Practical applications of an optimized plyometric training
– an overview

Thesis

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Abstract

Plyometric training has always been a topic of interest in terms of sport performance enhancement and development. The most relevant and up-to-date data has been reviewed to try to answer the question “what kind of plyometric training to use” to improve ones’ performance. The present study demonstrates the use of reactive strength index (RSI) and force-velocity profiling. In the text there is also a presentations of common jumping tests that help practitioners to establish a profile of an athlete. Main findings of this study are: general strength should be developed alongside reactive strength qualities, plyometric training optimized and guided by RSI is highly effective in improving reactive strength ability, demands of a sport determine the manner in which plyometric exercises should be performed, RSI can be used as a representation of neuromuscular fatigue, force-velocity (F-v) approach may help improve the training practice for performance in explosive push-off actions like jumping, through a more efficient monitoring and understanding of the individual determinants of athletic performance, showing the sensitivity of the F-v profile to specific training programs can result in either maximal force or velocity capabilities improvements (determination of F-v imbalances or $F_{V_{imb}}$) – which is termed “optimized training” and it has been found that an optimized and individualized training program specifically addressing the $F_{V_{imb}}$ is more efficient for improving jumping performance than traditional resistance training.

Keywords: plyometrics, stretch-shortening cycle, explosive performance, ballistic training, reactive strength index
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Preface

I have written this essay as an attempt to create a source that covers most up-to-date information in terms of improving jumping performance, which is one of the most basic, but most important aspects of an athletic performance. I wanted to create an overview of the theory behind it and connect it with the recent practical research to create some guidelines for everyone interested in the plyometric training and jumping performance. I would like to express my appreciation to my friend and colleague Miha Drobnič, to one of the pioneers of vertical jump training – S&C coach Kelly Baggett for all his help and useful information and my mentor professor Anna Hafsteinsson Östenberg for all her help with this paper.

Stockholm, den 13 april 2017
Introduction

During most sport situations, there is limited time to develop force and the capability to rapidly develop force is therefore of paramount importance for successful sport performance (Van Hooren et al. 2017). In strength and conditioning, or for performance enhancement, plyometric exercise should play an integral part of the exercise program (Davies et al. 2015). So it is essential that every training aspect is done as efficiently in the limited time frame that is available to athletes and everyone involved in their development. Advancements in strength and conditioning methodologies alongside evolution in physical demands of competition sports such as rugby, football, volleyball, or athletics, have led to an increased relevance of high-intensity, ballistic actions. Physical performance in these kinds of sports is clearly determined by high levels of force, power, and velocity during ballistic movements such as sprints, changes of direction, or jumps (Croinin & Sleivert 2005; Cormie et al. 2010, cited in Jimenez-Reyes et al. 2016).

Plyometrics or Shock Method

A thorough discussion of what is meant by the term plyometrics is essential, because one must distinguish clearly between plyometric actions, which occur as part of many running, jumping, hurdling, striking and other rebounding movements in sport, and plyometric training, which applies plyometric actions as a distinct training modality according to a definite methodology. The increase in popularity of plyometrics deems it necessary that the concept be more rigorously defined. Plyometrics or the ‘shock method’ means precisely that - a method of mechanical shock stimulation to force the muscle to produce as much tension as possible. Verkhoshansky and Siff have always consistently favoured the use of the term ‘shock method’ instead of ‘plyometrics’ to distinguish between naturally occurring plyometric actions in sport and the formal discipline he devised as a discrete training system to develop speed-strength in particular. This is why the term ‘powermetrics’ has been suggested to refer to plyometric training, as opposed to plyometric actions which occur quite naturally in many natural ballistic movements (Verkoshansky & Siff 2009). The earliest published use of the word plyometrics seems to have been in a Soviet publication (Zanon 1966, cited in Verkoshansky & Siff 2009).

This (plyometric or shock) method is characterised by impulsive action of minimal duration between the end of the eccentric braking phase and initiation of the concentric acceleration phase. It relies on the production of a very brief explosive isometric and eccentric-isometric phase which precedes the release of the elastic energy stored in the tendons and other components of the serial elastic component of the muscle complex during the eccentric deceleration phase. If the transition phase (or, coupling phase) is prolonged by more than about 0.15 second, the action may be considered to constitute ordinary jumping and not classical training plyometrics. A useful visualisation is to imagine that the surface being touched by the hands or the feet during the plyometric contact phase is red hot, so that any prolonged contact would be dangerous (Verkoshansky & Siff 2009).

It is important to note that the activity is not accurately plyometric if the athlete relies upon ongoing feedback processes to control the isometric and concentric actions instead
of upon feedforward programmes established before any movement begins. True plyometric training usually involves ballistic rather than cocontraction processes, a concept discussed in the following pages (Verkoshansky & Siff 2009).

This paper could be an important contribution to all the strength and conditioning practitioners and coaches on how to approach the matter of plyometric training and how to improve athletic abilities of their athletes. There is quite a lot of research available on the topic of plyometric training, but not all of it represents a valuable and applicable research for practitioners so having the current, up to date, data in one place could be valuable and useful.

Background

In the following pages I will look into the definitions, mechanisms underlying the plyometric ability and related mechanisms. I will try to present all the theoretical background on the matter of plyometric training, look at the classical studies and the most recent research on the topic of plyometric training.

Reactive Strength

A loose definition of reactive strength is the ability to react effectively to forces placed on the body by the environment (e.g. ground reaction forces). Typically, this reaction is followed immediately with a coordinated movement utilizing powerful, concentric muscle action. Specialized jumping or plyometrics are exercises that target one’s ability to change quickly from an eccentric to concentric muscle action, commonly referred to as the stretch-shortening cycle (Enoka 1993). Reactive strength and the stretch shortening cycle are often defined synonymously (Flanagan et al. 2008a).

However, one’s ability to react effectively to environmental forces may be considered independent of one’s ability to subsequently produce a powerful concentric movement (Sheppard & Young 2006), as tasks that require a reaction may not always be followed with ‘explosive’ concentric actions (e.g. drop landings). Additionally, reactive strength should be broadly defined as ‘the ability to react to environmental forces placed on the body, since it is dependent on the integration of multiple biological systems (e.g. neuromuscular) and not specific to the mechanics of the musculotendinous unit (MTU)’ (Louder et al. 2015).

Reactive strength is a representation of the fast SSC function. It shows athletes’ ability to change quickly from an eccentric to a concentric contraction and their ability to develop maximal forces in minimal time. It has also been described as a measurement of stress on the calf/Achilles muscle/tendon system. A research study from Lockie et al. (2011) shows that the faster athletes had significantly shorter ground contact times from stride to stride in 10m sprints and greater reactive strength compared to slower ones. Reactive strength testing was the biggest differentiator between the slow and fast athletes across a range of tests and measures including the CMJ, bounding tests, and the 3RM back squat. The authors suggest that reactive strength qualities may help explain the lower ground contact times attained by the athletes with better acceleration in the short sprints. The quality of reactive strength translates into allowing faster athletes to be “able
to (tolerate) higher eccentric loads, and convert this into concentric force over a shorter period of time.” The application of more force in a shorter period of time is pure gold in terms of athletic performance.

As shown in research by Young et al. (2015) the reactive strength was correlated to player's change of direction (COD) ability. Those players who were faster in change of direction test demonstrated much higher reactive strength abilities (>25% difference) than slower athletes. Authors said that “reactive strength of the leg extensors is important for change of direction speed performance.” The push-off involved in rapid change of direction tasks involves a fast SSC muscle action of the hip, knee, and ankle leg extensors. So a conclusion to take from this is that training designed to improve acceleration and reactive strength may potentially transfer and enhance the change of direction speed performance, which is relevant to all sports that require COD speed.

Rate of force development (RFD) should also be mentioned. RDF is a measure of explosive strength, or simply how fast an athlete can develop force – hence the ‘rate’ of ‘force development’. This is defined as the speed in which the contractile elements of the muscle can develop force (Aagaard et al. 2002). Therefore, improving an athlete's RFD may make them more explosive as they can develop larger forces in a shorter period of time. Developing a more explosive athlete, may improve their sporting performance. In fact, higher RFDs have been directly linked with better jump (Laffaye et al. 2013, 2014; Haff et al. 2005; Kawamori et al. 2006; Nuzzo et al. 2008), sprint (Slawinski et al. 2010), cycling (Stone et al. 2004), weightlifting (McLellan et al. 2011; Haff et al. 1997) and even golf swing performances (Leary et al. 2012). The RFD is commonly believed to be manifested during the stretch-shortening cycle (SSC).

### Stretch-Shortening Cycle

The SSC is described as a rapid cyclical muscle action whereby the muscle undergoes a lengthening movement (“eccentric contraction”), followed by a transitional period prior to the shortening movement (“concentric contraction”) (Llody et al. 2012) - reverse action of muscles (Zatsiorsky & Kraemer 2006).

Commonly, the stretch-shortening cycle is ambiguously described as a stretch of the muscle followed by a phase of shortening. However, the elements of the muscle that stretch and shorten are not distinguished, and this can lead to incorrect interpretations. For example, it is often assumed that there is an eccentric action (i.e., active lengthening) of the fascicles of the leg muscles during the downward movement of the CMJ (van Hooren & Zolotarjova 2017). Although some studies indeed show that the fascicles lengthen during the downward phase of a CMJ, this lengthening is mostly passive and occurs primarily, but not exclusively in monoarticular muscles (Finni et al. 2000; Finni et al. 2001a; Finni et al. 2001b, cited in van Hooren & Zolotarjova 2017). Furthermore, studies also show a shortening of fascicles (Finni et al. 2001a; Kurokawa et al. 2003, cited in van Hooren & Zolotarjova 2017) or suggest an isometric action of the contractile element during the downward phase of a CMJ (Kopper et al. 2013; Kopper et al. 2014 cited in van Hooren & Zolotarjova 2017). Therefore, there is usually no active lengthening (i.e., eccentric action) of the fascicles during the downward movement of the CMJ. The fascicles may passively lengthen only during slowly executed, submaximal, and large-amplitude (i.e., deep countermovement) CMJs, thereby dissipating energy, whereas they remain isometrically or

Hence, it can be recommended that future research refers to the downward and upward phases rather than the eccentric and concentric phases of a counter-movement jump (CMJ) and avoids the use of terminology that refers to an eccentric phase. Furthermore, attributing the difference between the CMJ and squat jump (SJ) to an effective utilization of the eccentric phase and mechanisms occurring during eccentric muscle actions is problematic because there may be no eccentric phase during the CMJ. Instead, the better acute performance in the CMJ may be the result of other mechanisms (van Hooren & Zolotarjova 2016).

The CMJ is usually incorporated in training with the rationale of optimizing the stretch-shortening cycle or, more specifically, to improve the storage and utilization of elastic energy (van Hooren & Zolotarjova 2017). However, the findings of the review by van Hooren & Zolotarjova (2017), suggest that elastic energy has only a small contribution to the enhanced CMJ performance. It can therefore be questioned whether the capability to store and use elastic energy is effectively trained during a CMJ. Instead, CMJ training may decrease the capability to effectively create pretension and quickly build up stimulation because the athlete is not forced to create pretension and quickly build up stimulation as the countermovement reduces the degree of ‘muscle slack’ and allows more time to build up stimulation. Muscle slack is a new term proposed by van Hooren & Bosch (2016) and it describes the delay between the start of contractile elements’ contraction and Serial Elastic Element/Component (SEE) recoil. The CMJ training may therefore be detrimental to high-intensity sports performance, especially when performed without time-pressure.

**Mechanical model: Active State**

Among the older, classical studies there is a widespread agreement to suggest that the active state is the largest contributor to the performance enhancing effects of the SSC, as it allows for a greater build-up of force prior to concentric shortening (Bobbert & Casius 2005; Turner & Jeffreys 2010; Bobbert et al. 1996; Schenau et al. 1997). Muscles function in various sporting activities as force production generators, and eccentric decelerators/shock absorbers primarily due to the active and elastic properties within the muscles. These elastic proper ties form the mechanical basis of muscle mechanics and are due to the three structural components within the muscles: contractile components (CC), serial elastic components (SEC) and parallel elastic component (PEC). The active state is the period of time in which force can be developed during the eccentric and amortization phases of the SSC before any concentric contraction occurs (from the lowest point of the curve to the highest one). For example, during the ‘countermovement’ or ‘dropping’ action of the CMJ, the active state is developed during the eccentric and amortisation phases. It is commonly believed that exercises which possess longer eccentric and amortization phases of the SSC will allow more time for the formation of cross-bridges, therefore enhancing joint moments, and thus improving concentric force output.
Increasing the amount of force, and the time available for force to be developed, typically leads to a concurrent increase in the impulse (Impulse = Force x Time) (Schenau et al. 1997). In other words, increasing the force application will lead to improvements in power output and therefore athletic performance. But this must be understood in a context of an individual athlete and not universally accepted that this can be done to an extent.

**Fast and Slow SSC**

Schmidtbleicher (1992) has suggested that the SSC can be classified either as:

- **Fast-SSC**: contact time <250 milliseconds (0.25sec); short contraction times; small angular displacements of hips, knees and ankles (i.e. depth jump);
- **Slow-SSC**: contact time >250 milliseconds (0.25sec); longer contraction times; larger angular displacements (i.e. maximal effort vertical jump);

Although data from Flanagan (2007) shows that slow SSC actions such as maximal effort countermovement jumps generally produce ground contact/contraction times far greater than Schmidtbleicher’s (1992) threshold of 0.25 seconds and that the difference between slow and fast SSC activities is easily discernible.

**Table 1**: Stretch shortening cycle durations of common exercises.

<table>
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<tr>
<th>Exercise</th>
<th>SSC Duration in ms</th>
<th>SSC Classification</th>
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<tbody>
<tr>
<td>Race Walking (Padulo et al 2013)</td>
<td>270-300</td>
<td>Slow</td>
</tr>
<tr>
<td>Sprinting (Taylor and Beneke 2012)</td>
<td>80-90</td>
<td>Fast</td>
</tr>
<tr>
<td>Countermovement Jump (CMJ) (Laffaye and Wagner 2013; van Hooren &amp; Bosch 2016)</td>
<td>500-1000</td>
<td>Slow</td>
</tr>
<tr>
<td>Squat Jump (van Hooren &amp; Bosch 2016)</td>
<td>300-430</td>
<td>Slow</td>
</tr>
<tr>
<td>Drop Jump (20-60cm) (Ball et al. 2010; Walsh et al. 2004)</td>
<td>130-300</td>
<td>Fast / Slow</td>
</tr>
<tr>
<td>Long Jump (Stefanyshyn and Nigg 1998)</td>
<td>140-170</td>
<td>Fast</td>
</tr>
<tr>
<td>Multiple Hurdle Jump (Flanagan and Comyns 2008)</td>
<td>150</td>
<td>Fast</td>
</tr>
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The primary differences between the fast and the slow SSC are that the fast SSC involves a fast, short downward phase and a rapid transition between the downward and upward phase. The slow SSC is identifiable by a longer downward phase and a slower transition. As result much greater joint moments, power outputs and rates of force development are observed in fast SSC plyometrics. Alternatively, greater jump heights can be observed in slow SSC plyometrics due to the increased time allowed to develop force. Slow SSC plyometrics are also very useful coaching tools to teach athletes appropriate jumping and landing techniques before progressing to the more challenging fast SSC plyometrics.
Purpose

The purpose of this thesis is to provide an overview on plyometric training and how to practically apply the scientifically backed data. The overview includes the definitions of the terms, phases, the physiological mechanical and neurophysiological basis of plyometric based on scientific background. Another goal is to provide practical applications for practitioners on how to program and implement plyometric training to either improve athletic performance. I have briefly covered the underlying physiological and biomechanical mechanisms, the development of the plyometric training and attempt to answer what are the most optimal practical means used regarding the plyometric training, how to utilize them and improve ones’ jumping ability and in turn the sport performance.

This study is done as an overview of the most relevant research done in the field up to the present day. I wanted to answer the following questions:

- what are the underlying mechanisms of plyometric movement?
- what do different terms associated with the popular coaching term “explosive training” actually mean?
- how to establish a baseline for plyometric training and how to monitor improvements?
- what exercises to do to most efficiently improve jumping performance and how intensive should it be?
- how to create an optimal training plan to improve jumping performance?
- what kind of plyometric training to use to improve ones’ performance?

The most important question and its answer being the “how to”, meaning what kind of means to use to improve athletes’ plyometric ability, how to program it and how to make use of it in a particular sport or activity.
Methods

For this study the databases that have been searched are: MEDLINE (1966-May 2017), EBSCO (1944-May 2017) and ResearchGate (2008-May 2017). Terms used in the search engine were a combination of: plyometric OR pliometric OR stretch-shortening cycle OR drop jump OR depth jump OR jump training OR reactive strength OR ballistic movement OR reactive strength index AND force-velocity. Manual searches have also been conducted from relevant journals and reference lists obtained from articles. The following literature review studies published in journals that have presented original research data on healthy human subjects. No age, gender or language restrictions were imposed at the search stage. Abstracts and unpublished theses/dissertations were not excluded from this analysis but it is noted in the text that it is not a published source.

Inclusion criteria in this study was: (1) relevant to the topic of plyometric training and stretch-shortening cycle; (2) studies published in peer-reviewed journals (if not otherwise noted in the text); (3) age of material was important, but did not exclude some classical studies, which are older, from the review; (4) only articles with original versions in English language were reviewed; (5) land-based plyometric training studies which lasted >4 weeks.

All the information was obtained lawfully from databases or journals with available content and also all the information is accurately reported in the text.
Main Body

**Individualized Force-velocity profile**

At the beginning of the training design process it is important to establish the individual athletes’ profile. Numerous studies have highlighted neuromuscular power as the primary variable related to ballistic performance, yet this analysis only provides a partial representation of the athlete’s true maximal mechanical capabilities (Cronin & Sleivert 2005, cited in Jiménez-Reyes 2016).

Although ballistic performance such as jumping height is largely determined by maximal power output \( P_{\text{max}} \) that lower limbs can generate (Yamauchi & Ishii 2007, cited in Jiménez-Reyes 2016), it is also influenced by the individual combination of the underlying force and velocity mechanical outputs, known as force-velocity \( (F-v) \) profile (Samozino et al. 2012, 2014; Morin & Samozino 2016). Same authors also concluded that the goal in enhancing performance should always be to provide the most accurate and integrative mechanical representation of athlete’s maximal capabilities, so the inclusion of \( F-v \) relationship and their contribution to ballistic performance is essential. This relationship, encompass the entire spectrum, from the theoretical maximal force \( F_0 \) to the theoretical velocity \( v_0 \) capabilities. In studies by Samozino et al. (2008, 2012, 2014) It has been theoretically proven and experimentally confirmed that there is an optimal \( F-v \) profile for each individual. This is very important as that provides us with the information necessary to maximize the ballistic performance and it is a representation of the optimal balance between force and velocity for this movements. That could prove to be of utmost importance to all those who want to improve their ballistic performance to actually train towards the ability they are lacking and to specify the training of an individual even further. The relative difference between actual and optimal \( F-v \) profiles for a given individual represents the magnitude and the direction of the unfavourable balance between force and velocity qualities (i.e., force-velocity imbalance, \( FV_{\text{imb}} \% \)), which makes possible the individual determination of force or velocity deficit. The actual individual \( F-v \) profile and \( P_{\text{max}} \) can be easily determined from a series of loaded vertical jumps (Samozino et al. 2008, 2014; Jiménez-Reyes et al. 2014, 2016; Giroux et al. 2015, 2016), while the optimal \( F-v \) profile can be computed using previously proposed equations based on a biomechanical model (Samozino et al. 2012, 2014).

Some traditional training methods have been considered for power improvement, such as: power and ballistic training (e.g., Wilson et al. 1993; Newton et al., 1996 Cormie et al. 2007, 2010; Argus et al. 2011; Markovic et al. 2011; Sheppard et al. 2011; Zaras et al. 2013, cited in Jiménez-Reyes 2016), heavy-load training (focusing more on strength; e.g., Gorostiaga et al. 1999; Harris et al. 2000; Chelly et al. 2009; Rønnestad et al. 2012, 2016, cited in Jiménez-Reyes 2016) and combined training (strength-power training; e.g., Wilson et al. 1993; McBride et al. 2002; Kotzamanidis et al. 2005; Cormie et al. 2007, 2010; Smilios et al. 2013; Zaras et al. 2013, cited in Jiménez-Reyes 2016). This kind of global power training prescription similar for all athletes resulted in contrasting findings as to the effects on jumping performance (Wilson et al. 1993; Gorostiaga et al. 1999; Harris et al. 2000; McBride et al. 2002; Kotzamanidis et al. 2005; Cormie et al. 2007, 2010; Chelly et al. 2009; Rønnestad et al. 2012, 2016; Smilios et al. 2013; Zaras et al. 2013, cited in Jiménez-Reyes 2016), likely because of the various levels and \( F-v \) characteristics of the
populations tested. So to put the above stated F-v profiling in perspective, lack of such individualization and profiling could lead to improvement of $P_{max}$ but also increasing $FV_{imb}$ which could result in a lack of change, or even a decrease in jumping performance.

The relationship between reactive and maximal strength must also be observed. A study by Dymond et al. (2011) proved that there is a strong positive relationship between the reactive and maximal strength, which leads us to a conclusion that stronger athletes tend to demonstrate higher reactive strength. At the same time, we must be careful with the interpretation as only 40% of the variance of the reactive strength measure was explained by the maximal strength, leaving 60% of the not explained by, or associated with, maximal strength. They also examined the difference between lower (1.5 X BW back squat) and higher strength levels (1.9 X BW back squat) in the drop jump of different heights and found that stronger athletes produced moderately higher levels of reactive strength at the highest drop of 50cm. But this certainly does not mean that one should start with plyometric training only after they achieve 1.5 X BW in squat exercise, this is most certainly not a pre-requisite and plyometric training can be done much sooner, especially with younger athletes only familiarizing themselves with ballistic type movements.

**Plyometric Intensity**

Definition of plyometric intensity is the amount of stress the plyometric drill places on the muscle, connective tissue and joints involved. The intensity is usually determined by the eccentric loads involved and the time period in which the eccentric loads are applied.

When designing a plyometric training program some basic guidelines provided by the research of Ebben (2007) are: single leg plyometric exercise is more intense than the same bilateral one, fast SSC usually produce greater intensities than slow SSC due to shorter time period of force application resulting in greater loading rates, exercise that are being repeated have higher total stress than individual reps, the height of the drop or elevation to jump down from or up to is a very potent predictor of intensity, using arms in jumping exercise results in greater jump heights and as such greater landing stress.

So considering this we can put plyometric exercises into different categories based on intensity (Flanagan et al. 2008b):

- **Low intensity**: submaximal jumps & hops, concentric jumps, countermovement jumps (could be moderate intensity as well)
- **Moderate intensity**: tuck and pike jumps, drop jumps (could be high intensity as well)
- **High intensity**: fast SSC single-leg jumps

**Reactive Strength Index**

Reactive strength is assessed primarily through the Reactive Strength Index (RSI). Reactive strength index is derived from the height jumped in a depth jump, and the time spent on the ground developing the forces required for that jump. Using a contact mat during a depth jump exercise, one calculates the RSI by dividing the height jumped by the time in contact with the ground before take-off (Flanagan et al. 2008b). It is a simple ratio in-
volving two metrics: *jump height and ground contact time*. The index is calculated by di-
viding the height jumped with the ground contact time. The RSI can be improved by in-
creasing jump height or decreasing ground contact time, or both.

The RSI has been described by Young (1995) as an individual’s ability to change quickly
from an eccentric to concentric contraction and can be considered as a measure of “explo-
siveness.” Explosiveness is a coaching term that describes an athlete’s ability to develop
maximal forces in minimal time (Zatsiorsky & Kraemer 2006).

The RSI also has been described as a simple tool to monitor stress on the muscle–tendon
complex (McClymont 2003). Thus far, RSI has been used primarily during plyometric ac-
tivities such as depth jumps, which have a distinct, observable ground contact phase.
Depth jumps are one of the most commonly used and most commonly researched plyom-
eetric exercises (Walsh et al 2004). In the depth jump, the athlete drops from a fixed height
and immediately upon landing performs an explosive vertical jump (Walsh et al 2004).
Because the RSI is a ratio between ground contact time and height jumped, both these
variables need to be considered in conjunction with the overall RSI score. The ground
contact times in plyometric exercises are an important variable to consider. By examining
the ground contact times during the performance of a plyometric exercise, the type of SSC
(fast or slow) can be determined (Walsh et al. 2004).

There are a few benefits of measuring the RSI as it is shown in the study by Flanagan et
al. (2008a). The first one is the ability to optimize the height from which plyometric depth
jumps can be performed from both a performance and injury risk perspective, secondary
benefit is the monitoring of ground contact times can provide a quick reference to indi-
cate plyometric exercise specificity. As if we disregard the RSI and use too great a depth
jump height in plyometric training can reduce the specificity of the athletes training, de-
crease performance, and be deleterious to athlete safety. A key contribution of reactive
strength is to allow impulse generated at the hip and knee to be effectively transmitted
into the ground. For many athletes, it doesn’t matter how strong or powerful they are at
the hip/knee, if they have poor ankle joint integrity and they “leak” force on ground con-
tact. However, the reverse can also be true. Continually targeting reactive strength de-
velopment in athletes with poor hip/knee strength and power may result in diminishing
transfer of training. Always when strength and conditioning practitioners design a pro-
gram they must look into the specific demands of a sport and tailor the plyometric pro-
gram to it.

*Neuromuscular fatigue and RSI*

Hamilton (2009) researched the use of reactive strength as a neuromuscular fatigue
monitoring tool, he examined the response of RSI (via a drop jump test) during tourna-
ment match play in youth soccer players. He found significant reductions in reactive
strength across the 4-game tournament in players who had high playing time were found.
His research study also suggested that reactive strength monitoring may be sensitive
enough to detect disruptions in neuromuscular function in response to extensive travel
demands and further highlighted the usefulness of RSI as a monitoring marker: it is sim-
ple, reliable, repeatable and can be performed anywhere, which is a key consideration for
teams spending much time “on the road”. The RSI seems to respond to training loads and
can be used to potentially highlight athletes who may be close to overtraining.
Testing

In this part I will examine some common tests of reactive strength index. RSI can be measured either in a single drop jump with maximal effort or in repeated hopping and jumping tasks. There are pros and cons to each, so the practitioners must look into the time available, number of athletes and depth of data required.

**The Incremental DJ-RSI test**

The incremental DJ-RSI involves an athlete performing a drop-jump on a contact mat or force platform. The test measures how an athlete copes and performs during plyometric activities by measuring the muscle-tendon stress and their reactive jump capacity (Flanagan et al. 2008b). It demonstrates an athlete's ability to rapidly change from an eccentric motion into a concentric muscular contraction and is an expression of their dynamic explosive vertical jump capacity (Young 1995).

One of the primary issues with the incremental DJ-RSI test is the duration of the ground contact time of the test used. For example, the ground contact time during the DJ can range between 130-300ms (Walsh et al. 2004; Ball et al. 2010). As the ground contact time of many sporting movements can be significantly less than this, there is a concern regarding the tests ability to actually measure sport-specific reactive strength.

**The Rebound Jump Test**

The rebound jump test (RJT) offers a quick and simple alternative to the incremental DJ-RSI test. We are assessing the same reactive strength quality although possibly at a lower intensity of eccentric loading. In the rebound jump, the athlete performs a single countermovement jump, but upon landing immediately jumps again. In this second jump, the rebound jump (RBJ), the athlete's aim is to minimize ground contact time, jump high and use a “stiff” ankle-dominant jumping action to recruit the fast stretch shortening cycle. The RBJ proved to be quick, easy and reliable (Flanagan 2007).

In an unpublished study by Flanagan, they explored the difference between the RBJ and the incremental DJ-RSI test with elite academy rugby players (19-21 years old). Results showed that the rebound jump produced very similar RSI scores compared with drop jumps, however it did not produce as high an RSI as the “optimal” drop height identified by the incremental DJ-RSI process.

**The 10/5 Reactive Strength Index Test**

Last option to test is the 10/5 RSI Test, since the majority of running based sports are heavily dependent on an athlete’s ability to repeatedly produce efficient fast SSC actions. Here an athlete performs a single countermovement jump but upon landing immediately transitions into a series of 10 repeated, bilateral hops. The 5 jumps with the highest reactive strength indices are averaged together for a total score (Harper 2011).
RSI testing options and its characteristics are shown in Table 2 below:

**Table 2: Reactive-Strength Index Testing Options.**

<table>
<thead>
<tr>
<th>DJ-RSI Test</th>
<th>RBJ Test</th>
<th>ID/5 Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most time consuming</td>
<td>Less time consuming</td>
<td>Least time consuming</td>
</tr>
<tr>
<td>High intensity of the test</td>
<td>Intensity individualised by the athlete</td>
<td>Intensity individualised by the athlete</td>
</tr>
<tr>
<td>Strength/Power athletes in need of deep analysis</td>
<td>Useful for teams &amp; novice athletes</td>
<td>Running based/repeat SSC athletes</td>
</tr>
<tr>
<td>Large depth of data</td>
<td>Low depth of data</td>
<td>Moderate depth of data</td>
</tr>
</tbody>
</table>

Data modified with permission from Flanagan (2016b).

Despite the increase in use of reactive strength testing, there is limited published RSI normative data. The table below outlines some basic thresholds to help guide interpretation of RSI results. It is based on the RSI being calculated as the jump height (in metres) divided by the contact time (in seconds). In some research studies, RSI is reported as flight time (total time spent in the air during the jump) divided by contact time. This gives a much larger RSI score than the jump height / contact time method. Both methods are perfectly valid, but result in different absolute values. The ground surface used in testing influences results. More compliant surfaces (rubber matting) produce lower RSI scores in comparison to stiffer surfaces (sprung flooring). Reactive strength testing of this nature is highly ankle-dominant, specifically challenging the calf-achilles muscle-tendon system (Flanagan 2016b).

**Table 3: Reactive-Strength Index thresholds for the Drop Jump.**

<table>
<thead>
<tr>
<th>RSI Index Thresholds</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.5 RSI</td>
<td>low reactive strength ability athlete is not yet prepared for moderate intensity plyometrics focus on general strength development &amp; low-level plyometric (technique)</td>
</tr>
<tr>
<td>1.5-2.0 RSI</td>
<td>moderate reactive strength ability athlete prepared for moderate intensity plyometrics reactive strength need most improvement</td>
</tr>
<tr>
<td>2.0-2.5 RSI</td>
<td>reactive strength ability is well established intensive plyometrics are appropriate to use</td>
</tr>
<tr>
<td>2.5-3.0 RSI</td>
<td>high level of reactive strength ability training returns could be small(er) for some athletes critical analysis: do greater reactive strength levels mean an improved performance?</td>
</tr>
<tr>
<td>&gt;3.0 RSI</td>
<td>world class reactive strength levels limited capacity for further improvements in reactive strength</td>
</tr>
</tbody>
</table>

Data modified with permission from Flanagan (2016b).

Progressions on the plyometric training are presented above, so we can use it with the athlete in question and progress them from their current level of ability towards more specific and demanding training modalities. Athletes above 3.0 RSI are rare, they present mostly some world-class level track and field athletes and scientific research on that pop-
ulation is hard to obtain. Also when an athlete reaches their optimal level in height/contact time and index is above 2.5 we must critically analyse the athletes’ sport as to whether the improvement in reactive strength will improve their actual sport performance.

Results

Constructing Plyometric Training Plan

Based on the reviewed research it should be pointed out that a need for an individualized and progressive plyometric training is needed, especially with athletes new to the plyometric training. Strength and conditioning practitioners should take into considerations all of the above chapters to design a proper plyometric training program to optimize the development of their athletes, focusing on determining the individuals profile, plyometric exercise intensity and specificity.

Table 4: 4-step progression for developing fast SSC performance and introducing contact time (CT) and reactive strength index (RSI) as feedback tools.

<table>
<thead>
<tr>
<th>Phase 1: Eccentric Jumping</th>
<th>Phase 2: Low Intensity Fast Plyometrics</th>
<th>Phase 3: Hurdle Jumping</th>
<th>Phase 4: Depth Jumping</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main focus:</strong> proper landing mechanics (quiet landings)</td>
<td><strong>Main focus:</strong> short ground contact &amp; jump height fixed and is somewhat important</td>
<td><strong>Main focus:</strong> short ground contact &amp; jump height</td>
<td><strong>Main focus:</strong> Short Ground Contact Times</td>
</tr>
<tr>
<td><strong>Instruction:</strong> Minimal flexion at knees &amp; hips; “Freeze” on ground contact (‘absorbing’ the forces)</td>
<td><strong>Instruction:</strong> Legs like “stiff springs”; “Stay on balls of feet”</td>
<td><strong>Contact time:</strong> as a feedback tool</td>
<td><strong>Instruction:</strong> “Jump fast, jump high”</td>
</tr>
<tr>
<td>Ankle Jumps &amp; Skipping</td>
<td></td>
<td><strong>Progression:</strong> Increased hurdle height when CT is indicative of SSC type</td>
<td><strong>RSI:</strong> used as feedback tool and used to optimize dropping height and to monitor plyometric performance</td>
</tr>
</tbody>
</table>

Data modified with permission from Flanagan et al. (2008b).

The goal of the first phase for novice athletes is the correct technique in jumping, landing, and hopping activities. While the ultimate goal may be to develop fast SSC reactive strength, slow SSC exercises can still be useful in this phase. In these exercises, the key focus is on short contact times over maximal jump height. Skipping or low intensity bounding could also be included here. That is one of the most important phases, as everything that follows will build upon that phase.

Second (development) phase should introduce the athlete to more moderate intensity fast SSC exercises (*i.e. repeated hops over very low hurdles*) is sensible. Also note that the height of the hurdle is used to limit the jump height, not to encourage it. The most important thing to look at here is still short, sharp ground contact time and tall, strong (*chest up, hips high*) posture during the movement. Different multi-directional plyometric activities will apply shearing forces to the ankle, hips and particularly the knee so they must be introduced conservatively and with great attention to its execution. Control and alignment of the joints is the centre of the attention, it would also be sensible to use being multi-directional work in more of a slow SSC fashion with full landings and longer contact times.
Third (realization) phase puts the focus on high-output, maximal-effort reactive strength training. Fast SSC plyometric exercises (i.e. *drop jump*, *maximal effort repeated hops*) are appropriate in this phase. To improve the mechanism of the fast SSC it is of important to apply a powerful (overload) stimulus and to measure ground contact times and use reactive strength index explained in the previous section to optimize intensity, to track progress and to give some kind of a feedback to the athlete.

All outlined methods are only means to improve physical capabilities, the goal for every athlete is to utilize these capabilities in a sport specific situation. So some methods to allow as the transfer of physical qualities to the sport itself must be chosen and depend on the sporting action being improved. For example, sprinters may focus more on plyometric exercises with greater horizontal and unilateral forces (i.e. *horizontal drop jump, single leg drop-jump, repeated bounding*) while on the other hand a field-sport athlete looking to improve his change of direction may use more high effort, multi-directional fast SSC exercises. In this final phase, the use of the reactive strength index may or may not be appropriate but unilateral, horizontal or multi-directional plyometrics may be key in ensuring effective transfer of training (Flanagan 2009, 2016a).

Based on this data, strength and conditioning coaches should always look at their specific athlete and their sporting needs and make the use of all outlined methods and characteristics of plyometric training program design. Always ask ourselves if a certain physical capability will improve the sporting performance and how. A term “*dynamic correspondence*” of the training exercises to the sporting demands is often used in the literature. There is nothing more specific than the sport and its actions itself, but specialized plyometric exercises can and should be included in the training plan to maximize the performance and enhance training transfer. Another thing to note is that research is not conclusive and thorough enough, or is even lacking, to develop a valid and reliable reactive strength testing techniques in unilateral and horizontally focused exercises.

Table 5: Phases of Plyometric Training Planning.

<table>
<thead>
<tr>
<th>Phases of plyometric training</th>
<th>Characteristics of the phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE 1: FOUNDATION</strong></td>
<td>Develop eccentric strength (jump-landings)</td>
</tr>
<tr>
<td></td>
<td>Develop jumping technique (slow SSC)</td>
</tr>
<tr>
<td></td>
<td>Develop hopping technique (low intensity fast SSC)</td>
</tr>
<tr>
<td></td>
<td>------</td>
</tr>
<tr>
<td><strong>PHASE 2: DEVELOPMENT</strong></td>
<td>Moderate intensity fast SSC exercises</td>
</tr>
<tr>
<td></td>
<td>Emphasis on short contact times and jump height</td>
</tr>
<tr>
<td></td>
<td>Develop reactive strength endurance (extensive methods)</td>
</tr>
<tr>
<td></td>
<td>------</td>
</tr>
<tr>
<td><strong>PHASE 3: REALIZATION</strong></td>
<td>High intensity fast SSC exercises</td>
</tr>
<tr>
<td></td>
<td>Emphasis on short contact times and jump height</td>
</tr>
<tr>
<td></td>
<td>Maximal effort activities</td>
</tr>
<tr>
<td></td>
<td>RSI used to asses and optimise training</td>
</tr>
<tr>
<td></td>
<td>------</td>
</tr>
<tr>
<td><strong>PHASE 4: TRANSFER</strong></td>
<td>Specific sport action</td>
</tr>
<tr>
<td></td>
<td>Specialized plyometric exercises resembling the actual sport</td>
</tr>
</tbody>
</table>

Data modified with permission from Flanagan (2009, 2016b).
These phases are overlapping between each other and are much less noticeable in real life setting then in theory. Important to take into consideration is also the frequency and duration of the plyometric training program. Current research by de Villareal et al. 2008 recommends 2 plyometric training sessions per week (as effective or more effective than 4 sessions), total duration of a program should be minimum of 10 weeks (more than 20 sessions in total needed to maximize performance improvement) and in high-intensity programs (phases 3 and 4) it is necessary to have at least 50-60 jumps per session to maximize performance improvement.

As it has been covered in previous chapters of this study, training of plyometrics based on an individualized F-v profile require special methods of approach to planning and conducting the training. Training should be aimed in two directions, based on the F-v profiling (Samozino et al. 2012):

- **Force deficit**: training aimed to increase $P_{max}$ while decreasing $FV_{imb}$, by increasing force capabilities ($F_0$) as a priority.
- **Velocity deficit**: training aimed to increase $P_{max}$ by improving maximal velocity capabilities (*i.e. capacity to produce force at very high contraction velocities*).

Looking into previous studies, there is clear effectiveness of strength training aiming at specifically increasing maximal force capabilities (Cormie et al. 2007, 2010; Rønnestad et al. 2012, 2016; Zaras et al. 2013, cited in Jimenez-Reyes 2016). They have shown improvements in maximal strength parameters (e.g., 1RM, 1RM/BM ratio) through trainings involving the use of high loads (>70% RM), in order to achieve the maximal neuromuscular adaptations, in periods ranging from 6 to 12 weeks. On the other end of the spectrum, velocity training should be oriented toward maximal velocity efforts during high accelerated movements with minimal or null braking phase, for example a throw at the end of a lift and displacing low (<30% RM) or negative loads (Argus et al. 2011; Markovic et al. 2011; Sheppard et al. 2011, cited by Jimenez-Reyes 2016). The effects of this type of training, commonly referred to as ballistic, can be observed in studies where protocols with a removed deceleration phase during lifts have been shown more effective (Newton et al. 1996; Cormie et al. 2010, cited by Jimenez-Reyes 2016). These studies and others (Markovic and Jaric 2007; Argus et al. 2011; Markovic et al. 2011, 2013; Sheppard et al. 2011, cited by Jimenez-Reyes 2016) show how employing loads lower than body mass (referred to as *negative loads*) may result in a training-induced shift in force-time curves and force-velocity relationships toward more velocity-related capabilities (Djuric et al. 2016, cited by Jimenez-Reyes 2016).

In some cases, although not very often, in case of a F-v profile close to the computed optimal profile (low deficit), the training program should target a balanced combination of force, velocity, and power in order to shift the entire F-v relationship to the right, and so to increase $P_{max}$ as a priority (Wilson et al. 1993; Harris et al. 2000; McBride et al, 2002; Kotzamanidis et al. 2005; e.g., Cormie et al. 2007; de Villarreal et al. 2011, cited by Jimenez-Reyes 2016) while maintaining the F-v profile close to the optimal value (and thus $FV_{imb}$ close to 0%). The effects of studies aiming to both increase maximal power and shift the entire F-v curve show how combining a wide range of loads (heavy, optimal, and ballistic loads) is an appropriate stimulus (Harris et al. 2000; McBride et al. 2002; Kotzamanidis et al. 2005; Cormie et al. 2007, cited by Jimenez-Reyes 2016).
A FV\textsubscript{imb} value around 0% indicates a F-v profile equal to 100% of the optimal profile (perfect balance between force and velocity qualities), whereas a F-v profile value higher or lower than the optimal indicates a profile too oriented toward force or velocity capabilities, respectively.

In the study from Jimenez-Reyes et al. (2016) they created 5 F-v imbalance categories (High Force Deficit, Low Force Deficit, Well-Balanced, Low Velocity Deficit and High Velocity Deficit), with F-v profile in % of optimal thresholds being <60%, 60-90%, >90-110%, >110-140% and >140% respectively. They also suggested ratios of certain portion of strength being trained (Strength, Strength-Power, Power, Power-Speed and Speed) based on the imbalance calculated. With focus for the athletes with force deficit shifting from more strength and power based training (i.e. 3:2:1 ratio for high force deficit, with 3 being strength, 2 strength-power and 1 power) to more speed-power based for high velocity deficit (i.e. 3:2:1, with 3 being speed, 2 power-speed and 1 power). They also suggest the training to contain 6 exercises per week, 3 sets per exercise and a total of 18 sets per week. But this was a pilot study, so the training program and suggestions are not valid and reliable enough to say, they are significant enough and future research should be done on the topic.

One critique here is that no research proved whether strength training directly improves reactive strength or vice versa, meaning that the “stronger” athletes not necessarily display greater reactive strength because of the general strength, but because of their training age and experience in structured training programs involving maximal and reactive strength training. Stronger athletes will be less likely to get injured or suffer muscle soreness following plyometric training. The stiffness of the tendon allows stronger athletes to utilise the fast SSC more effectively and handle larger expressions of force in the plyometric activities. On the other hand, it is sensible to conclude that having higher level of strength could be and is beneficial, but only up to a certain point, as this new F-v profiling clearly shows, that the optimum is the balance between the two components.

One study by Barr and Nolte (2014), done on female rugby players using drop jumps, concluded that it is beneficial for female athletes to achieve high levels of maximal leg strength as that allows them to utilize higher heights of drops when performing drop jumps. Without much hesitation, this can also be concluded for male population.

**Discussion**

The current stance on the plyometric training regarding general strength is that, it should be developed alongside reactive strength qualities for optimal physical development. Often used is a “strength threshold” below which athletes should not complete plyometric training, but this is not nearly as important as some literature presents. Maximal strength should be a priority for athletes below 1.1-1.5 x BW squat and it would be sensible for them to avoid high-intensity plyometric exercises. I recommend that strength and conditioning coaches look into their athletes’ individual characteristics and characteristics of their sport. As this threshold level of maximal strength must be taken into consideration - an advanced athlete in a sport which does not require high maximal strength, but there is a lot of plyometric and ballistic activity (i.e. diving off springboards) does not need that high
level of maximal strength in order to be successful. On the other hand, a young rugby player would definitely need to get his strength levels up to, or above this threshold. Also, as suggested by Flanagan et al. (2008a) low to moderate level fast SSC plyometric work can and should be part of almost every young athlete program to develop reactive strength qualities that are important to performance in a large variety of sports.

F-v profiling should also be a big part of plyometric training design, for novice and advanced athletes alike. This could be useful so we have a direct measure of athletes’ deficiency on either Fo or vo. The study by Jimenez-Reyes et al. 2016 showed that groups following individualized training programs displayed large increases in vertical jump height as opposed to groups following the non-individualized program or groups doing no training (control). Individualized training programs also improved the force-velocity imbalance, by moving the athletes force-velocity profile (FVP) closer to the optimal FVP.

RSI is a sensitive measure which makes it ideal to examine neuromuscular fatigue on an on-going basis (Flanagan 2009). Depending on the circumstances, the DJ-RSI, the rebound jump or the 10/5 RSI test could all be appropriate monitoring tools. That could prove to be useful to all the practitioners in the field, as it could provide a useful guide in to the volume and intensity of the plyometric training. However, more research needs to be done to make it scientifically justifiable.

Jump performance depends not only on maximal power output, but on an optimal force-velocity profile (Samozino et al. 2014; Morin & Samozino 2016). That is an important finding as it provides a reliable and valid data on the plyometric training and it provides a marker on what should be the focus of an individual athletes’ program to improve their jumping performance and in turn their sport performance.

The measures of rapid force development, such as the slope of the force-time curve, may provide more detailed information than vertical jump height (Van Hooren & Zolotarojova 2017). This is also an important conclusion, as most research is focusing on the jump height or ground contact time, without looking at the slope of the F-t curve, which can provide in-depth information regarding the movement of an athlete. Another important point is that resistance training has a limited transfer to rapid force development in unloaded dynamic isoinertial multi-joint movements (i.e., most sports and daily living movements) and this effect is most pronounced in movements that do not involve a counter-movement. Furthermore, the findings also suggest that this transfer is less pronounced in well-trained individuals (Van Hooren et al. 2017). A useful piece of information for a lot of practitioners and athletes trying to improve their plyometric abilities, as it shows that the higher the ability of an athlete, the more specific or closer to the real sporting environment, the movement must be in order to provide transfer and improvement.

Plyometric training (PT) and jump performance is an already researched area. PT has been extensively used for improving jumping performance in healthy individuals. The research has proved that PT is able to improve the vertical jump height in healthy individuals. Value of this study is in an attempt to include newest research on the matter at hand and to provide an overview for an interested person. The data provided is enough to give an idea of how to construct a plyometric training program and how to implement it in a
well-rounded physical preparation plan for a particular athlete. It also provides some in-
sight into the physiological and biomechanical background of the plyometrics and pro-
vides significant data and approach on individualized training profile to determine an
optimal training profile and the means to improve the vertical jumping performance in
the most optimal way.

Conclusion

Most commonly plyometric training and jump performance is being enhanced mostly by
strength training and not putting much attention to an individual. With this study I
wanted to show the scientific background of considering constructing an individual
plyometric program to improve ones’ jumping abilities. It is based on assessing the Force-
velocity profile and determining the imbalance in either end of the curve. This way, the
training program can put more emphasis on the imbalance and prescribe the optimal re-
sistance training to improve ballistic performance.

Another conclusion is that there is no minimal threshold in maximal strength (i.e. squat
minimum of 1.5x body weight) in relation to when to start with the plyometric training.
Low and moderate intensity plyometric training can be done with both young athletes or
novice athletes to the ballistic (jump) training. Aim is always to use the least stressful
method to elicit biggest possible physiological and neuro-muscular changes.

The study also looked at the use of reactive strength index as both a testing battery and
as a mean to monitor the neuromuscular fatigue, although the practitioners must take
into consideration the level of training and experience of their athletes in plyometric
training. I believe it can be as a useful measure to determine reactive ability and can pro-
vide more in depth information about the status of ballistic performance of an athlete.

Also important is the use of terminology, for example in counter movement jump the lit-
erature shouldn’t refer to the eccentric and concentric movement, but rather to down-
ward and upward phase, as it is highly likely there is no eccentric phase during the CMJ.

The biggest use of this paper is that it provides a way for strength and conditioning prac-
titioners on how to determine athletes’ ballistic performance, how to monitor it and how
to construct a plan and what to pay attention to in training and to give an idea when an
athlete is ready to move on to the next phase. Plyometric training is a very potent method,
so practitioners should pay close attention to monitor and program their athletes training
properly, for the biggest possible performance increase and the smallest possible injury
risk. Future research should focus on finding a valid and reliable way to test the RSI with
the 2 tests presented here (10/5 RSI Test and Rebound Jump Test) and to develop similar
testing for horizontal ballistic mov-

[24]
Reference List


