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Resistance exercise and sports performance: The minority report

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ABSTRACT

Resistance exercise is typically performed to increase both muscle size and strength and is regularly incorporated into training programs for sports performance. Presumably, the exercise would be expected to increase the force producing capabilities of skeletal muscle, which may have subsequent influence on various sports related abilities. Interestingly, few studies are designed to examine sports related benefits of resistance exercise while including a proper control group to account for adaptations to simply performing the sports related task. Much of our knowledge on resistance exercise for sport is based off cross-sectional work showing that stronger athletes tend to perform at the highest level, along with cross-sectional work demonstrating that higher levels of strength are associated with various performance related parameters. Although there is a large body of cross-sectional literature providing a rationale for resistance exercise for sport, its implementation is largely based on the following: 1) An increase in muscle size will produce an increase in strength and 2) a stronger muscle will increase sports performance. However, there is a lack of evidence to support these assumptions. The weight of evidence suggests that resistance exercise may indirectly impact sports performance through injury prevention, as opposed to directly improving sport related abilities.

Introduction

Resistance exercise is typically performed with the intention of increasing both muscle size and strength. Given these expected outcomes, resistance exercise is regularly incorporated into training programs to improve sports performance [1]. Presumably, resistance exercise would be expected to increase the force producing capabilities of skeletal muscle, which may have subsequent influence on various sports related abilities. An early paper by Sutherland and Wiley [2] reported that all teams in the National Football League had strength and conditioning programs and that the majority of professional baseball, and basketball teams have full time strength and conditioning professionals on staff. Despite the widespread incorporation of resistance exercise across a wide variety of sports [3–7], the performance benefits are not entirely clear. Notably, few studies are specifically designed to examine sports related benefits of resistance exercise while including a proper control group to account for adaptations to simply performing the sports related tasks. It appears that much of our knowledge on resistance exercise for sport is based off cross-sectional work showing that stronger athletes tend to perform at the highest level [8], along with cross-sectional work demonstrating that higher levels of strength are associated with various performance related parameters [9]. Although there is a large body of cross-sectional literature providing a rationale for resistance exercise for sport, its implementation is largely based on the following assumptions: 1) An increase in muscle size will produce an increase in muscle strength and 2) a stronger muscle will increase sports performance. These assumptions seem intuitive, but recent studies have brought up questions regarding the role of exercise induced muscle growth on exercise induced strength adaptation [10], as well as how important specificity is for strength adaptation [11,12]. Considering these suggestions, the role that resistance exercise has for sports performance may be largely based on cross-sectional derived intuition rather than experimental evidence. The purpose of this review is to examine the evidence behind these assumptions and to examine the experimental evidence suggesting that resistance exercise (lifting weights with the intention of increasing muscle size and strength) improves sports performance.

Assumption 1: An increase in muscle size will produce an increase in muscle strength

Within sport, resistance exercise is often implemented through a programming strategy known as periodization. Modern periodization techniques place a great focus on skeletal muscle hypertrophy

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(hypertrophy phase) under the assumption that skeletal muscle growth during this phase will play a role on subsequent strength adaptation [13,14]. Although it seems that prior to and independent of resistance exercise, a larger muscle is a stronger muscle [15], the influence that *exercise induced* increases in muscle size have on *exercise induced* increases in muscle strength has become an area of debate [16,17]. Indeed, our understanding of the role that muscle growth has on muscle strength is driven primarily by cross-sectional associations [15], as well as retrospective correlations [18–20]. In addition, recent experimental evidence from our laboratory has demonstrated that performing a resistance training protocol to increase both muscle size and strength does not result in greater strength gains than simply practicing a one-repetition maximum (i.e., the strength test) in both trained [21] and untrained individuals [12]. Although these studies do not completely rule out the possibility that exercise induced muscle growth can contribute to exercise induced strength, it does allow for renewed discussion on how influential muscle growth is upon this change in strength.

Despite a lack of strong experimental evidence that increasing muscle size is necessary or important for strength adaptation, cross-sectional data has demonstrated that athletes have greater amounts of lean mass compared to controls or non-athletes [22,23]. To many this may stress the importance of muscle mass in sport, underlying the importance of resistance exercise. However, considering the relatively small amount (compared to that gained during development) of muscle mass that an individual can gain as an adult [24], this more likely highlights inherent differences in individuals who are capable of excelling in sport. This suggests that an individual with higher levels of baseline muscle mass (independent of resistance exercise) may be predisposed for success in a given sport. In addition, skeletal muscle growth does not appear to be infinite [24], which may suggest that the majority of adult athletes will not gain a great deal of muscle mass beyond that of their first year of resistance training. Further, it appears that most of these athletes may be capable of maintaining those adaptations following the initial months of training with much lower volumes of exercise than it took to accrue them initially [25]. Following this logic, there may be some merit to resistance exercise for younger athletes (still growing/developing), as resistance exercise may help them to attain a higher baseline [26]; however, the resistance training focus can likely be drastically reduced into adulthood.

Assumption 2: A stronger muscle will increase sports performance

Skeletal muscle hypertrophy may not be necessary or important for strength adaptation; however, resistance exercise may still be efficacious for sport if it could improve performance by augmenting strength. The idea that resistance exercise will increase sports performance is generally accepted [9,27]; however, it appears that this assumption is largely based off cross-sectional data demonstrating that strength is associated with being a starter or non-starter [8], as well as with various tasks related to performance [9]. For example, Iguchi et al. [8] found that Japanese football starters had greater bench press and back squat strength compared to non-starters. In addition, Fry and Kreamer [27] found that bench press, power clean and vertical jump could differentiate between starters and non-starters in 5 of 6 different positions in American collegiate football. In addition to being associated with a higher level of athletic ability, strength is also associated with higher task performance in skills that are believed to be important for sports performance. For example, performance measures such as rate of force development, external mechanical power, and sports related skills such as jumping, and sprinting are associated with strength [9,28]. For the purposes of this review, we will discuss the impact of resistance exercise on rate of force development, jumping abilities, as well as "sports specific" abilities. In addition we will discuss the reliance on cross sectional data in our understanding of strength and how it applies to sports performance.

Rate of force (torque) development

Rate of force development is also known as "explosive muscle strength" and is defined as the rate of rise in contractile force at the onset of contraction [29]. Although rate of force development has been shown to increase following resistance exercise [30,31], the reason increases in rate of force development are believed important for athletes appears to be largely based off a body of cross-sectional literature which suggests that starters have greater rates of force development compared to non-starters [32]. In addition, it has been shown that greater rates of force development are positively associated with other factors such as vertical jump [33] and muscle cross-sectional area [34]. Andersen and Aagaard [35] found that maximal strength may account for up to 80% of the shared variance in rate of force development further underscoring the importance for resistance exercise. Although these cross-sectional associations certainly create a case that rate of force development might be an important factor for sports performance, it does not appear that there are any studies designed to show that *increasing* the rate of force development through resistance exercise improves actual sports performance. Meaning, rate of force development may be associated with high sports performance, but this does not necessarily mean that increasing this in a laboratory test through resistance exercise will reflect any meaningful change in sports performance. This is an important distinction, as there are countless associations within the literature, which may drive many of our presumptions regarding the influence of resistance exercise on sport (in this case through rate of force development). In order to better answer the question, interventions should be designed to elicit a change in rate of force development and compare changes in sports outcomes to individuals practicing their sport related skills.

Jumping Abilities

Vertical jump is often used as a surrogate for sports performance. Cross-sectional literature has demonstrated that stronger individuals are able to jump higher than weaker individuals [36]. Suchomel et al [9] examined correlations amongst 116 different studies, finding that 91 (78%) of the studies displayed a greater than moderate correlation between jumping ability and strength. Experimentally, Cormie et al. [37] observed increased jump performance following 10-weeks of either heavy resistance training or ballistic power training. Lamont et al. [38] found that 6-weeks of periodized resistance training (with or without the application of whole body vibration) could improve 30-cm depth jumps and 20-kg squat jump performance. Thus, it appears that jumping performance can be improved through resistance exercise. This may provide some efficacy to resistance exercise for sports performance, as the ability to jump is important across a wide variety of sports and sporting events. However, it is still unclear if a laboratory measure of jumping performance will actually translate to jumping performance in the sports setting. Fatouros et al. [39] found that vertical jump increased approximately 5–8 cm following 12 weeks of either plyometric training, weight training or a combination of both in untrained individuals. The authors conclude that "combination" training may be an effective strategy for athletes to improve explosiveness, but we must consider that vertical jump was executed from a "2-footed standing position without a step into the jump". If we use American football as an example, it is unclear how this increase would apply to a wide receiver running down the football field in full gear prior to jumping. An athlete is very skilled in the execution of their sports specific jumps/movements; however, they are likely much less skilled at a laboratory test of vertical jump. Any increase in vertical jump for an athlete may simply reflect the acquisition and improvement of a new skill in which they were not already efficient. Such laboratory based skills may have more meaning for sports such as volleyball, where the sports specific jumps may more closely mimic the laboratory test [40,41]. Nonetheless, no study to our knowledge has examined the effects of simply practicing the jumping task versus resistance training to improving jump performance. This would be an important study as it has never been demonstrated if progressive overload is necessary for improved jumping abilities. There may be merit to increasing strength for power based skills such as jumping where the training itself may be incapable of providing an overload. However, experimental design could be used to compare the effects of simply practicing the skill to resistance training to improve the skill in order to determine if increased strength is necessary to improve jumping performance.

Resistance exercise increasing actual sports performance

In sports such as powerlifting and Olympic lifting, resistance training becomes very specific to the sport and is absolutely necessary because the training can essentially mimic the actual competition. However, in sports that do not involve lifting a barbell, the discussion of whether resistance exercise increases sports performance is very important as resistance training may ultimately take time and recovery away from the performance of the actual sport. At present, there is scarce literature showing increases in sports performance measures following resistance training programs. This is due to that fact that many studies consider increases in vertical jump or other laboratory based tasks an increase in sports performance; however, based on our previous discussion of skill acquisition, these are not likely strong surrogates for actual changes in sports performance. Kraemer et al. [1] found that a periodized resistance training program increased serve velocity in collegiate women tennis players over a 9-month period, whereas a non- resistance training control group saw no increase in this measure. Judge et al. [42] found that a sport-specific resistance training program improved maximal neural drive during rapid isometric contractions in track field athletes. In addition, authors found that overhead shot, long jump and vertical jump improved from test session 1 to test session 4 by 9%, 4% and 8% respectively, which showed moderate correlations with the laboratory-based strength measurements (overhead shot distance r = 0.60, long jump distance r = 0.52 and vertical jump height r = 0.61. However, the control group in this study were a group of non-athletes who did not perform that actual sports tasks (overhead shot, long jump and vertical jump); thus, conclusions on the impact of resistance exercise on sports performance are limited. In addition, there is some literature showing that resistance exercise can influence throwing speed/velocity [43–45]. However, these changes are typically small (i.e., $0.6\,m{\cdot}s^{-1}$–$1.3\,m{\cdot}s^{-1}$ at the group level [44,45]), with studies not accounting for differences in baseline abilities. Bimson et al. [46] found that the addition of isometric knee extensor training to regular soccer practice resulted in more favorable changes in counter movement jump and kicking distance compared to a group just practicing soccer. However, no differences were observed in straight sprint speed and zigzag sprint speed, with and without a ball [46]. Admittedly, it is difficult to measure sports performance as in most cases the best marker of performance may be actual success (i.e., winning) at the sport. Interventions with athletes would require control groups, as well as, control over many confounding factors (i.e, practice, existing strength program, etc) that make these study designs difficult to conduct. This is presumably why cross-sectional data is so readily used to justify the incorporation of resistance exercise in sport. Experimental studies could begin to examine the effects of resistance training versus simply practicing the skill of interest to better understand the role that strength may have on certain performance related tasks. In addition, future research could focus on skills that are very specific to sport in order to avoid the confounding influence of skill acquisition. Ultimately, such studies are more realistic for sports such as sprinting, where the performance test very closely resembles the actual sport. This may provide a starting point for better study design; however, given the widespread incorporation of resistance training across a variety of sports, many well designed interventions are warranted.

A larger and stronger muscle could not be a bad thing?

Despite limited evidence that resistance exercise is beneficial for sports performance, many may argue that an increase in muscle size and strength could not possibly be a negative adaptation. However, if resistance exercise does not largely contribute to an increase in sports performance then several hours a week spent on resistance training may be doing little more than prolonging recovery. Our research group has previously discussed the lack of evidence supporting the thesis that a periodized resistance training program will result in superior increase in muscle size and strength to that of a non-periodized resistance training program implementing progressive overload [47]. This led us to examine the general adaptation syndrome, the proposed theory underlying the periodization of resistance exercise [48]. The original concept of "adaptation energy" proposed by Selye suggested that a resistance (or adaptation) to one drug may limit the ability to adapt to another (i.e., morphine, atropine) [49]. Meaning, if a rat is treated with a drug (building up a tolerance against a toxic dose), their ability to withstand a toxic dose of another unrelated drug is decreased. Although it is unclear if this concept has any relevance for resistance exercise, if applied properly it would predict that resistance exercise would actually limit an individual's ability to adapt to sports related activities. This is not acknowledged within the periodization literature, which simply attempts to balance resistance exercise with sport training in order to avoid overtraining. We would suggest that the least amount of resistance training possible may be the most desirable scenario for an athlete. This concept was discussed in a review by Fisher and Steele [50], who suggested that the high volumes of exercise typically recommended are unnecessary and that equal or better results can be achieved in a minimal amount of time. In addition, if muscle growth is not playing an appreciable role with exercise induced increases in muscle strength, this may undermine the traditional model of periodized resistance exercise for sport which incorporates a hypertrophy phase intended to increase muscle size before entering the strength phase of the programming [51]. This hypertrophy phase is typically characterized by having large amounts of volume which are believed necessary to elicit a maximal growth response [51]. Newer models of periodization also incorporate hypertrophy work (under the assumption that hypertrophy is necessary to maximize strength) [52,53]. However, if not contributing to strength, this extra volume may be unnecessarily contributing to fatigue. To try and account for this additional fatigue, some have suggested that the hypertrophy day should be distanced from the strength day. Zourdos et al. [54] found that a training configuration which allowed 96 hours between hypertrophy and strength training sessions resulted in greater increases in bench press strength compared to a training group that only had 48 hours between hypertrophy training and strength training. Although this seemed beneficial for the bench press, there were no differences in the squat strength, deadlift strength, or Wilks coefficient (which ultimately determines the winner in powerlifting). All things considered, we believe that removing the hypertrophy day altogether may be more ideal for the athlete (no longer necessary to program around the high volume day). If hypertrophy does not in fact lend itself to a meaningful increase in voluntary strength, it seems reasonable to suggest that athletes may spend many unnecessary hours in the weight room, which could be used for practicing sport or for recovery.

Indirect effects on sport performance

Resistance exercise may not have a direct effect on sports performance, but may indirectly improve performance through the prevention of injury. Coppack et al. [55] found that the inclusion of progressive resistance exercise along with stretching during a 14-week military style physical conditioning program resulted in a 75% reduction in anterior knee pain risk compared to a control group that did not perform resistance training and stretching. Askling et al. [56] examined the influence of 10-weeks of hamstring specific resistance training (emphasizing eccentric overload) on subsequent hamstring injury in elite level soccer players. The authors found that individuals performing the specific hamstring training had a lower occurrence (3 out of 15 versus 10 out of 15) of hamstring injuries compared to a matched group performing regular pre-season training. Similarly, Peterson et al. [57] found that the addition of eccentric hamstring exercise (Nordic hamstring exercise which attempts to maximize loading in the eccentric phase) in addition to the regular training program for professional and amateur soccer players resulted in a much lower occurrence of hamstring injuries compared to a control group not performing the additional eccentric training (3.8 versus 13.1 injuries per 100 players). A systematic review and meta-analysis on the effectiveness of exercise interventions to prevent sports injuries by Lauersen et al. [58] concluded that resistance exercise reduced sports injuries to less than one-third and reduced overuse injuries by half. Although these authors do not speculate on the mechanisms of injury prevention, it has been previously suggested that resistance exercise may prevent injury through an increased strength of tendons, ligaments, joint cartilage, connective tissue sheaths, tendon to bone strength, ligament to bone junction strength and bone mineral content [59]. Given the lack of data for sports performance, a better justification for resistance exercise in sport may be injury prevention. If true, then resistance training programs may need to be programmed for reducing injury as opposed to peaking different strength tests throughout a training cycle with the intention of improving performance.

Considerations

It is important to note that not every systematic review/meta-analysis/original paper on strength and performance is included in this paper. We cite (to our knowledge the most recent) paper by Suchomel et al. [9] showing that strength is associated with various aspects of sports performance. However, a major point of this paper is that associations between strength and performance measures may not provide a proper justification of the importance of resistance exercise for sports performance. As such, their exclusion is not due to bias but because they provide no additional insight to help answer the research question. Furthermore, as discussed above, it is unclear how many of these markers of sports performance relate to actual sports performance (i.e. vertical jump, rate of force development, sprinting). It seems reasonable to suggest that a group of soccer players who repeatedly practiced the sprinting test would improve their performance in the sprint test just as well (if not better) as a group of soccer players who were lifting weights. Nevertheless, the point remains, does this improvement in sprint time really translate to an increase in soccer performance? This paper is novel in that it discusses resistance exercise for sport operating under the assumption that the exercise induced increase in muscle size has little to no role on the exercise induced increase in muscle strength. We believe this is worth discussing as the evidence that the change in muscle size is important for the change in muscle strength is currently non-existent. We agree that intuition and anecdote suggest that resistance exercise influences sports performance, but we also agree that the plural of anecdote is not evidence. This paper serves to offer ideas for how training for sport might change, if in fact, changes in muscle size do not influence changes in muscle strength.

Conclusions

Resistance exercise for sports appears to be largely based on cross-sectional literature demonstrating that stronger individuals are more successful at sport [8] and that strength is associated with various performance related abilities [9]. Although there is evidence demonstrating that resistance exercise can improve performance related measures such as rate of force development and performance skills such as jumping ability, the majority of these studies do not include a control group for proper comparison (can practice of the skill itself produce similar or greater improvement than resistance exercise). Although resistance exercise likely has a role in sports practice, the importance of that role is still unclear. Resistance exercise is often programmed to increase sports performance [1,60], however, the weight of evidence suggests that resistance exercise may be more beneficial for injury prevention as opposed to directly improving actual sport performance [55–57]. Future experimental interventions are necessary to better understand the benefit of resistance exercise for sports performance.

Compliance with ethical standards

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Conflicts of Interest

Authors declare that they have no conflicts of interest relevant to the content of this review.

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