Isometric Strength and Its Relationship to Dynamic Performance: A Systematic Review

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Abstract

Study Design: Systematic Literature Review
Objective: 1) to identify the overall trends of association of isometric strength and dynamic activities 2) to summarize the findings of reported literature on the relationship of Isometric strength and dynamic performance.
Background: Isometric Strength measures have been used for many years to predict dynamic performance but there are considerable controversies regarding the potential of isometric muscle assessments to predict dynamic performance. Although researches have been conducted to study the relationship, it is important that the current available literature be reviewed to summarize the findings for clinical use.
Methods: A systematic review was conducted to identify the published studies that correlated the Isometric and dynamic variables. Studies were searched using electronic databases and the methodological quality of each study was assessed using the modified Downs and Black 13 point criteria.
Results: Fifteen studies met the inclusion criteria. Marked difference in the methodology and variables used for isometric and dynamic activities were observed. Most studies correlated isometric strength assessments to dynamic activities or dynamic strength measurements.
Discussion & Conclusion: Although there are conflicting opinions regarding the use of isometric measurements, most studies in our review report moderate to strong correlation between Isometric strength and dynamic performances specially those which involve large amounts of force and explosive power.

Keywords: Isometric, dynamic, strength, power, performance, methodological quality

Introduction

Strength is a fundamental quality necessary in achieving optimal physical function and is defined as the ability to produce more force.(Siff M; Stone MH et al., 1993). Thus the display of strength has characteristics which include a magnitude, rate and direction. The force production can be measured by isotonic, isometric or isokinetic methods. The isotonic techniques require lifting a particular weight through a fixed number of repetitions such as 1RM testing or using prediction equations *(Bryzcki, 1993).* The Isokinetic measurements involve the use of isokinetic devices. The isometric testing is done by a maximal voluntary contraction performed at a specific angle against an unyielding resistance which in series with a strain gauge, cable tensiometer, force platform or similar device whose transducer measures the applied *force (Stone et al., 2002).*

In dynamic activities such as sports, if greater strength makes a difference then the stronger teams should perform better. Sports requiring rapid directional changes and acceleration or movement sequences primarily depend upon average power production but activities such as jumping, sprinting, and weightlifting may depend a lot on peak power *(Garhammer, 1993; Thomas et al., 1996; McBride et al., 1999; Kauhanen et al., 2000).* It can be argued that peak power depends to great extent on maximal strength. Therefore, it might be expected that maximum strength would have a greater effect in sports in which relatively larger loads have to be overcome *(Stone et al, 2002)* such as throwing events and American football.

Isometric assessment of muscle function have been used in exercise science for over 40 years and often both maximal force and rate of force development are recorded *(Wilson & Murphy, 1996).* These tests have shown high reliability in both single and multijoint test protocols *(Murphy & Wilson, 1996; Wilson & Murphy, 1996).* Isometric tests are easy to perform as they require only a single maximal contraction and relatively simple equipment. In spite of the potential clinical relevance of measurement of isometric strength, there appears to be considerable controversy regarding the use of isometric assessment and the ability of these tests to monitor changes in dynamic performance.

Therefore the purpose of this review is 1) to identify the overall trends of association of isometric strength and dynamic activities 2) to summarize the findings of reported literature on the relationship of Isometric strength and dynamic performance

Methods

Inclusion and Exclusion Criteria

Peer reviewed publications that studied the association between Isometric Strength of muscles and its association with dynamic tasks were included. Non - peer reviewed articles and invited clinical commentaries in professional magazines were excluded. The inclusion criteria required that the subjects were measured for their Isometric strength and for performance of a dynamic task which involved similar muscles and a correlation was done between the two.

Literature search

The electronic literature search was done using databases such as Pub MED, CINHAL, and MEDLINE. "Isometric Strength", "Isometric muscle assessment/testing" were used as key words for the search combined with other keywords such as "dynamic activities", "dynamic performance", "Isotonic" and "Isokinetic". Various abstracts obtained from the search were scrutinized as per our inclusion criteria. Full texts of these articles were obtained from various electronic databases and libraries. Help of colleagues in different universities was also taken for obtaining some articles which were not available in libraries accessible to the authors.

Assessment of Methodological Quality

The methodological quality of each study was assessed independently using the Downs & Black revised checklist for measuring study quality which is appropriate for non randomized controlled trials *(Downs & Black, 1998; Santamaria et al., 2010).* The checklist has good test-retest reliability (r=0.88) and inter-rater reliability (r=0.75). Only the criteria relevant to assessing potential sources of bias in randomized control trials were applied leading to a modified checklist of 13 items with a maximum score of 13.

Results

The literature search from various sources yielded more than 80 articles. Following the deletion of duplicate articles and analyses of abstracts and titles as per the inclusion and exclusion criteria, only 21 studies were considered for the review. The full texts of these studies were analyzed for the detail content and only 15 studies were finally included in the systematic review.

<u>Study Quality</u>

Table 1: Assessment of Methodological Quality of Study

Downs & Black Criteria	*McGuigan et al (2010)*	*McGuigan et al (2008)*	*Requena et al (2009)*	*Stone et al (2004)*	*Kraska et al 2009*	*Cuhna et al (2007)*	*Stone et al (2003)*	*McGuigan et al (2006)*	*Lord JP et al (1992)*	*Folland et al (2005)*	*Murphy & Wilson (1996)*	*Aleksander et al (2009)*	*Merek Guy et al (1996)*	*Khamoui et al (2011)*	*Nuzzo et al (2008)*
Item 1. Clear Aim	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Item 2. Outcomes described	+	+	+	+	+	-	-	+	+	+	+	+	-	+	+
Item 3. Subjects described	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Item 4. Interventions described	+	+	+	+	+	-	-	+	+	+	+	+	+	-	+
Item 6. Main findings clearly described	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Item 7. measures of random variability	+	+	+	+	+	-	+	+	+	+	+	+	-	-	-
Item 10. reporting of probability variables	-	-	+	+	-	-	+	-	-	+	-	+	-	-	-
Item 11. Subjects asked representative of entire population	+	-	+	-	+	+	+	+	-	+	-	-	+	+	-
Item 12. Included subjects representative of entire population	+	+	+	-	+	+	+	-	-	+	-	-	+	-	-
Item 16. Planned analysis	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+
Item 18. Appropriate statistics	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
1Item 20. Accuracy of outcome measures	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Item 22. Power calculations	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-
TOTAL SCORE	**11**	**10**	**12**	**11**	**10**	**8**	**10**	**10**	**9**	**12**	**9**	**10**	**8**	**9**	**8**

Following application of the modified Downs and Black checklist *(Downs & Black, 1998; Santamaria et al., 2010),* a mean score of 9.9 (with a minimum of 8 and a maximum of 12) was obtained. The findings of the methodological assessment are listed in Table 1. Some studies only reported p < .05 and did not mention the exact p values. Also only two studies out of a total of 15 performed priori power calculations. In 3 studies the interventions were not clearly described probably because the interventions used were well established and commonly used procedures.

Participants

In the studies reviewed, a total of 569 participants were evaluated with age ranging from 13.72 $\pm$ 3.14 to 32.9 $\pm$ 9.2 and were behaviorally ranging from healthy active individuals (non-sportspersons) to professional sportspersons.

Variables Used For Finding the Relationship

Isometric Measurements

Isometric Mid Thigh Pulls

Isometric strength assessment testing using the isometric midthigh pull exercise (Peak Force-PF) was observed to be one of the most commonly used Isometric test in various researches included in our review *(Stone et al., 2003; Stone et al., 2004; McGuigan et al.,2006; Winchester, 2008; Kraska et al., 2009; McGuigan & McGuigan et al., 2010).* Vertical ground reaction force data were collected using a force platform. Subjects were instructed to pull on the immovable bar (performed in a power rack with pins) as quickly as possible and were required to maintain effort for 5 seconds. It has been suggested that instructions stated as ‘‘hard and as fast as possible’’ produce optimal results for recording maximal force and Rate of Force Development RFD. The knee angle was adjusted to 130^0 (extended leg = 180^0). The subjects were required to maintain this knee angle throughout the duration of the trial *(Bemben et al., 1990; Sahaly et al., 2001; Haff et al., 2005)*. After the warm-up, subjects performed three 3-second long maximum isometric mid-thigh pulls inside a power back while standing on a force plate.

Isometric Strength of isolated muscles

Isometric Maximal force of the Knee extensor muscles with the knee and hip angles equal to 90 and 110 degrees, respectively were used by *Requena et al (2009)* in their study. The unilateral knee extension isometric force of the dominant leg was recorded by standard calibrated strain-gauge transducer.

Lord et al (1992) measured the Isometric Peak force of knee extension and flexion on an Isokinetic Rehabilitation System at velocities of 0 degrees, 60 degrees, 120 degrees, and 180 degrees/sec.

A standard variable resistance leg extension machine (Cybex VR2) was adapted for isometric Work in one study *(Folland et al, 2005)*. The participants completed four sets of 10 repetitions of 2s duration, with one set being completed at each of four angles of knee flexion: (50^0, 70^0, 90^0 and 110^0). The other leg was trained for isokinetic strength for 9 weeks. After 9 weeks of training the strength was compared in both lower limbs.

Isometric Squats

In the study conducted by *Nuzzo et al (2008)* an isometric squat force was measured at, a knee angle of 140^0 because this angle is closely associated with maximal force when assessing isometric squats at various knee angles. Following the test administrator’s verbal instruction, subjects pushed with maximal effort as quickly as possible against the immovable bar that was located on their shoulders

Isometric Bench Press

Aleksander et al (2009) performed the measurement of maximal muscle strength and Rate of Force Development under isometric conditions on specially designed isometric equipment. The subjects were tested in the bench press machine while the bar with a dynamometer was placed in two different positions. In the first position, the bar was fixed at a 2-5cm distance from the chest and in the second position the bar was fixed at a 30-50 cm distance from the chest, depending on the position where the elbow joint angle was 135º (180º full extensions). These two positions represent critical spots during the bench press.

Murphy and Wilson (1996) performed similar isometric tests at two joint angles and examined their relationship to dynamic performance. In addition, electromyography data were collected from the triceps brachii and pectoralis major muscles to compare underlying neural characteristics between the isometric tests and dynamic movement which was a seated medicine ball throw. The subjects in this study performed two isometric tests in a bench press position, at elbow angles of 90 and 120 degrees.

In a study conducted *by Guy et al (1996),* strength was determined isometrically for right and left grip, back pull, and leg lift. Total strength was calculated as the sum of the four measurements. Relative strength was calculated by dividing total strength by body weight.

Dynamic Strength Variables

The isometric strength was correlated to a variety of dynamic variables in the studies included in our review. It was observed the dynamic variables studied could be divided into two types-those which measured the dynamic strength or power directly and those which were activity related such as running, jumping and cycling.

1 RM Squats

The 1RM for the back squat was used as measure of dynamic strength using free weights in a study by *Murphy and Wilson (1996).* The squat exercise required the subjects to rest the bar on their trapezius and was performed to the parallel position, which was defined as when the greater trochanter of the femur was lowered to the same level as the knee. The subjects then lifted the weight until their knees were fully extended. 1RM, maximal peak power output (MPP), and the peak power attained with an external load equivalent to the 50, 75, 100, and 125% of the body weight were also tested in half-squat exercise *by Requenna et al (2009).* These variables were measured by means of 2 different half-squat tests.

Nuzzo et al (2008) used similar 1 RM squats but they were performed so that the depth corresponded to a 70^0 knee angle.

Bench Press (1RM)

The bench press was used as an assessment of upper body strength by *McGuigan et al (2010)* and was performed in the standard supine position. The subjects lowered the bar to midchest and then pressed the weight until the elbows were fully extended. No bouncing of the weight was permitted. For estimation of the subjects 1RM *Aleksander et al (2009)* used a regression equation *(Bryzcki, 1993).* The formula permits one to "assess muscular strength in a safe, efficient manner, without requiring subjects to attempt maximum lifts.

Isokinetic Measurements

Isokinetic knee extension and flexion strength was measured in some studies. *Lord et al (1992)* measured quadriceps isokinetic strength at velocities of 0 degrees, 60 degrees, 120 degrees, and 180 degrees/sec. Isokinetic strength Knee extension strength was also measured at three velocities by *Folland et al (2005)* and correlated the values with Isometric strength.

Dynamic mid thigh pulls

Dynamic midthigh pulls begin at a position identical to the isometric position: dynamic pulls were finished with a simultaneous maximum effort shoulder shrug and plantar flexion *(Stone et al, 2003).* This method (midthigh pulls) of assessing Peak Force and Peak power was chosen because it was a movement position used in training. Previous research has established its potential usefulness as a test, and the positions (hip and knee angle) achieved in the test and the explosive nature of the tests is similar to that of critical aspects and positions of weightlifting and throwing movements

(Lanka, 1982; Bartonietz, 1996; Bartonietz, 2000; Lanka et al, 2000). Dynamic force-time variables were also obtained from a mid-thigh high pull by *Khamoui et al (2011).* Velocity-time parameters (peak velocity, rate of velocity development) were derived from 2 different dynamic activities: the mid-thigh high pull with a 30% IsoPF load and the vertical jump.

Dynamic Performance Variables

15meter sprint time (Requenna et al., 2009) was measured using photocells at the start and finish lines. The players performed 20 minutes of individual warm-up including several accelerations.

Cycle power (WPP) was measured using a modified (18 second) inertia-corrected Wingate protocol *(Stone et al, 2004).* The test was conducted using a pan-loaded cycle ergometer equipped with competition racing handlebars, saddle, and chain. The test ergometer was configured to the exact dimensions (saddle height, headset height, and saddle-to-headset distance) as that of the athlete's competition cycle. Wheel revolution was determined using an optical sensor. The measurement time (18 second) was chosen due to the similarity with riding time for a 250-m standard velodrome sprint.

Track Cycling Times Times for a 1-lap (333- m) maximum-effort sprint were measured by *Stone et al, (2004)* using a custom timing gate system.

Sprint times. For the 60m run *Cuhna et al (2007)* used video footage collected from a digital video camera images. The subjects ran over the entire 60m start from a standing position, with out spike shoes. 40-yd dash timing was also used by *Guy et al (1996).*

Vertical Jump. Vertical jump height was measured using two types of jumps *(Requenna et al, 2009)* - Squat Jump SJ and Countermovement Jump CMJ. In the Static Jump upon stepping onto the force plate, athletes were instructed to get in the "ready position," which consisted of assuming a squat position with a 90° knee angle measured with a handheld goniometer. Once in position, a countdown of "3, 2, 1 Jump" was given. A 3-s hold of the bottom position was used to eliminate the involvement of the stretch-shortening cycle *(Nuzzo et al, 2008).* Countermovement jumps were performed without a pause to a self-selected countermovement depth.

Kraska et al (2009) in their study performed the same jumps in weighted situations also using PVC pipe (0 kg) or barbell (20 kg) and assuming a squat position with a 90° knee angle measured with a handheld goniometer. Once in position, a countdown of "3, 2, 1 Jump" was given. A 3-s hold of the bottom position was used to eliminate the involvement of the stretch-shortening cycle *(Cuhna et al, 2007).* As a part of the vertical jump testing, vertical jump Peak velocity**,** vertical jump Height and vertical Jump rate of force development were also studied by *Khamoui et al (2011)* and correlated with isometric strength characteristics.

Broad jump

Standing broad jump was measured via a tape measure. Subjects were required to stand with their toes behind the zero point of the tape measure prior to jumping *(McGuigan & Winchester, 2008).* Subjects were not allowed a preparatory step of any kind but arm swings were allowed at the discretion of the subject. Distance was determined measuring the point at which the heel of the trail leg touched the ground.

Anaerobic power was measured using Lewis power jump (LPJ), standing long jump (SLJ), Margaria-Kalamen stair run (M-K)

Aerobic power was assessed from a VO_2max test predicted from two 6-min bicycle ergometer rides. Heart rate was taken during the last two minutes of each ride, and the rides were separated by a 48-hr recovery period. No correlation was found with Isometric tests *(Guy et al, 1996)*.

The other dynamic characteristic which were studied and compared with Isometric characteristics were - Sport-specific explosive strength tests such as Power snatch (SN), the Shot-put (SP) and the Weight throw (WGT) *(Stone et al, 2003).*

Table 2: Summary Of Study Design Features

Study	Participants Characteristics	Isometric force measurements	Dynamic activity/ strength test	Results
McGuigan et al (2010)	26 active males Age 22 ± 1 years Participating in regular exercise programs	Peak Force using mid thigh pull exercise	1 RM for back squat and bench press Vertical jump	r = 0.97 r = 0.70
McGuigan et al (2008)	22 male Age 18.4 ± 0.7 years NCAA Division 1 footballers	Peak Force using mid thigh pull exercise	1 RM for back squat and bench press and power clean Vertical jump Broad jump	r = 0.61-0.72 No correl-ation No correl-ation
Requena et al (2009)	21 males Age 20 ± 3.8 years Soccer players	Isometric muscle force (MF) of knee extensors (IMF) and Plantarflexors (PF)	1 RM Isokinetic Peak Torque Vertical Jump SJ CMJ Sprint Performance	Iso MF was significantly correlated to Vertical Jump height IMF was not correlated with sprint time IMF was moderately correlated to half squat measures Isokinetic peak torque was not correlated to IMF and half squat
Stone et al (2004)	30 male cyclists for Part 1 (Age 30 ± 7.53) 16 male and 4 female for Part 2 (32.9 ± 9.2) International .	Isometric mid thigh pull on a custom made isometric rack (IPF)	Power tests Track Cycle times (in low gear and high gear)	All correlations between IPF and dynamic /power performances were significant
Kraska et al (2009)	41 females and 22 males Age 19.9 ± 1.3 years Collegiate athletes	Isometric mid thigh clean pulls	Countermovement Jump (CMJ) Static Vertical Jump testing (SJ)	R = 0.36 R = 0.40
Culhna et al (2007)	72 subjects (athletes 14.05 ± 1.58; non athletes 13.72± 3.14 years)	Isometric Leg press	60 m sprint run Static Jump Countermovement jump Drop Jump Horizontal jump	R = - 0.716 R = 0.696 R = 0.674 R = 0.652 R = 0.793
Stone et al (2003)	5 males and 6 females Age 18-21 years Collegiate throwers	Isometric mid thigh pulls(IPF) close to training positions (knee 135-145 deg)	Dynamic peak force (PF) Peak power(PP) 1 rep movement power snatch (SN) Throwing ability (WGT)	R = 0.92(at 60% of IPF) R = 0.87(at 60% of IPF) R = 0.94 0.79
McGuigan et al (2006)	88 males Age 20.0 ± 0.4 years NCAA div II wrestling team	Isometric mid thigh pull exercise	1 RM Power clean 1 RM Squat 1 RM Vertical jump	R = 0.73 R = 0.97 R = 0.96 No correlation reported
Lord JP et al (1992)	20 males	Isometric Peak Torque (PT) of Knee extensors and flexors	Is kinetic measurement of the Knee extensors and flexors Angular velocity on joint angle at peak torques (JAPT)	R = 0.88-0.93 R = 0.48- 0.52 (only for 60 deg & 180 deg per sec)
Folland et al (2005)	33 recreationally active males Age 18-30 years	Isometric Quadriceps strength TRAINING & measurements at 4 angles in one lower limb	Isokinetic quadriceps strength TRAINING at 3 velocities in other limb	Increase in Isokinetic strength was similar in two groups (intra-individual design)

Murphy & Wilson (1996)	24 healthy male subjects	Two isometric tests in bench press positions At elbow angles of 90 & 120	Seated Medicine Ball throw distance	R = 0.47 -0.55
Aleksander et al (2009)	22 males Age 21.5 ± 1.75	Max Force in a bench press action (isometric)	1 RM bench press using Matt Bryzki equation in Initial position Final position	 R = 0.16 R = 0.33
Merek Guy et al (1996)	86 men Age 19.5 ± 1.6 Enrolled in fitness classes	R grip L grip Back Pull Leg lift	Vertical Jump Lewis Power jump Standing Long jump Margaria kalamen Stair run 40 yard dash	All strength measurements had significant but low relationships with power measurements
Khamoui et al (2011)	19 recreationally trained men Age 23.89 ± 2.92 years	Isometric PF(mid thigh pulls) Isometric mass adjusted PF(IsoPF/BM)	High pull peak velocity (HPPV) Vertical Jump (VJPV)	HPPV, VJ height & VJ peak velocity had significant relationship with Iso peak force/BM
Nuzzo et al (2008)	12 male athletes Age 19.83 ±1.40	Isometric PF(mid thigh pulls)	Countermovement Jump Squat and powerclean 1 RM testing	Isometric mid thigh Peak force was significantly correlated to Jump height Iso RFD was significantly correlated to Jump peak power

Discussion

Most of the studies we reviewed attempted to relate Isometric strength measures to dynamic strength measures or dynamic performances which required explosive power and speed. Although different studies have used different isometric measurements and dynamic variables, majority of researches have reported some relationship between the two. Most of the studies measured the isometric strength of various muscles in group action such as mid thigh pull *(Stone et al, 2003; Stone et al, 2004; McGuigan et al, 2006; Kraska et al, 2009; McGuigan & Winchester, 2008; McGuigan et al, 2010),* Isometric bench press *(Murphy & Wilson ,1996; Aleksander et al, 2009)* and Isometric squat *(Nuzzo et al, 2008).* Very few studies measured isolated isometric strength of muscles and related it to dynamic activity *(Lord et al., 1992; Folland et al., 2005; Requenna et al., 2009).*

The dynamic variables studied could be divided into two types-those which measured the strength/power directly and those which were activity related such as running, jumping and cycling. The studies that measured dynamic strength utilized either 1 RM methods or Isokinetic measures (Table 2)

Amongst the Isometric measures studied, the midthigh pull was the most commonly used method to assess Isometric strength and was found moderately to strongly correlated to dynamic tasks such as Vertical jump, Power tests, Track Cycle times, Countermovement jump testing(CMJ) and 1 RM testing *(Stone et al., 2004; Kraska et al., 2009; McGuigan et al., 2010).* The significant correlation between mid thigh pull and dynamic variables such as Track cycle times and Throwing ability is interesting to note as the latter are speed and power related activities. This is in contrast to the findings of Wilson and Murphy, 1996 who reported that power and speed related activities are not correlated with Isometric activities It is also noteworthy that Isometric strength was found to be related to isokinetic measurements in a study done by *Lord et al (1992).* Another study conducted by *Folland et al (2005)* highlighted that after Isometric training in one leg and Isokinetic in the other leg of same subjects, 9 weeks later the isokinetic gains were similar in both legs. However conflicting results were reported by some researchers *(McGuigan et al., 2006;*

McGuigan & Winchester, 2008; Aleksander et al., 2009).

Isolated muscles were also measured in some studies reviewed. In only one study, aerobic activity was also measured and correlated with Isometric strength but was found to have insignificant correlation *(Guy et al, 1996).* Aerobic activity has completely different physiological mechanisms and it is understandable that no correlation was found between the two.

Conclusion

In spite of some conflicting reports on the subject, most studies included in our review indicate that Isometric strength and its testing has a strong potential to predict dynamic capabilities in activities involving strength and explosive power. Although, it would not be incorrect to comment that many dynamic power related activities have strong relationships to techniques and skill also. Many of the studies were done on skilled sportspersons and Isometric strength was still found to be correlated to force and explosive power activities. Therefore the use of Isometric strength assessments appears to be justified and can play an important role in assessments to predict dynamic performance of a particular type.

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