result in a diminished immune system (often resulting in upper respiratory tract infections), a decrease in the testosterone: cortisol ratio (which might be indicative of imbalance in anabolic and catabolic physiological states) and psychological disturbances and negative affective states (Halson & Jeukendrup, 2004; Hooper, MacKinnon, & Hanrahan, 1997). However, these symptoms might also parallel short-term strength decreases, which are identifiable using isokinetic technology. While overreaching might be relatively common in athletic populations and recovery appears reasonably brief (e.g., within 2 weeks), this is something to be avoided in the lay population. In this sense, where a common response to a decrement in strength is to do more training to overcome this, trainers at the Exercise Coach can guide clients over increased rest periods and reduced training frequency to ensure adequate recovery and adaptation. Just as with medication, a logical approach will avoid excess, and while a trainee's approach to strength training may begin with a minimum effective dose, that might later be adapted if necessary (Fisher et al., 2017).

# Range of Motion

The key considerations for range of motion in strength training are two-fold. Firstly, a person with poor mobility at a joint, or limited flexibility at a muscle, might need to exercise using a limited range of motion. Only a handful of studies have considered range of motion in strength training with a recent review suggesting there is insufficient data to definitively support whether full range of motion is more advantageous than partial range of motion exercise (Schoenfeld & Grgic, 2020). It should be considered that muscular tension can be a stimulus for muscular adaptations, but should not be used where pain or discomfort occurs. Additionally, the second consideration for range of motion is that, when properly performed, strength training can improve range of motion  (Fatouros et al., 2006) and is comparable to typical stretching protocols (Morton et al., 2011). Thus, while a client can train through limited range of motion to avoid discomfort (or as a result of injury) without lessened adaptations, muscular tension at the conclusion of the employed range of motion can enhance physiological performance over the longer term by increasing range of motion. This is due, at least in part, to the fact that a stronger muscle becomes a more relaxed muscle, and a more relaxed muscle enables greater range of motion (Monteiro et al., 2008).

# Supervision

The most forgotten variable within strength training is that of supervision. It has been stated that "the key element to effective resistance training is supervision by a qualified professional" (Kraemer, Ratamess, & French, 2002). However, when adopting an evidence-based approach to strength training, we must remember that empirical research studies are almost always supervised. In this sense, applying these protocols for use in an unsupervised environment might well be comparing efficacy to effectiveness (i.e., whether something works in a controlled setting as opposed to whether people will perform an effective exercise as prescribed when unsupervised). Supervised strength training has shown greater strength increases compared to unsupervised training (Coutts, Murphy, & Dascombe, 2004) and within supervised groups of 1:5 versus 1:25 (trainer: client) (Gentil & Bottaro, 2010). It's likely that supervised strength training produces more favorable adaptations due to the increased intensity of effort, as well as the benefit of technical coaching that ensures tension in the desired muscle groups. Unquestionably, supervision in strength training also reduces the risk of injuries associated with training unsupervised.

## SUMMARY

There exists a large body of research which now supports uncomplicated strength training methods (e.g., low volume, low frequency, high intensity of effort). By applying the evidence we have discussed in this section, we see that strength training can be safely practiced by all persons, of all abilities, from all age groups and should not be feared by anyone. Anyone and everyone can positively improve their physiological health, quality of life, and prospective longevity by performing strength training with supervision.

As we have shown, the traditional barriers to strength training can be overcome. Effective strength training does not require a large time commitment. In fact, it is probably more productive if performed to a high intensity of effort for a short duration, serving to overcome the time issue that concerns many people who desire or need to fit exercise into their lives but feel they cannot. Additionally, only a handful of exercises is necessary, and frequency of training can be minimal in nature without compromise of desire adaptations, although recovery from strength training is likely heterogenous across the population, and as such might be prescribed based on an individual's availability and other lifestyle factors.

Now that we have demonstrated the benefits of strength training as well as what is necessary to achieve desired adaptations, we will introduce you to "the world's smartest 20-minute workout," which puts research into practice.

# A TECH-ENABLED APPLICATION OF THE SCIENCE OF STRENGTH

**The preceding sections can be summarized in two statements:**

1. Increasing strength changes every system of the body for the better.
2. A science-based understanding of strength training fundamentally changes what is required for individuals to experience personal exercise success.

The science of strength has led to the development of a unique commercial fitness application called "The Exercise Coach®". A U.S.-based personal fitness training franchise, which operates hundreds of strength training studios worldwide. The programs offered by The Exercise Coach are designed to help people "get the results that matter most to them" with no more than two, 20-minute workouts per week.

Training at The Exercise Coach is a real-world techno-methodological application of the science of strength and resistance training. The technology utilized by The Exercise Coach is known as "Exerbotics" which is a line of isokinetic strength machines powered by software that has been customized for The Exercise Coach. The combination of The Exercise Coach plus Exerbotics was assembled through the leadership of Brian Cygan in order to apply the science of strength in an optimized fashion. Elaborating on the two summary statements above, the following elements were designed into The Exercise Coach and its use of Exerbotics:

1. The primacy of muscle strength and mass as a biomarker of health, fitness, and aging
2. The physiology of muscle fiber stimulation and adaption
3. The considerations for the production of maximum, beneficial, systemic results from a single modality of exercise which include:
    a. Intensity of effort
    b. Time-under-load
    c. Equipment selection
    d. Contraction type
    e. Exercise selection
    f. Repetition duration and movement velocity
    g. Frequency of training
    h. Recovery
    i. Range of motion considerations
    j. Supervision

Each of these considerations is discussed in prior sections of this work.

Fitness programming at The Exercise Coach, powered by Exerbotics, considers all of the foregoing in order to simultaneously satisfy the priorities of maximum safety, effectiveness, and efficiency.

## Safety

The safety of Exerbotics resistance training stems from the precise control of mechanical forces within certain limits. These limits are derived from the client's current abilities for each individual exercise as well as more general bio-mechanical factors.

Each individual client at The Exercise Coach completes an initial consultation and then multiple strength evaluations via Exerbotics. While dynamic exercises performed on Exerbotics machines are isokinetic in nature, the testing and evaluation functions of Exerbotics are isometric. Digital force sensors are used during Exerbotics isometric strength testing to establish ideal, ability-based, effort levels (ie., loads) for use during initial exercise sessions. Numerous studies support the decision to use isometric testing for its validity across multiple muscle groups and its usefulness as an actual test of strength (Fisher, Bruce-Low, & Smith, 2013; Fisher et al., 2018; Fisher & Steele, 2017; Stuart, Steele, Gentil, Giessing, & Fisher, 2018b).

Another advantage of isometric strength testing is its reliability. Specifically, isometric testing results, with good standardization of methods, will be consistent between measures and when supervised by differing professionals (Fisher et al., 2013; Fisher et al., 2018; Fisher & Steele, 2017; Stuart et al., 2018).

The bio-mechanical factors respected to maintain safety are related to the range of motion required for any given exercise movement. Exerbotics has been used to establish the ranges of motion that privilege the muscular absorption of force during exercise against that which the skeleton must absorb. While, these ranges of motion are less than those usually observed during traditional strength training exercise, this safety enhancement in no way compromises effectiveness. In fact, research has demonstrated that there is no appreciable difference between the gains in strength one can produce through limited range of motion exercise when compared to a greater/full range of motion exercise (Massey, Vincent, Maneval, Moore, & Johnson, 2004). As a matter of semantics, strength training is never actually performed through the full functional range of motion of a given joint or through the full shortening or extensibility of a given muscle. The range of motion strategy employed by Exerbotics enables individuals who may have compromised joint integrity to exercise with comfort and safety.

## Effectiveness

Ultimately, exercise effectives should be measured by the total-body health and fitness outcomes that it generates. We have argued that both the reversal of sarcopenia and the development of optimal strength levels trigger the systemic adaptations that matter the most for healthy living.

The Exercise Coach and Exerbotics provide an opportunity for maximum strength gains in three ways. First, Exerbotics exercise considers quality (intensity of) effort as the key to maximum strength gains. Based on initial isometric testing, Exerbotics isokinetic exercise delivers ability-based exercise that meets threshold intensity criteria to serve as a stimulus for results from the very first session. Furthermore, performance data generated during each exercise set is used to modulate effort targets which adhere to the requirement of progressive overload.

Next, Exerbotics isokinetic resistance adapts to the way the body's strength varies at key junctures in the resistance training experience. Namely, Exerbotics continually accommodates not only the way strength varies throughout the involved joint's range of motion, but also as the exerciser experiences fatigue as well as between concentric and eccentric muscle actions.

Ability-matched eccentric overload produces better gains in strength and hypertrophy than exercise which does not provide eccentric overload (Roig et al., 2009). This may be because strength gains stimulated by concentric and eccentric muscle actions may be mediated by differing mechanisms (Roig et al., 2009). It is notable that eccentric training studies are not only uncovering potential advantages for strength development but also for metabolic health results. One study of the effects of eccentric lower-body training on senior men led the authors of the study to write, "It appears that the magnitude of the eccentric exercise training effects on insulin sensitivity and blood lipid profiles are much greater than those normally found in pharmacological interventions that could cost more" (Chen et al., 2017).

Some question whether the strength gains made using machine-based strength training will transfer to other modalities such as free-weight or bodyweight-based exercise. Research at the College of New Jersey, using Exerbotics technology, concluded that multi-joint isokinetic resistance training increases dynamic muscular strength, local muscular endurance and maximal isokinetic strength. In this study, the Exerbotics training transferred to strength measured by both free-weight and body-weight exercises (Ratamess et al., 2016).

Interestingly, while eccentric overload involves higher force levels than standard resistance training, it does not require higher perceived discomfort. In fact, eccentric dominant training techniques can be used with less demand on the cardiorespiratory system than conventional training (Lastayo, Reich, Urquhart, Hoppeler, & Lindstedt, 1999). This has led researchers to begin investigating the implication of eccentric training among clinical populations. Some examples include research with participants who suffer from COPD (Bourbeau et al., 2020; Cruz & Burtin, 2021) and those who suffer from cachexia related to cancer (Gould, Lahart, Carmichael, Koutedakis, & Metsios, 2013).

Finally, each session at The Exercise Coach includes real-time motivation guidance through professional supervision and digitally displayed biofeedback. This combination of verbal encouragement as well as digital feedback has been studied repeatedly and has been found to elicit the highest quality of strength training among both untrained and trained subjects (Coutts et al., 2004; Gentil & Bottaro, 2010).

## Efficiency

Arguably the most common barrier people face when starting and sustaining an effective exercise plan is the time requirement. The Exercise Coach and Exerbotics address the challenge of time requirements by leveraging the available scientific evidence discussed in this paper. Since Exerbotics maximizes each client's individual ability to safely strength train at higher effort levels than with conventional methods, training sessions at The Exercise Coach are necessarily brief and performed no more than two times per week. Since 2011, The Exercise Coach has delivered millions of these data-driven, coach-led, 20-minute workouts, and clients cite this efficiency as a significant practical and motivational benefit.

Furthermore, Exerbotics machines and protocols generate results in a shorter time-course than is usual and customary. This compression of time needed to maximize results may be explained in part by the finding that the body begins to change for the better in response to a single bout of exercise with an emphasis placed on eccentric overload (Dolezal, 1998; Thompson, Scordilis, Clarkson, & Lohrer, 2001). Large scale data analysis indicates that strength gains made by clients of The Exercise Coach may occur at a faster rate than those produced by more conventional methods. For example, one cohort of 7,462 females trained at The Exercise Coach using a standard protocol on the Exerbotics Leg Press experienced an average increase in strength of 33% in just six sessions. This performance progression compares favorably to a study that looked at training records of male and female subjects who underwent professionally supervised resistance training with conventional weight stack machines. In the study of more than 15,000 people, it took one year for the average strength performance to progress by 30% (Steele et al., 2021).

## SUMMARY

The tech-enabled fitness delivery system of The Exercise Coach powered by Exerbotics is based on the science which calls attention to sarcopenia, the age-related loss of strength and muscle. This phenomenon, and its associated co-morbidities, is a usual, but not normal, part of the modern lifecycle that can be prevented and reversed. An effective intervention must target and stimulate the remodeling of fast-twitch muscle fibers, as sarcopenia selectively impacts these cells. Decades of research and practice have elucidated the principles which under-gird a rational approach to optimizing exercise for safety, effectiveness, and efficiency. Fortunately, these findings encourage practical and approachable methods that are motivating and effective for people of all ages and fitness levels, methods pioneered by and practiced daily at The Exercise Coach.

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