The Effectiveness of Resisted Movement Training on Sprinting and Jumping Performance

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Abstract

Hrysomallis, C. The effectiveness of resisted movement training on sprinting and jumping performance. *J Strength Cond Res* 26(1): 299–306, 2012–Resisted movement training is that in which the sports movement is performed with added resistance. To date, the effectiveness on enhancing sprint speed or vertical jump height had not been reviewed. The objectives of this review were to collate information on resisted training studies for sprinting and vertical jumping, ascertain whether resisted movement training was superior to normal unresisted movement training, and identify areas for future research. The review was based on peer-reviewed journal articles identified from electronic literature searches using MEDLINE and SPORTDiscus data bases from 1970 to 2010. Resisted sprint training was found to increase sprint speed but, in most cases, was no more effective than normal sprint training. There was some evidence that resisted sprint training was superior in increasing speed in the initial acceleration phase of sprinting. Resisted jump training in the form of weighted jump squats was shown to increase vertical jump height, but it was no more effective than plyometric depth jump training. Direct comparisons between resisted jump training and unresisted normal jump training were limited, but loaded eccentric countermovement jump squat training with unloaded concentric phase and eccentric landing was shown to generate superior results for elite jumpers. More prospective studies on resisted sprint training are required along with monitoring both kinematic and kinetic adaptations to fully determine any underlying mechanisms for any improvements in sprint speed. Based on the available data, the benefits and superiority of resisted sprint training have not been fully established. As for resisted jump training, although there are some promising findings, these results need to be duplicated by other researchers before resisted jump training can be claimed to be more effective than other forms of jump training.

KEY WORDS weighted jump squats, ballistic training

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Introduction

There are a number of training options that bring about specific adaptations depending upon the requirements of the sports. Efficient and effective training methods are continually sought after by strength and conditioning staff, coaches, and athletes to enhance sports performance (3,17). A principle of exercise prescription is specificity of training, which stipulates that there should be similarity between the movement velocity and specificity of the training exercises in relation to sport performance (6,16). Resisted movement training is an example of the application of the specificity of training principle. Resisted movement training is used in athletic conditioning to try and enhance power and athletic performance by executing a movement important to sport with added resistance that is not excessive and does not adversely affect the movement pattern. Traditional weight training exercises performed slowly with heavy resistance are well suited to enhance strength but may not be optimal for power development requiring higher velocity because there are considerable portions of deceleration during the motion, whereas resisted movement training can allow for acceleration throughout the range of motion (18). Resisted movement training provides a greater resistance than normal training does and may provide a greater stimulus to the working muscles and optimize training adaptations and crossover to dynamic athletic performance. Two activities that are very important for sport success and lend themselves to resisted movement training are sprinting and vertical jumping.

Despite resisted movement training being prescribed for athletic conditioning across a variety of sports (8,9,19), the effectiveness of resisted movement training on crucial components of sport had not been reviewed. The aims of this review were to compile the current knowledge in the area of resisted movement training for sprinting and vertical jump performance, identify the general findings, determine whether resisted training is superior to normal, unresisted

Table 1. Resisted sprint training influence on sprint speed.*

Study	Subjects	Training programs	Sprint tests	Significant findings ($p < 0.05$)
Zafeiridis et al. (26)	PE students	3 per wk for 8 wks	50 m	Resisted ↑ 0–10 and 0- to 20-m speed
	Normal sprint group (11 M)	4 × 20-m and 4 × 50-m sprints		Normal ↑ 20- to 40-m, 40- to 50-m, and 20- to 50-m speed
	Resisted sprint group (11 M)	Weighted sled 5 kg (≈7% BW)		
Kristensen et al. (13)	PE students (12 M, 7 W)	3 per wk for 6 wks	20 m	Resisted ↓ speed
	Normal sprint group	5 × 22-m Sprints		Normal and assisted ↑ speed
	Resisted sprint group	2.7-kg Pulley system		
	Assisted sprint group	7.5-kg Pulley system		
Myer et al. (17)	High school soccer players	2 per wk, for 6 wks, periodized	9.1 m	Both groups ↑ sprint speed
	Resisted sprint group (14 W)	Light-heavy resistance bands, 5.5–55 m, 6–45 s, 1–3 sets.		
	Incline treadmill group (17 W)	Incline grade 0–35%		No difference in speed between groups
		10–32 $km \cdot h^{-1}$, 6–30 s, 1–3 sets		
Spinks et al. (24)	Footballers first grade level	2 per wk for 8 wks, progressive.	15 m	Both groups ↑ sprint speed
	Normal sprint group (10 M)	5–20 m, 3–5 repetitions, 1–3 sets		
	Resisted sprint group (10 M)	Weighted sled ≈10% BW		No difference in speed between groups
	Control (10 M)			
Harrison and Bourke (10)	Rugby players pro and semipro	2 per wk for 6 wks, 6 × 20-m sprints	30 m	Resisted ↑ 0- to 5-m speed, control did not.
	Resisted sprint group (8 M)	Weighted sled ≈13% BW		
	Control (7 M)			
Clark et al. (3)	College lacrosse players	2 per wk for 7 wks	18–55 m interval	All groups ↑ sprint speed
	Normal sprint group (7 M)	6–9 sets of 18–55 m		
	Resisted sprint, sled group (7 M)	Weighted sled ≈10% BW		No difference in speed between groups
	Resisted sprint vest group (6 M)	Weighted vest ≈18.5% BW		

*↑ = increased; ↓ = decreased; BW = body weight; W = women; M = men; PE = physical education; Pro = professional.

training, and highlight future research needs. The review was based on peer-reviewed journal articles identified from electronic literature searches using MEDLINE and SPORT-Discus data bases from January 1970 to January 2010 using the following search terms in various combinations: "resisted," "weighted," "ballistic," "training," "sprinting," and "jumping." Articles were accepted if they pertained to prospective training studies and included a practical and relevant measure of sport performance such as sprint speed or vertical jump height without additional load.

Influence of Resisted Training on Sprint Speed

Sprinting speed is critical to performance success in many sports. The 100-m sprint may be divided into 3 phases: initial acceleration (0–10 m), attaining maximum speed (10–36 m), and maintaining maximum speed (36–100 m); and sprint training programs may be effective for 1 phase but not for another (6). The resisted sprint training studies are summarized in Table 1, and they have all used distances not >55 m. This is probably because the majority of sports involve sprinting for short distances, and it may be uncommon to sprint continually beyond attaining the maximum speed phase. The mode of resistance most commonly investigated has been sprinting while towing a weighted sled (3,10,24,26); weighted vests (3), pulley systems (13), and elastic resistance bands (17) have also been used. The optimal load for resisted sprint training has not yet been determined from longitudinal training studies, but to achieve an overload response while not adversely affecting sprint biomechanics, it has been suggested that resistance load should decrease the sprinting velocity during training by about 10%, not more (3). This usually needs to be determined by pilot work before the training intervention because it can be influenced by the friction of the training surface and physical characteristics of the subjects (3).

The first 2 prospective studies on the influence of resisted sprint training involved physical education students (13,26), and subsequent studies have involved field sports athletes from various football codes and lacrosse (3,10,17,24). Two studies used elite trained subjects: footballers (24) and rugby players (10). Unfortunately, there haven't been any prospective studies using track sprinters. The training frequencies in the studies have been 2–3 per week, durations of 6–8 weeks, and weighed sled resistances of 7–13% body weight. Because the optimal resistive load for sprint training has not been established by longitudinal studies, future prospective studies comparing different loads (e.g., unresisted vs. 10% decrease in sprint velocity vs. 15% decrease in sprint velocity vs. 20% decrease in sprint velocity) are required. The sprint training and testing distances have ranged from 9.1 to 55 m, and the number of training sets has usually been between 3 and 9 per session. Most of the studies (3,13,17,24,26) also determined sprint kinematics, namely, stride rate and length so as to determine mechanisms for any improvement in sprint speed. The 1 study that did not record kinematic data measured lower limb power during jumping (10).

The majority of the studies found that resisted sprint training increased sprint speed, but it was usually no more effective than normal sprint training in enhancing sprint speed (3,13,17,24). Only 2 studies were able to show that resisted training increased sprint speed more than normal sprint training (26) or a control group (10), and this was mostly for the initial acceleration phase. Both these studies (10,26) used a weighted sled as the resistance, but they varied in training frequency, duration, weighted sled load, and training status of the subjects.

Other modes of resistance such as weighted vest, pulley system, or resistance bands were not shown to enhance sprint speed beyond that of normal sprint training. The superiority of resisted training with weighted sled in increasing the initial acceleration in trained athletes in the 1 study (10) was not demonstrated in another study also using elite trained athletes (24). Resisted sprint training has not been reported to lead to superior results for distances >20 m; in fact, normal sprint training was shown to produce better results than those of resisted sprint training for distances of ≥20 m (13,26). The one study using a pulley system for resistance surprisingly reported that the resisted training actually had a negative effect on sprint performance (13).

Sprint speed can be improved by increasing stride length or stride rate as long as there is no significant detriment to the other (17). It is assumed that resisted sprint training would increase strength and power levels, which would generate greater propulsive forces of the limb muscles and increase stride length or rate (10,24). Although improvements in sprint speed were reported for most studies, changes in kinematics were not always detected (3,13,24). Only one study found a change in stride length after training, and this was for the normal sprint group in the maximum speed phase (26). Stride rate was found to increase in 2 studies for the resisted sprint group during the acceleration phase (17,26). The 2 studies that found resisted sprint training was superior to normal training or a control group reported that the resisted sprint group increased stride rate in one study (26); the other study (10) did not record kinematics but measured and reported an increased lower limb power, which can help explain the increase in sprint speed.

Influence of Resisted Training on Vertical Jump Height

Vertical jump ability is important for success in many athletic pursuits, for example, basketball, volleyball, team handball, and many of the football codes. Resisted vertical jump training commonly involves jump squats, which are in-place vertical jumps with additional load. Jump squats start from an erect standing position and involve the stretch-shorten cycle of the lower limb muscles where a countermovement is the lowering phase with the muscles undergoing stretch and acting eccentrically before the upward propulsive phase, which involves the muscles shortening and acting concentrically. The term "jump squat" should not be confused with term "squat jump," which is sometimes used to describe a jump that starts from a static semi squat position, does not involve an eccentric countermovement, only the concentric upward phase is performed (18). Resisted jump squats can be performed with exercise machines or with free weights. Exercise machines options include a Smith machine or variation such as the Plyometric Power System (25), which has a guided barbell that tracks along vertical rods or the Cormax jump squat machine which does not have a barbell but has a lever arrangement (11). There are also elastic resistance machines that can be used for resisted jump training such as the Vertimax (16), which comprises a platform with 4 retractable elastic cords of adjustable length and tension that are attached to a waist belt and can also be held in the hands; it incorporates a pulley system underneath the platform designed to keep the resistance constant, unlike traditional elastic resistance in which resistance varies and is proportional to distance stretched. Free weight options include jump squats with a barbell positioned across the back of the shoulders (12) or with holding weights in the hands (23).

The effectiveness of resisted jump training has been compared with other forms of training designed to increase vertical jump height (Table 2), namely, conventional weight training using heavy squat exercises, plyometric depth jumps, and normal jump training. For this review, plyometric training will refer to depth jumps, whereas normal jumps will be considered separate to plyometrics. Depth jumps involve stepping off an elevated box, landing with a very short contact time, and then rapidly and maximally jumping upward. The amortization phase which is the time between the concentric and eccentric phases is kept to a minimum to enhance potentiation (20). When stepping off the box, the initial acceleration of the body mass increases the eccentric loading of the stretch-shorten cycle so as to try and optimize use of elastic energy and stretch reflex to enhance jumping performance (20). The term "normal jumps" refers to countermovement jumps without additional loading or resistance.

Prospective studies on resisted jump training have ranged in training frequency from 2 to 3 times per week with most being 2 times a week (Table 2). The durations of the studies have been between 5 and 10 weeks, and the resistance used for the weighted jump squats has been between 30 and 80% 1RM, with 30% being commonly used (12,14,18,25). The resistance reported in 1 of the elastic resisted jump squats training studies using the Vertimax was 1.4–6.8 kg (16); it is unclear if this was the load per elastic cord or total load. The load used in the other elastic resisted jump squat training study has not been quantified (2).

Resisted jump training using weighted jump squats has been found to increase vertical jump height in all (12,14,18,23,25) but 1 study (11), which had the least number of total training sessions and possibly insufficient volume to elicit improvement. Weighted jump squat training has been shown to increase force output and in particular rate of force development (18), which may be a mechanism for enhancing jumping ability. Resisted jump training using elastic resistance was not found to improve vertical jump height (2,16), and it was suggested that the resistance of the elastic cords increased the amortization time, which diminished the benefits of the stretch-shorten cycle (16) and limited improvement in jumping height. It has been reported that elastic resisted jump training increased lower body power in 2 other studies that did not report jump height (21,22). Resisted jump training was not found to be superior to plyometric training using depth jumps (14,16,25), and in fact, 1 study found plyometric training to be superior to elastic resisted jump training (16). One study found that weighted jump squat training increased vertical jump height more than traditional weight training did, with heavy squats for a group of weight-trained subjects (25), whereas another study (2) found no improvement or difference when comparing combined elastic resisted jump training and weight training with just weight training only for college athletes.

In the case of jumping, there are 2 phases of eccentric activity: The first is the association with the preparatory countermovement before upward propulsion, and the second occurs during the landing phase. A concern with weighted jump squats is that the impact force during the landing phase might increase discomfort or injury risk, particularly for untrained subjects along with the fact that eccentric loading leads to a higher level of delayed onset of muscle soreness than concentric loading does (12). On the other hand, eccentric loading is thought to be an important training stimulus for improving functional performance (5). When performing resisted jump squats, the resistance can be applied to both the eccentric and concentric phases or to only 1 phase of the jump squat using machines or free weights. The Plyometric Power System has an electromagnetic braking system (18), and the Cormax jump squat machine (11) has a hydraulic mechanism that can unload the resistance during the eccentric landing phase. When training with free weights, the resistance can be unloaded during the concentric phase by releasing weights held in the hands at the end of the eccentric phase of the countermovement (23), so no additional loading is experienced during the propulsive or eccentric landing phases. Electromagnetic braking devices are also available that can be attached to a barbell to unload the eccentric phase during jump squat landing (12). The 2 studies that compared resisted concentric and eccentric jumps with resisted concentric-only jumps found no difference between groups (11,12), yet resisted eccentric countermovement (not landing) training produced vertical jump performance superior to that of normal jump training (23). This might suggest that loaded eccentric countermovement (not landing) training is more effective than loaded concentric training.

The amount of resistance used for the jump squats is an important consideration because it would be assumed that it needs to be sufficient to elicit a training response without being too great so as to impair the kinematics of the stretch-shorten cycle component of the jumping motion. No longitudinal studies have directly compared the influence of weighted jump squat training with different percentages of 1RM on unloaded vertical jump height. There is some indirect support that a lighter jump squat load may be optimal. One study (15) reported that weighted jump squat training for 8 weeks using 30% 1RM was more effective than 80% to improve loaded jump height using a resistance of 30% 1RM, but this could be explained by the notion of specificity of training and testing bias because 1 group was at a distinct advantage by training at the load they were tested. The optimal loading for acute peak power output during jump squats has been found to be just body weight with no additional loading (1,4); if this were to translate to the optimal training load for maximal vertical jump height gains,

Table 2. Resisted jump training influence on vertical jump height.*

Study	Subjects	Training programs	Jump test	Significant findings ($p < 0.05$)
Wilson et al. (25)	Weight trained	2 per wk for 10 wks, progressive overload.	Standing VJ height with plyometric power system with 4-kg bar	Resisted ↑ jump height more than squat group but not more than that of the plyometrics group
	Heavy squat group (15 M)	All groups did 3–6 sets, 6–10 reps		All training group ↑ jump height, control did not
	Plyometrics group (13 M)	Depth jumps 0.2–0.8 m		
	Resisted jump group (13 M)	Weighted jump squats 30% 1RM		
	Control (14 M)	Usual activity		
Lyttle et al. (14)	Non–weight trained	2 per wk for 8 wks, progressive overload	Standing and running VJ height with Vertec	No difference between training groups
	Combined heavy squat and plyometrics group (11 M)	Squats 1–3 sets, 6–10RM and depth jumps 1–2 sets, 8 reps, 0.2–0.6 m		Both training groups ↑ jump height, control did not
	Resisted jump group (11 M)	Weighted jump squats 2–6 sets, 8 reps, 30% 1RM		
	Control (11 M)	No training		
Newton et al. (18)	Volleyball players college division I	2 per wk for 8 wks (plus normal training)	Standing and running VJ height with Vertec	Resisted ↑ height for both jumps, control did not
	Resisted conc. jump group (8 M)	Weighted jump squats 6 sets (2 each at 30, 60, 80% 1RM) 6 reps		
	Control (8 M)	Squats and leg press 3 sets, 6RM		
Hoffman et al. (11)	Football players college division III	2 per wk for 5 wks (plus normal training)	Standing VJ height with Vertec	No improvement or difference between any of the groups
	Resisted jump group (15 M)	Weighted jump squats 4 sets, 4 reps, 70% 1RM		
	Resisted conc. jump group (16 M)	No weighted jump squats		
	Control 16 M)			
Hori et al. (12)	Untrained	2 per wk for 8 wks	Standing VJ height with Yard Stick	No difference between the groups
	Resisted jump group (10 M)	Weighted jump squats 6 sets, 6 reps, 30% 1RM		Both groups ↑ jump height
	Resisted conc. jump group (10 M)			
McClenton et al. (16)	Untrained college students	2 per wk for 6 wks, progressive overload	Standing VJ height with Vertec	Plyometric ↑ jump height,
	Resisted jump group (8 M, 3 W)	Elastic resistance 2–4 sets, 4–8 reps		elastic resisted and control didn't
	Plyometrics group (6 M, 4 W)	Depth jumps 2–4 sets, 4–10 reps, 0.5–1.0 m		
	Control (6 M, 4 W)			

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Sheppard et al. (23)	Volleyball players elite	3 per wk for 5 wks (plus normal training)	Standing VJ with light pole and linear transducer	Resisted ecc. ↑ jump height, normal group did not
	Resisted ecc. countermovement not landing jump group (6 M, 2 W)	Weighted jump squats 5 reps, 4–10 sets		
		20–40 kg, releasing weight before conc		
	Normal jump group (4 M, 4 W)	No additional resistance		
Carlson et al. (2)	College athletes division III (15 M, 22 W)	Progressive overload 3 per wk for 6 wks	Standing VJ height with Vertec	No difference between groups
	Weight training only	3 sets 10 reps, standard exercises		No improvement in any group
	Normal jumps + weight training	7 sets of 6–10 jumps		
	Resisted jumps + weight training	Elastic resistance 6 sets of 10 jumps		
	Resisted jumps with resisted arm swing + weight training	Elastic resistance 6 sets of 10 jumps		

*Conc = concentric; ecc. = eccentric; W = women; ↑ = increased; M = men; reps = repetitions; RM = repetition maximum; VJ = vertical jump.

it would be expected that normal jump training would be superior to resisted jump training and this would need to be confirmed by prospective training studies.

Studies directly comparing normal vertical jump training with resisted jump training are limited. One study using loaded eccentric jump training found it to be superior to normal jump training for elite male and female volleyball players (23). The subjects held weight plates in their hands (10 kg in each hand for women and 20 kg for men) and then dropped the weights at the end of the countermovement before the start of the concentric motion, an active arm swing was used in the upward phase of the jump. In effect, the eccentric countermovement was loaded but not the concentric propulsive phase or eccentric landing. The findings of this study are very encouraging because improvement was found in a group of elite jumpers who are claimed to have a smaller window of adaptation (11) and the training modality does not require expensive equipment and is relatively easy to execute and safe because of no additional loading during the landing. Another study (2) compared combined resisted elastic jump and weight training with normal jump and weight training for college athletes and found no improvement or differences in vertical jump height after 6 weeks. There were 2 groups of elastic resisted jump training, one applied the elastic resistance of the Vertimax to the waist belt only and used an unresisted arm swing, whereas the other group had elastic resistance also applied to their arm swing via wrist straps. There was no difference detected between any of the groups; the additional resisted arm swing was not found to be beneficial.

An arm swing is commonly used for vertical jumps in sport and does increase jump height, possibly by the production of additional energy or by the slowing of leg extension, which allows the muscles to operate in a more favorable region of the force-velocity curve (7). The majority of weighted jump squat studies did not use an arm swing when training because the hands were required to be kept in position to hold onto a barbell or machine (11,12,14,18,25), yet most of the vertical jump height tests involved an arm swing and were measured with a Vertec (11,14,18) or similar device (12). Given that an arm swing is an important part of performing a vertical jump, it would be desirable to perform an arm swing during jump training. Although elastic resisted jump squats allow for an arm swing, this modality has not been shown to increase vertical jump height (2,16), and more work is required in this area. Future resisted jump squat research should also consider other options that allow for an arm swing such as hand-held weights that are released before the concentric phase (23) or the use of a weighted vest.

Participants in the Training Studies

The research findings of the training studies may be influenced by subject characteristics such as initial training status, age, gender, and sample size. Two of the 3 studies that used highly trained subjects found that resisted sprint or jumping training was superior to conventional sprint or jump training. Of the 2 studies that used highly trained subjects for resisted sprint training, 1 study (10) found it to be superior to normal sprint training, whereas the other study (24) did not. The one study (23) that used highly trained subjects for resisted jump training and compared it with normal jump training found resisted training to be superior. Highly trained athletes that have used only normal sprint and jump training methods may benefit from the new stimulus provided by resisted movement training, but this would need to be further supported by more research.

Virtually all the subjects in all the studies were either in their twenties or late teens, and this is likely to be the optimal age bracket for training adaptations to occur. The majority of the training studies used exclusively male subjects: 4 out of the 6 sprint training studies (3,10,24,26) and 5 out of the 8 jump training studies (11,12,14,18,25). Some studies used a combination of male and female subjects unevenly split into training groups (2,13,16,23) with a between-subjects approach to analyze the data. There is the concern that a difference may not be detected because of possible variability in gender adaptation, but this was not usually found to be the case, most of these studies detected a difference between training groups. It would still be advisable for future researchers to proceed with caution before using a combination of men and women and between-subjects design.

The number of subjects used in the training studies can be influenced by subject availability, time, budgetary constraints, and equipment availability. A potential problem for studies with low sample sizes is that they may be statistically underpowered to detect significant differences. The number of subjects in the training groups ranged from 6 (13) to 17 (17). Many of the studies with the smaller size (10,13,18,23) were in fact able to detect significant differences between the groups.

Conclusions

In most cases, resisted sprint training was not found to be superior to normal sprint training, although they both did increase sprint speed. There are some limited data that showed resisted sprint training was superior in increasing speed in the initial acceleration phase. Data on the effectiveness of resisted sprint training on track sprinters are lacking. More prospective studies into resisted sprint training are required along with monitoring both kinematic and kinetic adaptations. None of the studies to date concurrently monitored stride rate and length along with strength and power of the lower limbs. This information is required to fully elucidate underlying mechanisms for any improvements in sprint speed. Based on the available data, the benefits and superiority of resisted sprint training have not been fully established.

Weighted jump squat training was found to increase vertical jump height, but elastic resisted jump squat training was not shown to increase vertical jump height. Although weighted jump squat training was found to increase vertical jump height, it was no more effective than plyometric depth jump training was. Acute power output from jump squats has been found to be maximized when there is no additional load and resisted jump squats actually generate less power out. This implies that resisted jump squat training may not be as effective as normal, unresisted vertical jump training and that this could be the case when the concentric phase is resisted, which occurred in all but one of the resisted jump squat training studies. A promising area worthy of further research because of the superior results for elite jumpers is loaded eccentric countermovement jump squat training with unloaded concentric phase and eccentric landing. The findings of this study need to be replicated by others, and more evidence from prospective studies is required before resisted jump training can be claimed to be superior to other forms of jump training. At the moment, caution should be exercised when promoting the benefits of resisted jump training.

Practical Applications

Resisted sprint training can be used to increase sprint speed. Resisted jump training can be used to increase vertical jump height. Consideration should be given to the inclusion of resisted movement training in athletic activities where sprinting and jumping are important because it may provide a novel training stimulus that results in positive adaptations. If resisted movement training is to be included in the overall training program, it would be advisable to adopt the training protocols used in the studies that demonstrated the superiority of resisted training for sprinting (10) and jumping (23). Although resisted movement training has been shown to increase sprint speed and jump height, it has not always been shown to be superior to unresisted forms of training, and caution should be exercised when stating the advantages of resisted movement training until more supportive evidence is generated.

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