A constraints-led approach to acquiring the power clean

A thesis submitted to the Auckland University of Technology in fulfilment of the requirements for the Master's degree of Sport and Exercise

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed:_____ Date:_____

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Ethics Approval

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See appendix B

Abstract

The purpose of this study was to apply a constraints-led approach to the acquisition of the power clean. Strength and conditioning coaches need to coach complex motor skills, where the common method involves explicit instruction and task decomposition. However, contemporary skill acquisition theory is in conflict with this explicit and reductionist approach. Through three case studies the examination of individualised task constraints were used to reshape the state space of the participants, and allow a self-organisation process for skill development to take place. Constraints were applied across ten coaching sessions then evaluated via video analysis of every training repetition and post testing 1RM. The constraints employed for all three case studies achieved movement change in the predicted direction as well as successfully facilitating learning, exploration, and searching of the motor perception landscape. In two of the three cases, the movement changes resulted in performance improvements measured through 1RM. In conclusion, the constraints-led approach was an effective method for changing movement behaviour in the context of strength and conditioning. Practitioners can apply the processes implemented in this research to facilitate learning of exercise related skill in similar complex movements.

<div align="center">**Chapter 1:**</div>

Introduction

Brief Background to the Problem

Every strength and conditioning coach needs to facilitate movement change either for enhanced sport performance or injury prevention. Hence, NSCA and Farve (2014) reports that to increase new coaches' chances of succeeding in this profession you need to become a "technician" in all aspects of coaching. Being able to change movement is critical because movements or exercises that are not performed correctly may apply stress to the body in an undesired place (Bahr & Maehlum, 2004). This undesired area may not be able to handle this stress causing potential injury (Hall, 2012). A traditional strength and conditioning method to changing movement behaviour is one where the coach uses an explicit instructional approach (Faigenbaum, Lloyd, MacDonald, & Myer, 2015; Hang, Drinkwater, & Chapman, 2015; Rucci & Tomporowski, 2010). An instructional approach, as reported by Rucci and Tomporowski (2010) is one where coaches administer feedback to their athletes about their performance on a given skill. Usually, this is the reproduction of a particular lifting technique. Underlying this approach is an assumption that an explicit approach is effective at changing movement behaviour. However this is not grounded in contemporary skill acquisition evidenced-based practice; as an explicit approach is considered to be a less effective method for movement change (Masters & Poolton, 2012). The negative effects of this explicit approach are decreased skill performance under pressure (Lew, Richard, & Graham, 1996; Masters, 1992), higher skill degeneration under physiological stress (Poolton, Masters, & Maxwell, 2007), increased coach reliance (Farrow, Barker, & MacMahon, 2013; Williams & Hodges, 2005), decreased skill retention (Reber, 1992) and decreased decision-making accuracy (Masters, Poolton, Maxwell, & Raab, 2008).

The field of skill acquisition is the study of skill learning and draws knowledge from the areas of motor control, neuroscience, motor learning and experimental psychology (Williams & Ford, 2009). Interestingly, the two major professional bodies in strength and conditioning, the American College of Sports Medicine (ACSM) and the National Strength and Conditioning Association (NSCA), provide no guidelines on the topics of coaching or skill acquisition. This approach highlights a lack of attention to skill development in this area of strength and conditioning related to skill learning.

Underlying a reliance on an instructional approach is the classical training theory rooted in a Cartesian view (Carlota & Natalia, 2006). This viewpoint reduces the athlete down to their parts to logically train these individual parts. With the assumption that these parts will reassemble logically back to the whole performance, however, nowadays we draw incite from dynamical systems theory, an alternative way of viewing sports training which is emerging (Davids, Button, & Bennett, 2008). A dynamic systems view looks to understand the whole system rather than reducing it down to its parts. In this way we do not lose sight of the whole system and how the parts of the system interact with each other. Hence, change in movement behaviour cannot be oversimplified into a clear set of instructions to follow to achieve the desired outcome (Davids & Araujo, 2010), but rather more as a complicated process of bringing many interacting systems into alignment (Davids et al., 2008). If all parts of the system are not present then they cannot be expected to co-ordinate together. In many ways, this is what happens when a skill is broken down in many parts such as seen in common strength and conditioning programmes (Hang et al., 2015). In contemporary coaching literature, learning is seen as a non-linear process and needs a matching non-linear pedagogy (Renshaw, Davids, Shuttleworth, & Chow, 2009). An example of contemporary non-linear pedagogy is a constraints-led approach. A constraints-led approach changes the constraints that affect movement by these constraints are categorised as either individual, task or environmental (Newell, 1996). This approach is an individualised pedagogy where the learner is at the centre and the coach will reshape the task and environment to change the movement behaviour toward the desired outcome (Davids et al., 2008; Newell & Yeou-Teh, 2012).

The power clean

The development of an athlete from a strength and conditioning coach's perspective is broad and requires athletes to be proficient in a variety of exercise related skills. One of these skills is the power clean; which is commonly used to develop explosive power (Stone, Pierce, Sands, & Stone, 2006). The power clean requires a high level of intrapersonal coordination (Schmidt & Richardson, 2008) and athletes often require significant time to acquire this skill (Winchester, Erickson, Blaak, & McBride, 2005). To best perform a skill, there are frequent questions about the investment of time in learning the skill versus improvements in performance (Hang et al., 2015). For instance, if an athlete is slow to acquire an effective technique, then they will have less time to maximise the stimulus intended for a training effect (Winchester et al., 2005). Given

this importance of learning time in relation to the power clean, more focus is needed to be put in effective strategies for motor learning in this field (Hang et al., 2015; Moir, 2016).

Through a close analysis of the power clean movement and associated skill acquisition, this thesis offers a broader argument that there is a lack of alignment between established coaching theory and the discipline of strength and conditioning. Well-established literature from the fields of coaching and motor learning suggests there is likely to be significant benefit to coaches and athletes regarding performance outcomes if coaching pedagogy methods are applied to exercise skills. Rather than utilising the more traditional instructional based approach, it is further argued that the adoption of a constraints-led approach in particular, could result in greater improvements in performance. This research has utilised changes in task constraints to reshape movement behaviour. These task constraints applied encouraged the performer to explore new movement solutions to the power clean. Given the potential benefit associated with using this approach, it is important to investigate the processes of skill learning in relation to the strength and conditioning discipline.

Purpose of Research

The purpose of this research is to implement a contemporary coaching method within the context of strength and conditioning. This research is then grounded in a practically applied setting to be useful to strength and conditioning practitioners. The research methodology is representative of this applied nature.

Research aim

To explore the use of a constraints-led approach in the strength and conditioning context.

Hypothesis

To make positive changes in power clean technique using a constraints-led approach.

Structure of thesis

The structure of this thesis will start with a literature review followed by the methodology used in this research. After this will be the results and discussion of results and concluding with limitations and future research.

Chapter 2: A Literature Review

Ultimately the goal of performance in elite sport is the attainment of success in sporting competition. Traditionally sporting performance was attributed to innate talent and genetics (Davids & Baker, 2007), whereas more recently Farrow et al. (2013) report high-performance sporting success has been attributed more to amount and type of practice individuals undertake (McGarry, O'Donoghue, & Sampaio, 2013). Davids and Baker (2007) report this relationship between performance and the quality and quantity of practice to be one of the most robust in behavioural science. Consequently, coaches seek to deconstruct sport to focus and plan practice on the different aspects which make up its performance. These aspects are not well defined in the literature but are traditionally categorised into four siloed areas; physical, technical, tactical and psychological (Janelle & Hillman, 2003; McMorris & Hale, 2006).

Technical aspects can be described as an individual's technical execution of sporting skill related activities (Janelle & Hillman, 2003). Examples of this is the refinement of one's technique with the goal of more accuracy. Tactical aspects also relate to the strategy of the sport. Tactical aspects involve interactions of athletes with each other and their decisions made relating to sporting performance (Tudor & Michae, 2005). Psychological aspects are the development of mental skills needed for high performance (Weinberg & Gould, 2011), such as mental toughness, motivation, self-efficacy, and imagery. Physical aspects are the subcomponents of physical fitness such as cardiovascular-respiratory (aerobic) fitness, stamina, strength, power, endurance, strength-endurance, flexibility and body composition (Fleck & Kraemer, 2004). It is these physical factors that are traditionally trained by strength and conditioning coaches to positively adapt from a physiological perspective (Baechle & Earle, 2008). This siloed approach to performance development is argued in this thesis to be limiting performance improvements, as it is impossible to separate the training of physiological adaptions from movement skill and practice. Hence, whenever we are training we are also practicing movement and co-ordination related to sport, and therefore, an integrated approach is required.

Strength and conditioning uses a principle called specificity or specific adaptation to imposed demands (SAID) (Baechle & Earle, 2008). This principle states that the type of training demand on the athlete dictates the type of physiological adaptation. For example the use of Olympic lifting

which is a high-velocity movement for the development of power. Baechle and Earle (2008) explain to maximise the transference of resistance training exercises to sport performance exercise programmes should include movements that mimic the movement pattern of the athlete's sport. This mimicking will improve the likelihood the correct muscles will be recruited. This somewhat narrow view only sees training as the development of physiological adaptation and neglecting the exercise or movement related skill is not maximising the transference of training to sport. Additionally only seeing this as training and not a part of practice highlights a lack of alignment with coaching literature. Farrow et al. (2013) report that the development of sporting performance is to be attributed to the amount and quality of practice, not the training of adaptations only.

The separation of skill from physical training is argued in this thesis to be detrimental to an athlete's development. This separation is also evident more broadly in the ACSM's (2014) definition of physical fitness where the factors health related and skill related are separated. Showing a distinct separation to the development of strength and cardiorespiratory fitness factors from other skill related fitness factors such as coordination. Nevertheless, in the context of movement and sporting performance, this separation does not exist (Renshaw, Davids, & Savelsbergh, 2010). The development of strength and cardiorespiratory fitness cannot be expressed without quality movement skill and efficiency. Therefore utilising the SAID principle, these need to be linked as closely as possible. This critique is shared by a recently published strength and conditioning book by Moir (2016) reporting in the preface that skill acquisition is rarely mentioned if at all in strength and conditioning textbooks, and this is a large oversight. So there is a striking disconnection between training and practice. In this way, one of the aims of this thesis is to demonstrate this intimate relationship between strength and conditioning and skill learning.

Expert strength and conditioning coaches possess knowledge regarding skill acquisition in their field that is unique to the discipline and themselves. This practical knowledge is described by Dorgo (2009) as "knowing-how". It is important in so far as it reflects extended time spent exploring what does and does not work. Millar, Oldham, and Renshaw (2013) argue that the development of this knowledge follows "memetic" or evolutionary rules whereby the strongest ideas survive within a competitive performance environment. Furthermore, it is thought by Kelso

(1995) that the inclusion of expert coach knowledge in modelling decisions will aid in the reduction of "inspired guesses".

Coach's knowledge is developed from learning situations; these situations can be formal education or informal experiences. The informal experiences can be on-the-job learning where the coach reflects on their own practice (Cote, Erickson, & Duffy, 2013). This reflection is where expert coaches cycle through strategy generation, experimentation and evaluation for any given problem. The coach may loop this cycle many times to refine their practice. Therefore the expert coach's knowledge is developed through deliberate reflection on real coaching experiences and is very valuable information (Cote et al., 2013).

Traditional coaching and skill teaching discourses

A distinction between coaching literature and strength and conditioning literature is the discourses utilised. Within the sport coaching context, there are many discourses or ways in which language is used to communicate with athletes. Of particular interest is how these coaching discourses are underpinned by beliefs, ideologies and power arrangements (Cassidy, Jones, & Potrac, 2009). According to Johns and Johns (2000) and Martens (2012) the dominant traditional discourse is coach dominant. In this coach centred discourse a higher importance is placed on specialist technical and factual knowledge; known as a command style of coaching. Here, the coach makes all the decisions, and the athlete responds to the coach's commands. The coach supplies this knowledge to the athlete who needs to listen, absorb and comply (Douge, 2013; Martens, 2012). Often this coaching approach views the coaching process as a clear, logical, linear sequence to achieve the outcome. On the other hand, this could be seen as oversimplified, and doesn't take into consideration individual athlete differences (Davids et al., 2008). The underpinning belief of this discourse views the athlete's body as a purely biological object which can be manipulated or trained and its movements minutely measured (Wright, 2000). This view is evident in a publication from Souza et al. "Athletes today are becoming faster and stronger while coaches are trying to find any edge that will help to create the most optimal machine" (Souza et al. 2002 p.471). Viewing the athlete as a machine is clearly demonstrating this traditional discourse. This approach is now widely criticised as it does not take into consideration the vast diversity of athletes (Cassidy et al., 2009). Leading to athletes attempting to carbon copy skills rather than allowing the athlete to explore their individualised

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movement solution (Renshaw et al., 2009). As a result, the coaching environment is characterised by consensus and conformity, which leads to social oppression physically to reproduce a particular athletic body shape and cognitive oppression limiting creativity and individuality (Cassidy et al., 2009). This approach will then negatively affect the athlete's long-term holistic development.

Traditional strength and conditioning coaching methods

Within the field of strength and conditioning, this traditional coach centred approach is very dominant. Rucci and Tomporowski (2010) report that strength coaches administer feedback to their athletes about their performance on a given skill and usually the reproduction of a particular lifting technique. This predominant approach is also evident when coaching the Olympic lifts. Where a recent study just published by Hang et al. (2015) utilise this method when coaching four naive elite athletes the hang power clean. In this study, an intervention was carried out by the primary author who instructed the athletes how to perform the skill by breaking the skill down into parts utilising a top-down linear method seen in figure 2.1 below (e.g. shrug, jump shrug) (Duba, Kraemer, & Martin, 2009). Reporting this type of methodology is to be the common approach in the coaching literature (Duba, Kraemer, & Martin, 2007). However as discussed earlier this top-down approach is in conflict with contemporary sports coaching literature and is only common within the field of strength and conditioning. Evident to this was the coach only allowing the athlete to progress when deemed proficient. Clearly demonstrating that the power resided with the strength and conditioning coach who controlled their rate of progression (Hang et al., 2015). Additionally, breaking the skill down into parts has been criticised by the coaching literature (Renshaw & Brymer, 2010). As this approach is considered skill decomposition where the skill has been changed significantly into a different skill. Hence, these athletes were no longer learning the hang power clean but a different skill. In contrast, to the coach centred approach contemporary coaching literature views the athlete-coach relationship as a "we" approach instead of an "us" and "them" approach. This fundamental difference views the athlete is a resource which the coach can draw on. Utilising their personal experiences and understanding of themselves to achieve what works for them. This respect for the athlete's knowledge and understanding flips the athlete-coach relationships to be in favour of the athlete. This approach is defined as an athlete centred approach (Kidman & Hanrahan, 2004).

An athlete centred approach fundamentally changes the decisions a coach will make about the coaching methods to be utilised. The reformed coach-athlete relationship is non-didactic where athletes now contribute actively to their development taking ownership for their performance (Kidman & Hanrahan, 2004). Also, this approach views the coaching process as a more complicated and a non-linear process. This non-linear process is in conflict with the reductionist view of task decomposition seen in strength and conditioning practice.

Underpinning this idea of an athlete being more complicated is dynamical systems theory where movement coordination is understood to be a complex interaction of many different systems (Cassidy et al., 2009). Within human movement, this dynamic system is a hybrid biological organisation, including a large number of different subsystems (neural, muscular, skeletal) (Davids et al., 2008; Renshaw et al., 2009). These subcomponents are connected in complex and intricate ways and operate at different rates. Hence viewing human movement behaviour in a simple and isolated manner is not taking into consideration the complexity of the system as a whole (Beek, Peper, & Stegeman, 1995). There is also a large assumption that training individual parts will automatically reassemble and lead to successful sport performance. As seen in strength and conditionings definition of athletic performance (Renshaw et al., 2010), which is misleading. Where the measures of this athletic performance being only linear speed, vertical jump, one repetition maximum or other fitness tests. This definition is clearly far from actual sporting performance but only a part of what makes up performance.

Strength and conditioning coaches need to become aware of this systems viewpoint when seeking to develop coordination, such as in the Olympic lifts. Coordinating the subsystems involve these parts being brought into proper relation to one another as well as the environment and equipment (Wilson, Newton, Murphy, & Humphries, 1993; Young 2006). In this way, Olympic lifts involve the bringing into relation of the complex systems of joints, muscles and so forth with the ground and the barbell to coordinate the entire system. This complex interpersonal coordination is a consequence of physical self-organisation (Turvey, 1990). The idea of self-organisation is of flexible and adaptive complex interactions between a large numbers of these subsystems. To form coordinated movements to ever-changing environmental conditions. This self-organisation

process relies on the speed of adaptability and re-organisation hence occurs without any explicit prescription to the coordination pattern.

It is through the dynamic interaction of the athlete and the environment that formation of spontaneous movement patterns emerge to achieve a specific task goal (Kelso, 1994). Hence, the environment plays a critical part in this process of self-organisation. "The environment refers to the surroundings of animals that perceive and behave" (Gibson, 1979). From this, we draw insight from the field of Ecological Psychology, which is the study of animals and the transference of information between living systems and their environment (Newell & Yeou-Teh, 2012). One of the fundamental pillars of ecological psychology is perception and action (Davids et al., 2008). Within a sporting context, an athlete needs to perceive their environment to understand their opportunities for action. In sport performance, there are many opportunities for movement depending on the environment. There may be opportunities to change direction, jump, throw, pass, tackle an opposing player or other movements (Davids et al., 2008; Renshaw et al., 2009). These opportunities change from moment to moment and Fajen and colleagues (2008) argue that an athlete needs to directly perceive their environment free from higher level slower cognitive processes called "direct perception" (Gibson, 1979). Direct perception stresses the reciprocity of the athlete and their surroundings as the environment is constantly changing so does the athlete's perception of their environment. Hence, an athlete needs to be attuned to key invariant information sources within the environment to create successful movement solutions (Fajen et al., 2008). This attunement establishes an intimate relationship between perception of the environment and action. These perceptual demands need to be considered when learning a new exercise skill such as the power clean. If however, key environmental information sources are not present, then there is a perceptual disconnection between practice and performance. As such the coach needs to ensure authentic practice situations. Therefore, the way in which strength and conditioning literature has broken the skill of the power clean down into its parts is in conflict with the perceptual demands understanding. These models are below in figure 2.1 (Duba et al., 2007) & figure 2.2 (Duba et al., 2009).

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                        ┌─────────────────────────┐
                        │   Hang Power Clean      │
                ┌───────┴─────────────────────────┴───────┐
                │         Power Shrug + Catch              │
        ┌───────┴─────────────────────────────────────────┴───────┐
        │           Power Shrug + Row + Catch                      │
    ┌───┴─────────────────────────────────────────────────────────┴───┐
    │                 Power Shrug + Row                                │
┌───┴───────────────────────────────────────────────────────────────┴───┐
│                       Power Shrug                                      │
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│   Hang Position (Romanian Deadlift) Catch Position (Front Squat)        │
└────────────────────────────────────────────────────────────────────────┘
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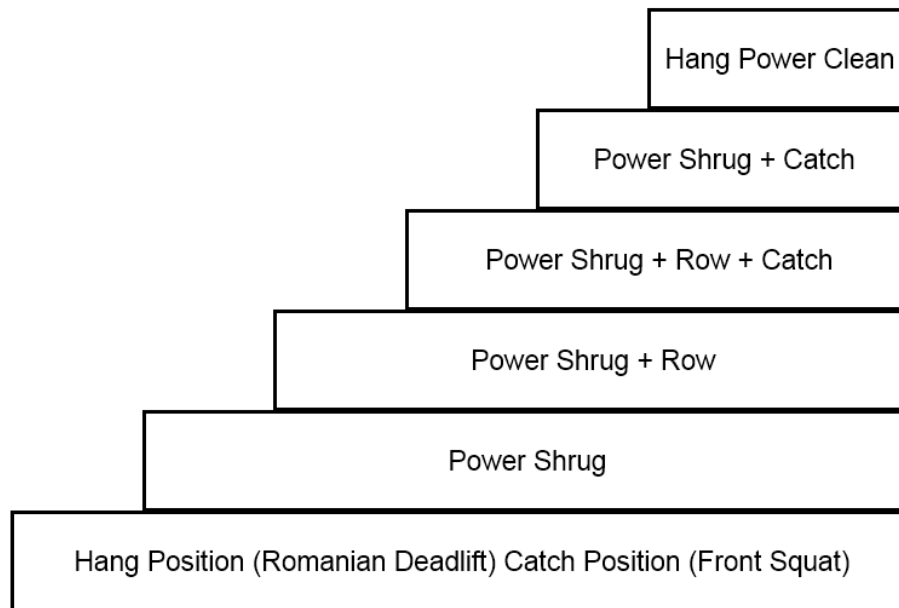
Figure 2.1 A 6-step progression model for teaching the hang power clean. (Duba et al., 2007)

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                        ┌──────────────────────────────┐
                        │  Power Clean: One Smooth and │
                        │       efficient movement     │
                ┌───────┴──────────────────────────────┴──────┐
                │ Clean Deadlift + Hang Power Clean: combo of the│
                │    two prerequisites for the power clean       │
        ┌───────┴────────────────────────────────────────────┴──────┐
        │ Clean Deadlift: base for first pull and transition phase   │
┌───────┴────────────────────────────────────────────────────────────┴──────┐
│ Develop Proper Hang Power Clean Technique: base for the power clean        │
└────────────────────────────────────────────────────────────────────────────┘
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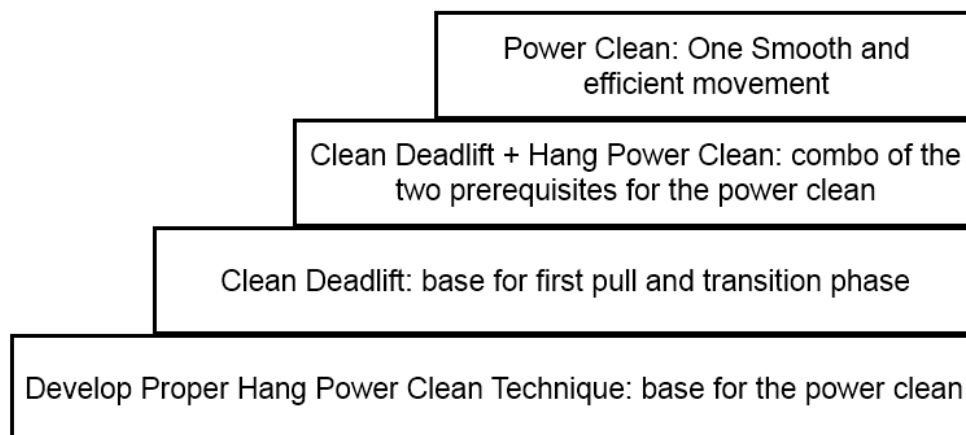
Figure 2.2 Progressing from the hang power clean to the power clean: A 4 step model. (Duba et al., 2009)

The figure 2.1 and 2.2 above shows a strength and conditioning method called the "top-down approach" where the skill progression is started at the top, and then the coach progresses the athlete down towards the floor in a linear stepwise manner. However from an ecological approach, key information sources are not present in the skill learning process. These internal and external information sources such as visual perception of the horizon and proprioception from

the floor are not there for the athlete to perceive. Emphasising Duba et al. (2007) and Duba et al. (2009) position that they have decomposed the skill into an entirely different skill. Confounding this Duba et al. (2007) only justification for this approach was a Hungarian weightlifting textbook from 1978. Hence, there is clearly no influence of contemporary coaching literature in this view. This type of skill breakdown is called part practice which is where the skill is broken down into smaller units (Fontana, Mazzardo, Furtado, & Gallagher, 2009). The coaching literature on part practice versus whole practice is not conclusive. However for discrete skills such as the power clean which have a clear start and an end. The research supports the whole practice methodology for this type of skill (Fontana et al., 2009). This top-down approach also is based on the belief that the skill of the power clean is to be taught in a linear fashion and athletes need to demonstrate the perfect or correct form before progressing (i.e. from Hang Power Clean to the Power Clean). The assumption that there is a perfect 'correct' movement pattern needs to be explored. To achieve this, we can follow a movement recipe Duba et al. (2009) to develop the 'correct' skill. This assumption is made from a belief that elite performers have very stable in-variable skills, which they can repeat over and over. However, this assumption has been shown to be false (Davids & Araujo, 2010) that experts often display more variability within their movement patterns than less skilled individuals (Slifkin & Newell, 1998, 1999).

Functional variability

Exploring functional variability is to be seen as essential in the development of skill (Davids et al., 2008), as it helps athletes adapt to ever-changing environments. From the dynamical systems viewpoint, we have a significant amount of redundancy within human movement (Scholhorn, Beckmann, Janssen, & Drepper, 2010). In other words, there are endless possible solutions for goal orientated movement to be achieved in different ways. The variability seen in the use of this redundancy was traditionally viewed as noise in the measurement of movement and if the accuracy of the measure were improved less variability is seen (King, Ranganathan, & Newell, 2012), however, this has not been the case. This concept is termed degeneracy of a dynamic system such as the human body, which allows the same structural parts to be used in different ways to achieve the same outcome (Bartlett, Wheat, & Robins, 2007). Davids et al. (2008) view this intra-individual variability as functional because it allows for greater flexibility and adaptability to non-stationary environments. The resultant functional variability of movement is achieved through the many degrees of freedom of the human movement system (Newell & Yeou-Teh,

2012). Degrees of freedom is a mechanical and mathematical understanding of human movement (Newell & Yeou-Teh, 2012). When considering the body as a mechanical system, there are thousands of possible degrees-of-freedom options that need to be controlled. That is, coordinating multiple joints, as they can functionally move in varying ways and achieve the same outcome. Having different ways to achieve the same result is due in large part to more joints being used, consequently, there are a large number of possible movement solutions. The added complexity from these added degrees of freedom needs to be understood when gaining an appreciation of the learning process and, in particular, an understanding of degrees-of-freedom problem (Bernstein, 1967; Vereijken, van Emmerik, Whiting, & Newell, 1992). Due to this range of movement solutions, novice performers tend to attempt to lock down joint segments or freeze the degrees-of-freedom used to simplify the task (Bernstein, 1967). As the athlete gains more experience, they progressively increase the variability of their degrees of freedom allowing for better skill execution (Davids et al., 2008; Vereijken et al., 1992). The addition of more degrees of freedom is critical to human ability to adapt to the ever-changing environmental conditions (Bartlett, 2008; Scholhorn et al., 2010). As a result, the performer needs to have the freedom to explore functional variability reflecting this non-linear process (Chow, Davids, Button, Shuttleworth, Renshaw, & Araujo, 2007).

Nonlinear Pedagogy

With the true nature of acquiring skill attributed to the individual differences of performers, a non-linear pedagogy is recommended (Fink, Kelso, Jirsa, & de Guzman, 2000). Non-linear means the performer may go through periods where their skill may progress as expected, go backwards or even plateau at times (Renshaw et al., 2009). This process has differing temporal speeds depending on the individual. As the formation of a new skill draws upon the performer's previous co-ordinated movement patterns and experiences to reshape the new behaviour to the new performance context (Chow, Davids, Button, & Renshaw, 2015). As each learner is different, the prediction of time periods in a linear fashion is the exception rather than the norm. Hence, as seen in figure 2.3 below from Newell and Yeou-Teh (2012) this learning change curve can be exponential (D-positively accelerated curve), linear (B-Linear curve) or curvy (S-Shaped curve) there is no predictability about the time this change will occur. As these learning curves are individual learner dependent.
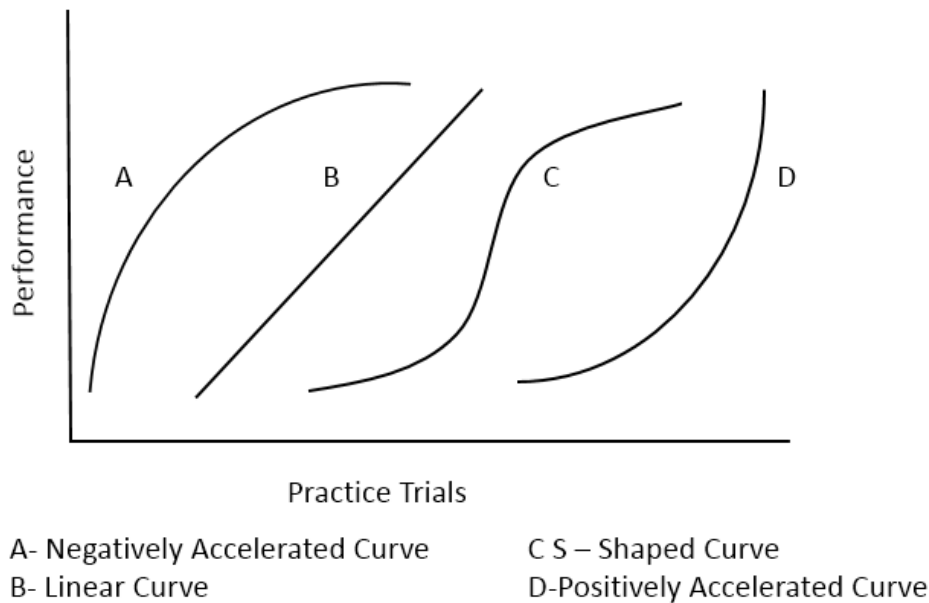
Figure 2.3 Typical theoretical learning curves Newell and Yeou-Teh (2012)

The rate of learning performance progress is dependent on feedback loops. A feedback loop is where the result of the previous attempt is feed back into the system where an internal conflict resolution process is engaged to determine the next action selection (Newell, Yeou-Teh, & Gottfried, 2001). This process is where competing movement behaviour attractor patterns are either reinforced or inhibited. An attractor simply is the point to which the movement behaviour is drawn towards (Prescott, 2008). Therefore, a positive feedback loop about an attractor state draws the performer towards this movement behaviour (Davids et al., 2008; Kelso, 1994). Then as more of the performer's subsystems start to align and coordinate together. The positive feedback loops get stronger and the behaviour may go through what is called a phase shift or bifurcation (Newell & Yeou-Teh, 2012). Where the old behaviour's attractor is now inhibited and the affinity to the new attractor causes a new emergent behaviour. This new behaviour is then reinforced and refined over time to become more coupled to the attractor. As Newell and Yeou-Teh (2012) describe learning as being typically a long-term persistent change and stability referring to the resistance to changing back.

In a nonlinear process, the first stage is the assembly of a coordinated pattern, as the learner establishes a basic relationship between the key components of the dynamical system. This coordination pattern goes through periods of stability and instability as patterns are developed. In this first stage, the learner may try to couple degrees of freedom to simplify segments into

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manageable components (Newell & Yeou-Teh, 2012). Newell builds upon Bernstein's original work on freezing of degrees of freedom. We understand that when learners first attempt to coordinate movement for a task, they will lock joint segments together to simplify the task. This locking of segments will initially form a coordinated movement behaviour. However, this is in contrast to higher skilled performers where these joints are not frozen but are coupled together to make subtle adjustments to the required outcome (Bernstein, 1967). Hence, this learning process moves from an initial coordinated pattern then the coach makes a change to the movement. Alternatively, in other words causing a perturbation to the system resulting in more complexity. This perturbation is needed for the system to reorganise around a new attractor (Renshaw et al., 2010; Vereijken et al., 1992). This addition of complexity cannot expect an instantaneous increase in performance but impose more instability in the movement behaviour (Chow et al., 2015). As the performer is forced to explore the new redundant degrees of freedom (Kostrubiec, Zanone, Fuchs, & Kelso, 2012). Throughout this exploration stage, a learner gains a tighter fit between their perception of the environment and coordination pattern (Newell & Yeou-Teh, 2012). Also, during this stage, coordinated structures can be reassembled to more flexible reflecting changing environments, reforming into slightly different configurations. Therefore, functional variability plays an important part in the skill learning process in forming adaptive motor patterns (King et al., 2012). When summarising this learning process, each learner will take their journey in their own way (Bartlett, 2008). Each learner will pass through periods where their movement will become more stable and then may pass through another period of instability as they attempt to self-organise. In relation to time, each learner will be different to each other and find their optimal performance at their pace (Chow et al., 2015). Therefore, instability in a skill should not be avoided but encouraged in the learning process, and instability is then a sign of learning or exploring movement.

To understand learning better, we must understand the main ways in which we learn. There are two ways learning can occur either explicit which is declarative and reliant on conscious processes. Then secondly implicit non-declarative and not reliant on conscious awareness or attention (Renshaw & Chappell, 2010). As implicit human learning developed first and explicit learning has only developed more recently (Maxwell, Masters, & Eves, 2000). In relation to ecological psychology and direct perception, much of the way in which we interact with our environment is implicit and occurs without conscious processing. Similarly, Reber (1992) report

conscious processing is limited by information processing capacity as there can be an overwhelming amount of information being perceived. It is not surprising that implicit processes underpin human movement as they move through the environment. Likewise Masters and Poolton (2012) suggest that subconscious control regulates most movement behaviors. In relation to coaching in a traditional explicit instructional manner, Bernstein (1967) believes this will force learners to switch to consciously controlled higher levels of action control, and this is what leads to disturbing the movement to now not be automatic (Beek, 2000). In addition, contemporary research suggests that acquiring a skill in an explicit instructional method like that of following a "recipe book". Leads to a decrease in skill retention and an increase the likelihood of choking under pressure (Davids & Araujo, 2010; Lam, Maxwell, & Masters, 2009; Masters et al., 2008). Interestingly, in relation to the context of strength and conditioning, a study from Lam et al. (2009) compared a skill learnt explicitly to implicitly and put under physiological, metabolic stress. The explicit group's skill was more likely to degrade. Hence the adoption of coaching methodology which improves implicit learning should be sought after in this context.

An implicit approach aligns with contemporary skill acquisition theory of a constraints-led approach (Poolton et al., 2007). This approach is based on how movement /skill is emergent from an implicit interaction of the individual, the task and the environment. The individual and the environment have different constraints or boundaries to action that have spatial or temporal components or both. Newell (1996) reports the dynamic properties of these constraints blend to change the movement outcome. As seen in the model figure 2.4 below the different constraints interact with each other through a direct perception and action process. An example of these task constraints are the goal of the task, specific equipment used and rules associated (Davids et al., 2008; Lam et al., 2009; Masters, 1992; Renshaw et al., 2009). Examples of Individual constraints are limb lengths, height, weight, muscle mass and range of motion. These would be termed as the organismic constraints. Some of these are modifiable and some are not (Davids et al., 2008). Ultimately these individual constraints affect the options for movement for the athlete, hence shape their movement intrinsically. Environmental constraints are physical variables within the environment such as weather, location, light and temperature (Davids et al., 2008).
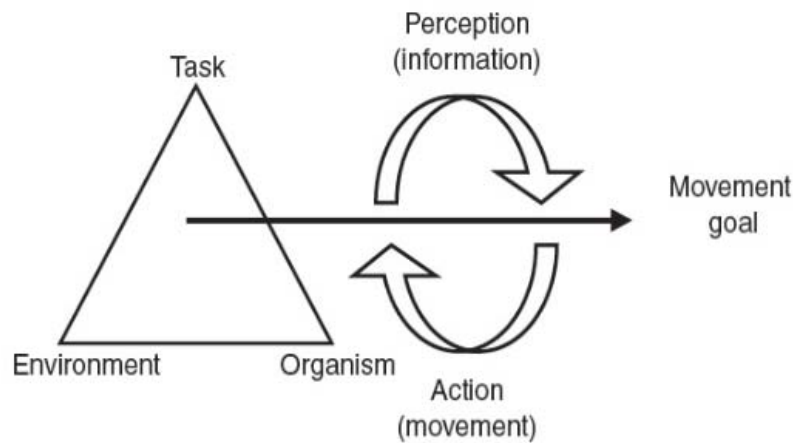
Figure 2.4 Constraints-led approach (Newell, 1996)

In a natural interaction, the coach manipulates the task and the environment to help shape the behaviour of the athlete. Practically the coach will create practice activities that provide the performer with many opportunities to become attuned to the specifying invariant information sources available in that environment (Scholhorn et al., 2010). In this way, coaching constraints can be view as a dynamic framework of boundary conditions that shape the way in which an athlete performs the skill (Renshaw et al., 2010). These sources of constraint to action, change what elements within the environment the athlete perceives and invokes the opportunities to explore new movement solutions (Chow et al., 2015). As a result of this the athlete shifts from attuning to variables that do not specify performance success to attuning to variables that do specify (Davids et al., 2008). Consequently, the key performance specifying variables need to be present within the practice environment so the athlete can detect the opportunities or affordances for action.

In this case, the current strength and conditioning practice where the power clean is decomposed into smaller parts does not allow the performer to detect the opportunities for action because the bar path is in a reverse order i.e. top-down instead of bottom up as the full movement. Hence, the use of a task constraint to aid in the performer's exploration of their entire movement has all the specifying variables within the task. The task constraint works by forcing the performer to explore the motor perception landscape for the attunement to specifying variables (Davids et al., 2008) . The motor perception landscape is represented graphically in the figure 2.5 bellow form Muchisky, Gershkoff-Stowe, and Cole (1996). The start and end of the line in the figure are representative

of the start and finish of a coordination pattern. Through the middle is a topological representation of the state space at which the system can move through (Moir, 2016). The hollows that develop are representative of the attractor state, and the deeper the hollow represents the stability of the system to that attractor (Davids et al., 2008). From the constraints-led perspective the path a system takes is dependent on the interaction of the three types of constraints (organismic, task, environment). The coach's role is then redefined to one of guiding the discovery of new effective attractors. The coach achieves this through constraint manipulation which changes the workspace configuration and guides the performer towards the movement solutions. The difficulty the coach faces is then in designing the workspace applicable to factors that are known to affect successful performance.
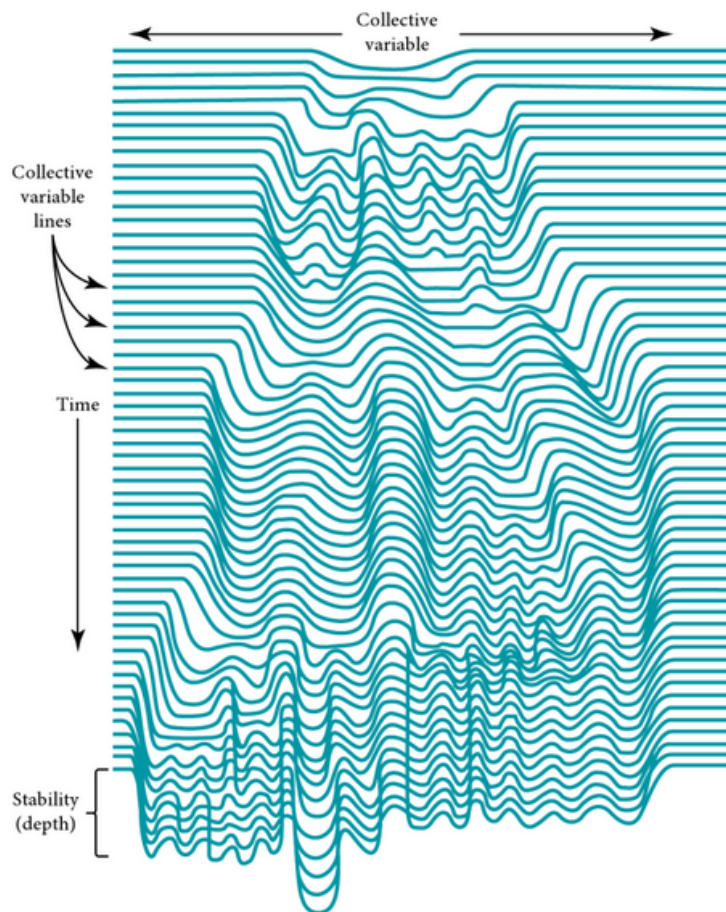

Figure 2.5 Motor perception landscape (Muchisky et al., 1996)

Inherent to this approach is an individualised method which takes into consideration the performer's own constraints and current movement behaviour to design appropriate task and environmental constraints. The reason why is, the fixed possible solutions to a movement problem

has been limited by the scope of the workspace imposed. When the boundaries of this landscape are set too tightly new areas of stability may be hard to find (Handford, Davids, Bennett, & Button, 1997). In contrast if the boundaries are too broad multiple attractor states may be present increasing the learner's difficulty at identifying the best attractor (Jacobs & Michaels, 2002; Muchisky et al., 1996).

A common skill in which the constraints-led approach could be applied to within the context of strength and conditioning is the power clean. This is because of its complexity requiring whole body intra-personal coordination to achieve the movement. The power clean skill has been derived from the sport of Olympic weightlifting. It involves moving a heavy barbell from the floor to the shoulders. Olympic weightlifting has been used as a power training modality for decades within elite strength and conditioning environments. It is a highly popular training modality nowadays in professional sport with 100% of NHL (Wilson et al., 1993), 95% of NBA (Ebben, Carroll, & Simenz 2004) and 88% of NFL (Simenz , Dugan, & Ebben, 2005) programmes utilising weightlifting movement's (Ebben & Carroll, 2001). Weightlifting movements are considered in strength and conditioning as highly specific to sports performance because they involve; the larger muscle groups of, the lower body, triple extension of the hip, knee and ankle and fast movement velocity (Hang et al., 2015). In more detail the power clean has frequently been used for its transference and close kinematic and kinetic relationship to vertical activities such as jumping (Comfort, Fletcher, & McMahon, 2012). Second, the optimal stimulus for training for the development of muscle power is to use an activity and load that optimises power output (Rucci & Tomporowski, 2010; Souza, Shimada, & Koontz, 2002; Stone et al., 2006).

Optimal characteristics of high-performance of the Power Clean skill.

To improve the power clean performance we need to understand clearly what the critical performance features are and what the individual differences could be. A key performance capability in performing the power clean is to produce a significant amount of force rapidly (Cormie, McGuigan, & Newton, 2010a; Wilson et al., 1993; Winchester et al., 2005). In order for the performer to achieve this rapid, force production safely. The bar needs to achieve certain positions in relation to the performer (Stone et al., 2005).

Power Clean Kinematics

The direction of the bar path during the power clean can be broken down into three phases; the first, second and catch phase, which are shown in the photos below (Figure 2.6, 2.7 & 2.8). Within these phases, there is also key positions identified by Stone et al. (2006), which have been shown to relate to lifters being able to achieve better success in the movement; these are:

Position one (figure 2.6 below) is the lift off in this position the shoulders are over and in front of the bar (Stone et al., 2006; Winchester et al., 2005). During this phase of the lift, the idealise bar path is towards the performer in the horizontal plane (Baechle & Earle, 2008). Stone, O'Bryant, Pierce, Williams, and Johnson (1998) Identified significant factors that correlate to a higher load lifted during this phase. One of these factors being torso angle needs to remain steady, constant and controlled this is not the explosive phase of the lift.

Position two (figure 2.6 below) the shoulders are still over and in front of the bar the knees have pulled back out of the way. The bar path is still tracking towards the performer in the horizontal plane. The bar velocity should be controlled to this point (Kristof, Redden, Sabick, & Harris, 2012)

Figure 2.6 First Pull Phase

Position three (figure 2.7 below) correlates to the double knee bend position or transition phase. The double knee bend is where the knees rebend driving forward under the bar. This double knee bend has been shown to be the most efficient technique (Winchester et al., 2005). This technique allows the bar path to track towards the hip joint. Through this phase is the highest rate of force development and peak force expression, while the feet are still flat, and the torso is almost vertical.

Position four (figure 2.7 below is the achievement of triple extension of the hip, knee and ankle (Kawamori et al., 2006; Stone et al., 2006).
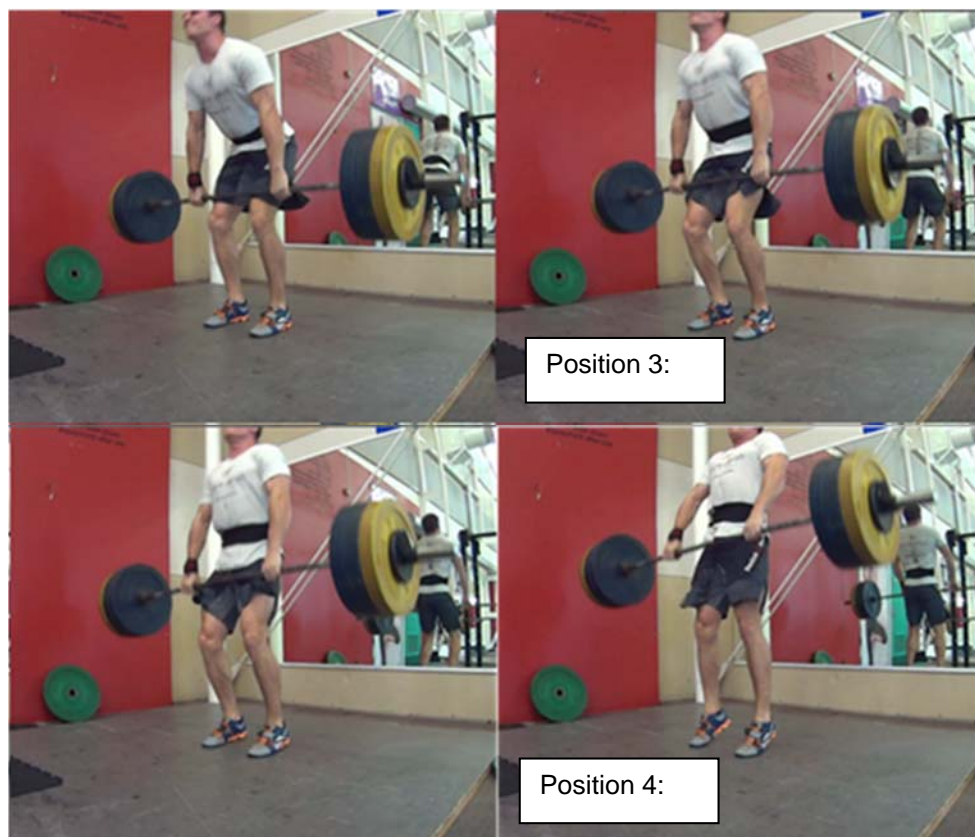
Figure 2.7 second pull phase

Position five (figure 2.8 below) is the catch phase in this position the bar path should be toward the performer in the horizontal plane but no more than 20cm behind the most forward position of the bar (Rucci & Tomporowski, 2010). Winchester et al. (2005) has also identified differences between non-elite and elite involving speed under the bar in this position which exploits shoulder flexibility requirements. If the bar is not resting on the body, this significantly impacts the total weight the performer can lift (Stone et al., 2006).

Position 5:

Figure 2.8 Catch phase

Bar path factors

Analysing this lift the bar path is critical at identifying the optimal lifting mechanics. Stone et al. (2006) identified key bar path factors that highly correlate to the successful performance of the power clean these factors are identified in the diagram below (figure 2.9).

Dx2 seen in figure 2.9 is a rearward direction of the barbell off the floor during the first pull. This rearward direction of the bar is where according to Winchester et al. (2005) the bar should make contact brushing the performer's thigh but not a drag or bang (as seen in position 3 in figure 2.7 above).

DxV is the amount of horizontal displacement from the end of the Second pull to the most forward position (figure 2.9). This measure is indicative of the force direction applied to the barbell more horizontal displacement is associated with "hipping" (Stone et al., 2006) or hitting bar aggressively with their thighs. Winchester et al. (2005) also associate this with a greater energy expenditure to bring the bar back toward the performer to successfully catch the bar on their shoulder.

DxT (figure 2.9) Total horizontal displacement of the barbell from the start of the lift to the finish which is indicative of the total forces applied during the lift. An example of this is a performer having to jump forward under the bar because the net displacement of the bar is forward of the start instead of a more vertical application of force where the performer does not need to jump forward.

DxL the most forward position to the most rearward position in the catch (figure 2.9 below). This DxL can be described as the amount of looping of the bar, which should not exceed 20cm

according to Stone et al. (2006). A larger DxL is associated with the degree the performer needs to pull the bar back towards them. Example if the performer has applied too much horizontal force forward they are either going to need to jump forward or pull the bar backwards. Hence, at higher barbell inertial loads the degree the performer can pull the bar back is more impaired. Overall this shaped bar path is often called an S shape seen in figure 2.9.
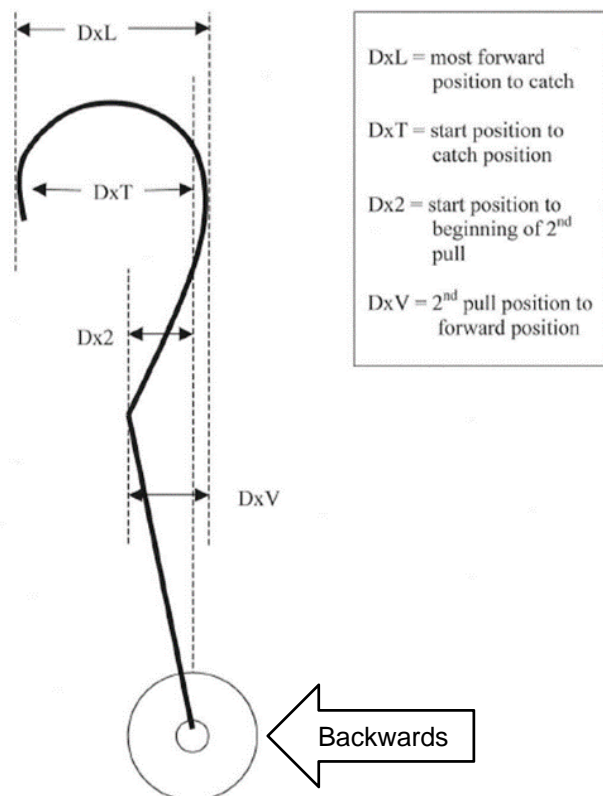

Figure 2.9 Bar path measures from Winchester, et al (2005)

In a similar weightlifting movement, the snatch Stone et al. (2006) reported a significant correlation in which 76% of successful lifts had a rearward direction to the bar path off the floor. More interesting of failed attempts 64% of them where caught in front of the starting position or had no rearward direction off the floor (Winchester et al., 2005).

These critical factors that are known to correlate to performance will underpin the task constraints a coach will apply. Hence, methods utilised should shape the performer's skill toward these known critical factors to performance.

Training loads changes and technique and performance

The common training loads utilised by strength and conditioning coaches have been investigated. According to Stone et al. (1998), loads of 100% measured through one repetition maximum are significantly correlated to maximum strength, power, jumping and sprinting performance. Additionally Hori et al. (2008) investigated optimal loading to be used for the power clean to optimise maximum power output reporting loads of 60-80% are best. Then normal training loads then vary from 60-100% of 1RM. In another study from Comfort et al. (2012) explored different training loads of 65 -75 -85% on kinetic and kinematic variables. Finding that load lifted changed joint kinematics of the joints of the lower extremity. Therefore even within a 20% training load change, there are significant differences in techniques used. From the limited previous research about applying coaching intervention to improve the power clean commonly, light training loads have been used. An example of this is Kipp, Harris, and Sabick (2011) applied an action observation facilitated learning method to a group of Australian footballers learning the power clean. Where the loading utilised in this study was only 30kg and justifying this as a safety reason. There is then a large assumption that light training loads of 30kg will teach the safe technique at much greater loads. However, this assumption is significantly flawed as the technique shown by Sakadjian, Panchuk, and Pearce (2014) changes dependent on load. The affordances of a heavy barbell are quite clearly different to a light bar. Additionally this 30 kg was never changed and in the field of skill acquisition learning is defined as stability to change under stress (Kipp et al., 2011). Then they cannot only use one training load to demonstrate learning has occurred. Hence, to prepare the athlete for the higher training load coaches need to ensure practice training loads are representative of the demands they are going to face. In this way safety is still a priority and coaches need to be careful what the boundaries of acceptable exploration they will allow while still keeping the athlete safe. The coach needs to observe the athlete and ensure movement exploration is occurring in the desired place and evaluate if modifications to the task constraint need to be made because the movement is unsafe. To be clear this approach is not advocating no coach involvement, as coached sessions have been found to be safer by Frost, Beach, Callaghan, and McGill (2015) when comparted to non-coached sessions in the gym context.

Conclusion

In conclusion, what is proposed in this constraints-led approach is in contrast to current strength and conditioning practice which emphasises reproduction of a particular technique through explicit "verbalisation, task decomposition, higher level cognition and a dependency for error correction external sources such as a coach" (Chow et al., 2015). The approach that is proposed in this thesis is to free the performer to explore the possibilities for movement rather than the reproduction of a "recipe book" (Handford et al., 1997) to movement. This learning process in the early stages according to Davids and Araujo (2010) should involve very little coach intervention as explicit instruction may only assist in the short term coordination of the skill. This explicit instruction will also impair the long term development of the learner as they will developed a provisional solution to the movement coordination. Where the learner is not coupled to the key environmental invariants. This may also affect the skill transfer to the variety of novel experiences within the sporting environment. As reported earlier one of the key goals of a strength and conditioning coach is a transfer of training to the real sporting context. Therefore, this current coaching practice may be limiting performance transfer and skill learning.

Chapter 3: Methodology

Introduction

From the literature review, it is apparent that there is a research gap for strength and conditioning coaches to apply coaching and skill acquisition theory and its method in their practice. In brief, this research will utilise an implicit skill acquisition approach involving self-organisation. The method used is a constraints-led approach. A constraints-led approach shapes the learning environment through the interaction of the task, organism and the environment (Davids et al., 2008; Renshaw et al., 2010; Renshaw et al., 2009). The strength and conditioning skill used in this study to explore the application of a constraints-led approach was the power clean. The power clean skill was chosen due to its complex nature requiring a significant amount of coordination and its prevalence in the strength and conditioning programmes (Rucci & Tomporowski, 2010). Hence, the purpose of this study is to apply constraints to reshape positively each of the participants' power clean skill.

Methodology

Ecological dynamics as described by Chow et al. (2015), along with Kelso (1994) dynamical systems and constraints driven approaches to learning Newell (1996), advocate a phenomenological approach to studying behaviour. That is to say these perspectives view learners as being embedded within a complex system that emphasises the uniqueness of that system and the way it shapes their actions. From this perspective two important directions should be acknowledged; firstly, any intervention fits the learners' needs and secondly, that resultant learning trajectories are unique. This in turn means that constraints to be applied to learners in this study, will not be the same and therefore, an intra-individual analysis forms the platform from which the efficacy of interventions will be assessed. Put in simpler terms, what needs to be improved will be unique to the lifter, consequently the means of measuring any improvement will also be different. With this in mind a case-study approach is most appropriate. These case studies will be examined through individually specified outcome variables and their respective non-linear behaviour in accordance with Newell (1996). Furthermore, in keeping with an

ecological approach and representative design; expert coach knowledge should be included in the development of any intervention where it can be reconciled with a constraints-led approach.

Methods

Study Design

The study design was through a series of case studies (n= 3). The case study design was selected due to its strength for studying contemporary phenomenon within the real life context (Robson, 2011). These case studies analysed individual participants progress with the acquisition of the skill utilising a constraints-led approach method; in particular, how a constraints-led approach can influence the movement of the bar path and participant during the power clean. The bar path and participant kinetics and kinematics were evaluated pre and post intervention. Additional repeated measures of bar path and participant kinematics were observed for every intervention session to track progress and measure learning.

Subjects / Participants Recruitment, Inclusion-exclusion criteria

Participants were recruited using posters placed within a commercial gym to identify if individuals had sufficient movement quality for them to undertake the power clean. The participants needed to demonstrate a minimum score of 14 out of 21 points on the Functional Movement Screen (FMS) and report no body pain (Minick et al., 2010). This FMS identified participants with movement compensations that would also impact on their ability to acquire the power clean (Cook, Burton, Hoogenboom, & Voight, 2014a, 2014b). A second movement competency assessment was undertaken using visual observation of the Front Squat to determine the pre-requisite upper extremity flexibility. The individual needed to know what the power clean movement is, but previous experience in performing the power clean was not necessary.

The participant invitation was contingent on analysis of their deviation from a good bar path and double knee bend technique described in the literature (Stone et al., 2006). Also, participants with a higher peak force on the strength test were preferred. Cormie, McGuigan, and Newton (2010b) showed that strength training is equally effective for power development in individuals lacking in strength. In a second study by Cormie et al. (2010a), they reported that stronger individuals had better adaptation to ballistic power training when they had a higher percentage 1RM back squat to body weight. Therefore, this study invited participants of a high strength ratio achieving a

minimum of 2.0 x bodyweight on the isometric mid-thigh pull. As these individuals would be representative of the type of athlete, appropriate for this mode of power training.

Table 3.1

Participants

Participants	Age	Weight	Height
1	20	102 kg	1.84 m
2	34	94.5 kg	1.86 m
3	21	93 kg	1.8 m

In addition to the FMS, mid-thigh pull and qualitative movement assessment a one repetition maximum (1RM) power clean was analysed. Kinematic and kinetic variables were taken from a portable force platform and video analysis. The force platform was used to calculate kinetic variables of peak force and rate of force development. Video analysis was used to derive kinematic variables from the barbell.

The participant's kinematics and body position about the bar will be established at 1RM. Also, the load of 70%, 80%, 90% of 1RM were analysed to assess any changes in lifting technique. From the video analysis the barbell kinematics variables were adapted from those identified by Winchester et al. (2005). These are; 1) the start position to most forward position to, 2) the start position to, 3) the start position to beginning of 2nd pull, and 4) the 2nd pull position to catch. Additional kinematics variables were taken from the participant adapted from Rucci and Tomporowski (2010); Sakadjian et al. (2014) listed below.

Research equipment

Kinetic data was recorded on a portable force plate (AccuPower, AMTI Watertown, MA) embedded in a custom built platform. Kinetic data was only collected during the pre and post testing. Kinematic data was collected using two 50 Hz, high definition digital video cameras (Panasonic HC-V520M) on tripods positioned 7m anterior (frontal plane) and 7m lateral (left side, coronal plane) to the athlete at a height of 75cm. A camera was then zoomed in to adjust the field of view to the full limits of the lift movement. A grid was taped to the floor 50cm x50cm as scaling measurement directly underneath the middle of the participant and a second scaling

rod 100cm was placed directly underneath the end of the barbell (as seen in figure 3.1 below). The bar path was then digitised using Kinovia version 0.8.15 software previously validated as a highly reliable video analysis method (r=0.9997) (Balsalobre-Fernández, Tejero-González, del Campo-Vecino, & Bavaresco, 2014). Marker less kinematic data was collected for every lift of every session for the duration of the intervention. Clear anatomical land marks such as the middle of the ear, olecranon process and end of the barbell where used to provide the kinematic data.
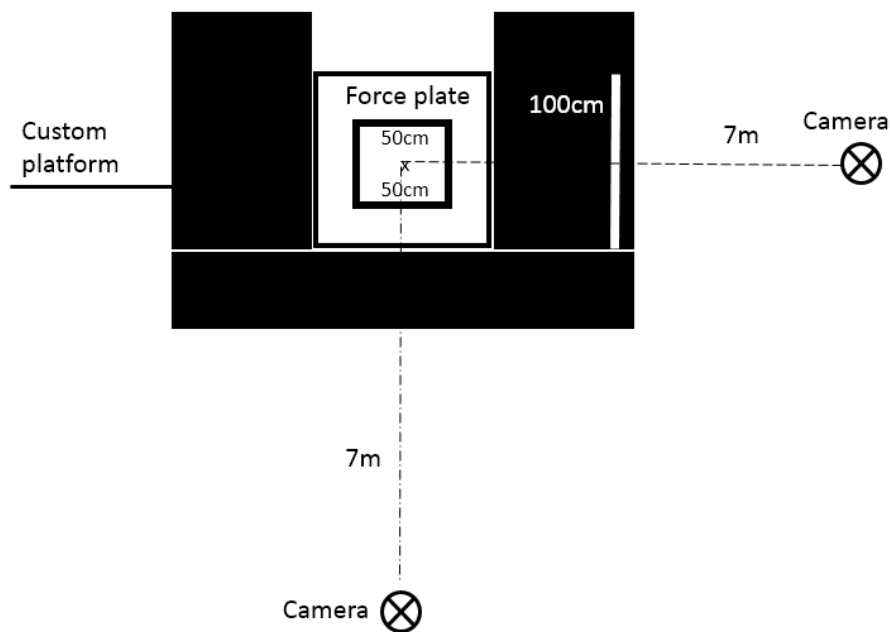

*Figure 3.*10 *Camera setup for testing session*

Intervention

The series of case studies were carried out across 6-7 weeks with two 60 min sessions per week; producing a total of 12 sessions. The 1st and 12th sessions involved testing.

Sessions 2-11

These coaching sessions the participants performed power cleans and then from the testing analysis, of these lifts they were then categorised based on their common faults. They were then allocated coaching activities (constraints) to shape their movement based on their individual needs.
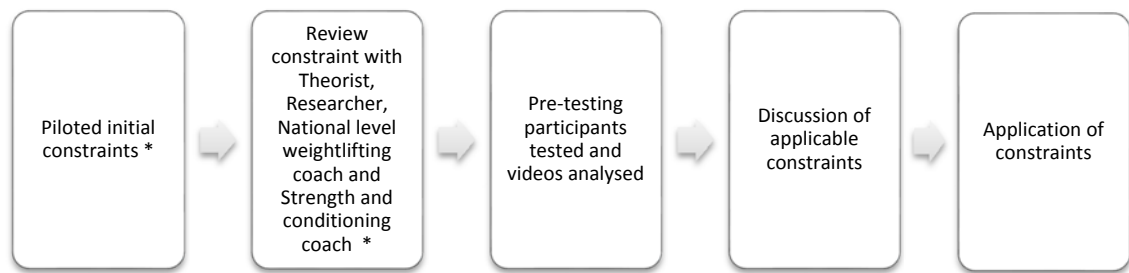
Figure 3.2 Constraint selection intervention process

See appendix A for the *constant development process

The process undertaken to design the constraints for this study followed the process in the flow diagram figure 3.2 above. Initially, a large list of constraints was formed; these constraints were then piloted with a group of athletes to evaluate their effectiveness qualitatively. This larger list was then reviewed and narrowed down substantially during a consultation meeting with a group including a National level Olympic Weightlifting coach, Theorist, Researchers and Strength and Conditioning Coach. In this way expert coach's knowledge was included in the constraint formation process. The next step was the analysis of the different case study participants to evaluate what constraint would apply best to optimise their power clean performance. Post analysis the constraint assignment was discussed between the researchers and theorist to ensure effective justification of constraint assignment.

Coaching session outline

For the ten training sessions, participants performed a standardised warm-up consisting of dynamic stretches (arm and leg swings) and warm up exercises of box jumps and barbell only front squats (3 sets of 6 reps). Training load was adapted from Winchester et al. (2005) where the two sessions per week were split into a heavy day and a moderate day. On the heavy session, the participants gradually worked up in weight across a standardised 6 set warmup to 3 sets of 1 repetition at 90% of their 1RM. The task constraint was applied through all warm up sets then removed on training sets to avoid developing a dependency on the task constraint. On the moderate sessions participants again gradually worked up in weight across a standardised 6 set warmup to 4 sets of 3 repetitions at 70% of 1RM. The task constraint was present during 70% sets and gradually removed to avoid the development of dependency.

Development of analysis for each case Study

Due to the individualised nature of the constraint assignment an analysis was developed for each individual case study to assess the effectiveness of the constraint on the desired outcome.

Statistical analysis

Root mean squared error (RMSE) was used to determine the amount of within-session variability of the primary variables. This RMSE assesses accuracy and stability of the movement. It is used to reveal the underlying (coordination) dynamics: The smaller the RMSE, the greater a pattern's accuracy and stability (Kostrubiec et al., 2012). A low RMSE is a result of a more accurate or stable pattern. RMSE in this study simplified is the average difference of each of the repetitions away from the mean. X_{mean} is the average difference of each repetitions variable.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs} - X_{mean})^2}{n}}$$

Figure 11 RMSE equation

Case study one evaluation and constraint assignment

In the post-testing evaluation, it was found that participant 1 used excessive bar "hipping." An average of 17 cm excursion away from their body during the 2nd pull as seen in figure 3.4 below. As established earlier in this paper excessive hipping of the barbell is less efficient due to more force being generated horizontally rather than vertically (Winchester et al., 2005). The constraint deemed to be most effective at correcting this was the poles constraint. Agility poles were put in front of the bar start position; now if the participant utilised their old movement they would hit the poles.
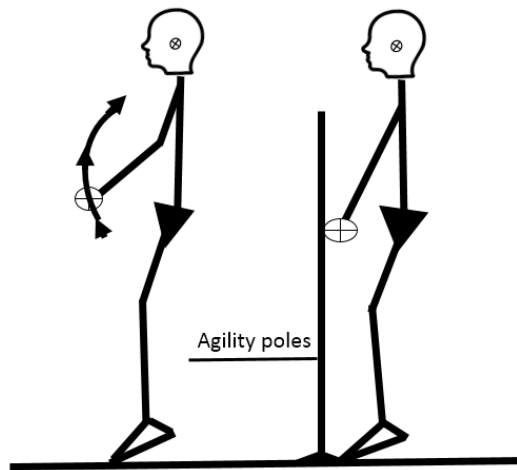
Figure 3.4 Pole Constraint

Case one hypothesis: The pole constraint will beneficially affect the horizontal displacement of the bar moving away from the participant's body.

Primary measure

Bar path variables were modified from figure 2.9 above (Winchester et al., 2005) to assess the specific effect of the constraints (modified barbell variable seen in figure 3.5 below). In the first case, the measure of the horizontal displacement of the bar in relation to the starting resting position of the bar before the participant moves. DxF, as seen in the diagram below, is a measure of the maximum horizontal displacement forward (DxF).

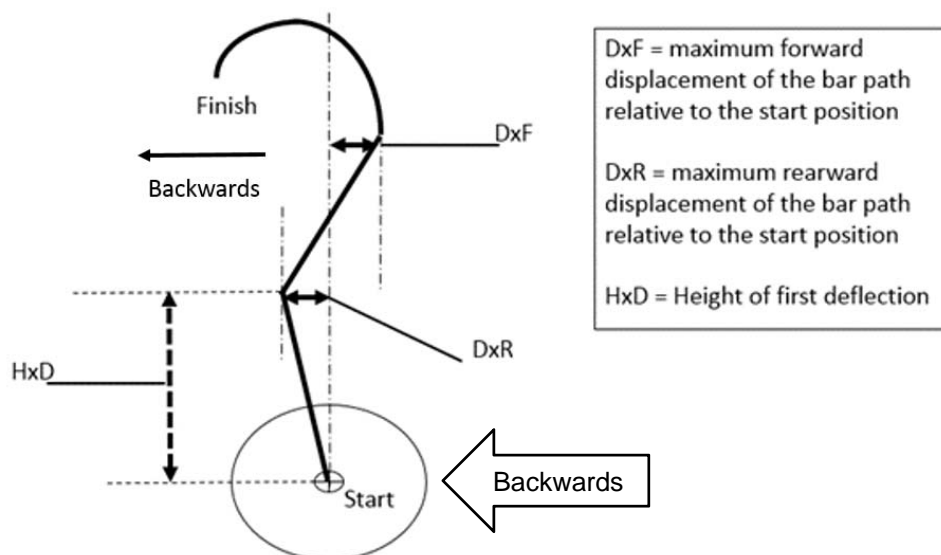

DxF = maximum forward displacement of the bar path relative to the start position

DxR = maximum rearward displacement of the bar path relative to the start position

HxD = Height of first deflection

Figure 3.5 Bar path measures

Secondary measures

In case study one additional measures were added as a second constraint was added. This constraint was added due to movement changes caused by the first constraint opening up new affordances with the participant's catch position. The verbal task constraint added was the participants needed to "have the bar contact their shoulder in the catch position". Hence, a measure of the participant's forearm in relation to absolute vertical as you see in the diagram below will give a measure of where the barbell load is. The higher the angle it is closer to being in the participant's hand or lower angle on their shoulder.
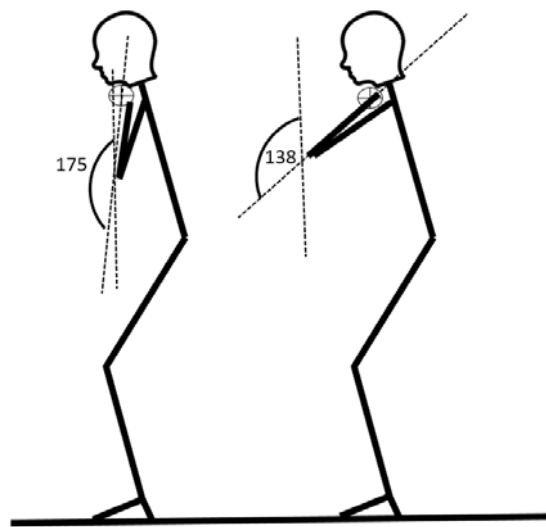

Figure 3.6 upper arm angle

Unexpected mediating variable

Post-intervention analysis of case study one an unexpected effect was seen. Therefore, a new mediating variable was added. The variable was shin angle in relation to horizontal as seen in the diagram 3.7 below. This variable was used to measure if the knee re-bent after they extended during the first pull phase.
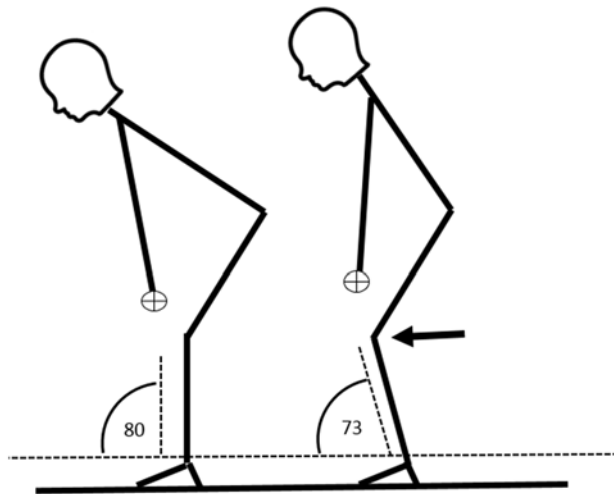
Figure 3.7 Double knee bend measure

Case study two evaluation and constraint assignment

Case study two pre-testing revealed very little rearward direction of the bar off the floor (0.7cm). With an overly straight bar path in contrast to a more advanced S shape (Stone et al., 2006; Winchester et al., 2005). In this case, the constraint deemed to be appropriate was chalk on the barbell just inside the hands. The participant was told they need to leave chalk on their thighs after the movement as seen in figure 3.8 below.
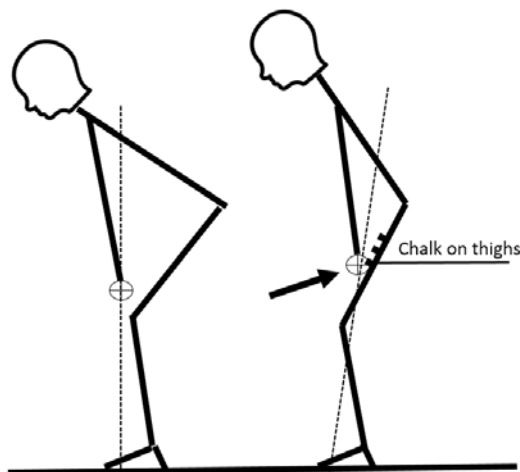

Figure 3.8 Chalk constraint

Case two hypothesis the chalk constraint will positively affect the horizontal displacement of the bar moving towards the participant's body during the first pull.

DxR if the figure 3.9 below is then a measure of the maximum horizontal displacement rearward (DxR). Case study two also used a measure of what height this DxR occurs to give the deflection point at which this occurs. This measure allow the understanding of if the participant was still exploring the timing of their hip extension.
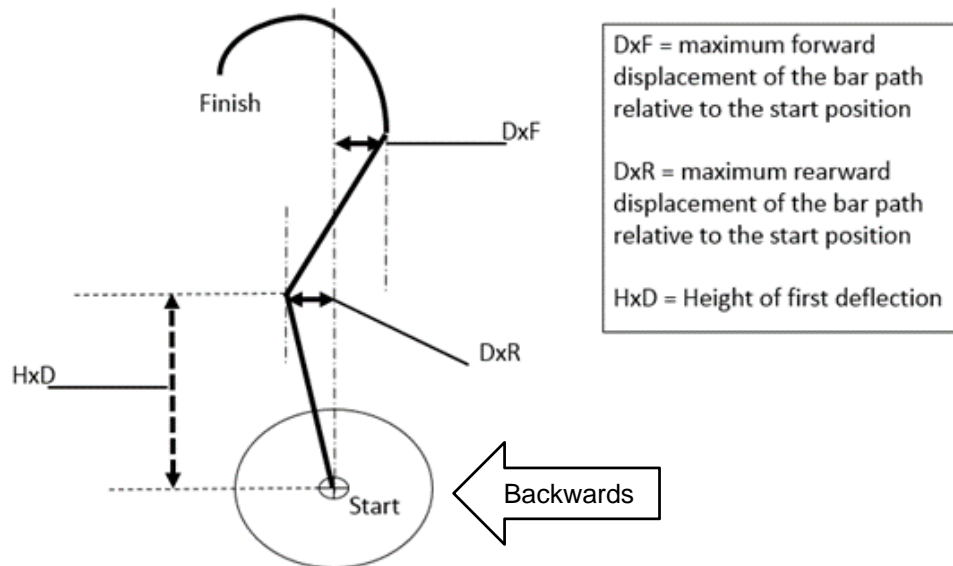

Figure 3.9 bar path measurements

Case study three evaluation and constraint assignment

The participant in case study three's movement during the power clean cause them to jump forward between 4-8 cm with an average of 6 cm. In this case jumping forward towards the bar is deemed less optimal than a jump backward. This technique being called "Pull back jump back" from the National level weightlifting coach involved in the study. As a result, the constraint used in this case was the cliff constraint. The participant was placed on the edge of an 8cm cliff (as seen in the figure 3.10 below). This constraint utilised the intrinsic dynamics of cliff avoidance seen in studies of motor development (Kretch & Adolph, 2013). The participant will instinctively avoid cliffs and to jump away from the cliff fixing the jump forward.

Case three hypothesis the cliff constraint will positively affect the horizontal displacement of the participant moving posteriorly after the second pull.
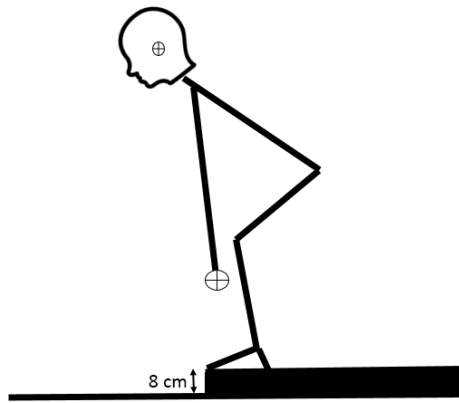
Figure 3.10 Cliff constraint

The measure used in this case for jumping forward is in contrast with Winchester et al. (2005) DxT, which was described in the research as being able to discern horizontal displacement of the barbell pre to post lift. However this measure is not valid in this case as the participant was jumping forward more with one foot than the other with as large of a different as 9 cm in the 1RM test causing the bar to rotate significantly changing the DxT measure to more positive due to the parallax error. Hence measuring each foot displacement was deemed reliable and a more valid measure.

Horizontal displacement of each of the participant's feet was taken from each toe after the first pull phase (as soon as the weight plate revealed toe) to the completion of the lift. Additional measures of the participant's ear position were added to indicate their direction of pull from their centre of mass position. The maximal horizontal distance the ear is in front (falling forwards) and maximum horizontal distance the ear is behind (falling backward) seen in the figures 3.11 and 3.12 below.
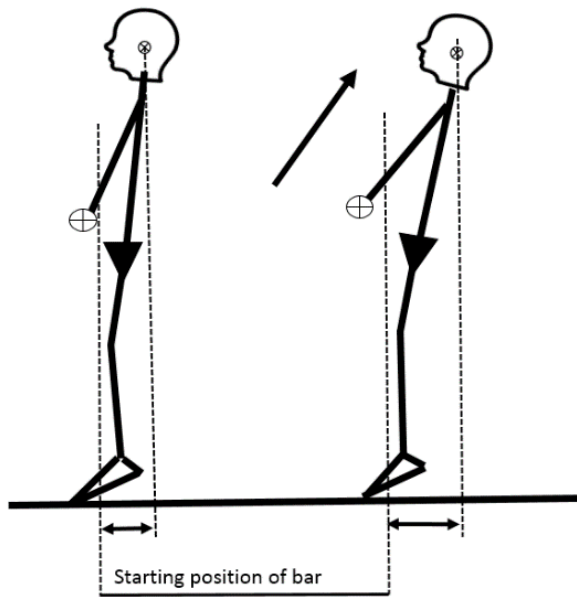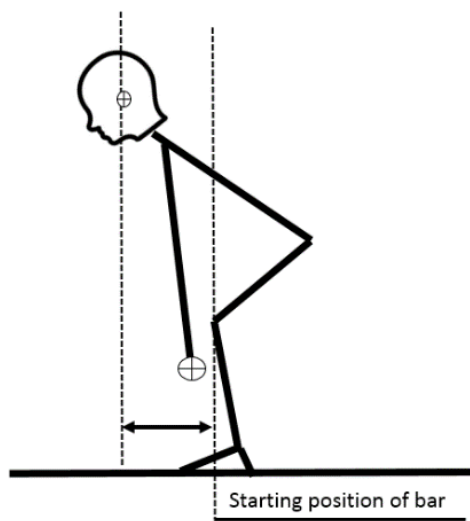
Figure 3.11 most rearward ear position

Figure 3.12 most forward ear position

Chapter 4: Results

Following a phenomenological approach and thus adopting an intra-individual analysis, the results of the three case studies will be presented individually. A summary table of the three case studies is presented in table 4.1. This table presents whether the constraints applied had a positive or negative effect on the outcome measures used to evaluate the effectiveness of a constraints-led method. Here it can be quickly seen that for each case study, the intended movement change was achieved. In addition, cases 1 and 2 had a performance increase in 1RM from pre-test to post-test, with case 3 having a performance increase following this period.

Table 4.1

Overall results on outcome measures

Case	Intended movement change (effect from constraint/s)		Performance (1RM)	RMSE (return to baseline)
Case 1	✓	✓	✓	✓
Case 2	✓		✓	X
Case 3	✓		X*	✓

*anecdotal performance improvement 2 weeks following

Below in table 4.2 is the reliability of the video analysis measurements. The typical error was calculated from randomly chosen repetitions from 6 training sessions and re-measured on 3 separate days for one of the participants.

Table 4.2 Reliability of video measures

	Horizontal Barbell	Vertical Barbell	Angle
Typical error	0.4 cm	3.0 cm	1.6°
Lower confidence Interval (95%)	0.2	2.1	1.1
Upper confidence Interval (95%)	0.7	6.5	3.4

Case study one results

From the pre-test analysis, participant one "hipped" the bar causing a large horizontal displacement forward of the barbell. Therefore, the use of a pole constraints was applied to decrease this horizontal displacement measured through DxF as seen in Figure 4.1 below. The second verbal task constraint ("the bar must make contact with your shoulder") also had a positive effect on the desired movement change where the barbell now rested on the shoulder and not in their hand.

DxF = maximum forward displacement of the bar path relative to the start position

DxR = maximum rearward displacement of the bar path relative to the start position

HxD = Height of first deflection
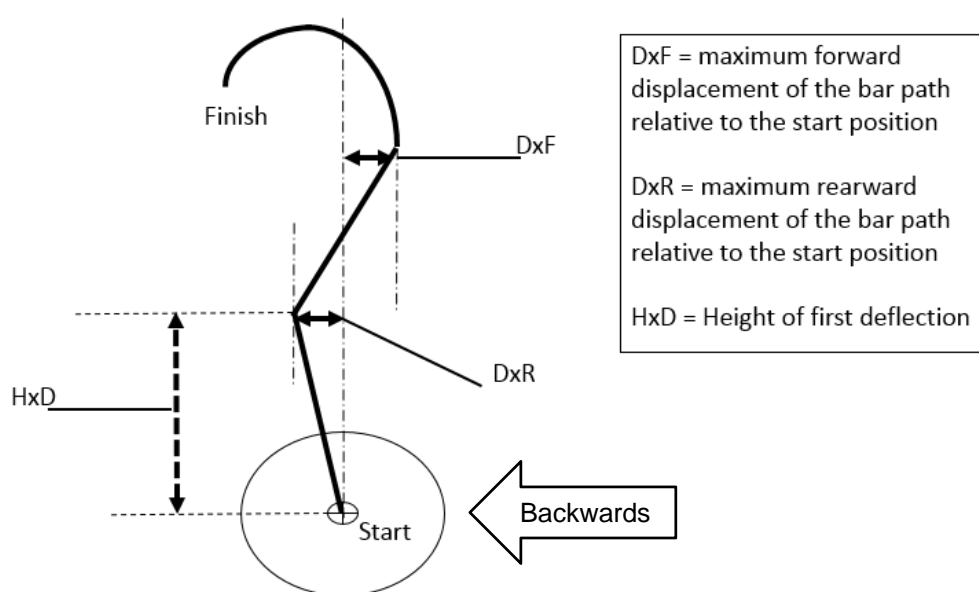
Figure 4.1 bar path measurements

Table 4.3 (below) displays the significant change in the positive direction in DxF from 16.9 cm pre-testing to 5.6 cm post testing. This result was in accordance with the expected change in technique where the bar now travels closer to the participant. There was a gradual change in this measurement until the 4th training session then a flattening off as seen in the graph in figure 4.2 below. In addition the RMSE post application of constraint of 2.32 cm to 1.24 cm shows a progression from more variability in this measure to more stability. Indicating the new movement behaviour becoming more coupled.

Table 4.3

Case study one bar path DxF measure

Session		Pre	1	2	3	4	5	6	7	8	9	10	Post
	90%	16.8		11.9		6.3		3.2		6.1		5.1	5.6
DxF (cm)	70%		11.8		7.6		4.3*		9.6		7.8		
	RMSE		2.3	3.3	2.3	3.0	1.5	0.9	2.7	1.0	2.6	1.2	

*Constraint present

Figure 4.2 Maximum forward horizontal displacement of the barbell from starting position. (DxF)
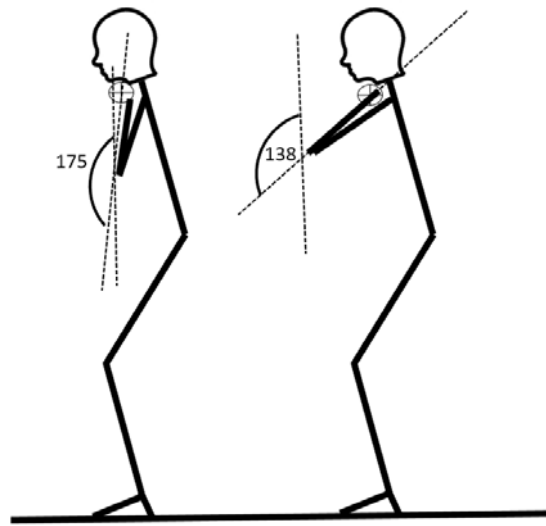
Figure 4.3 upper arm angle

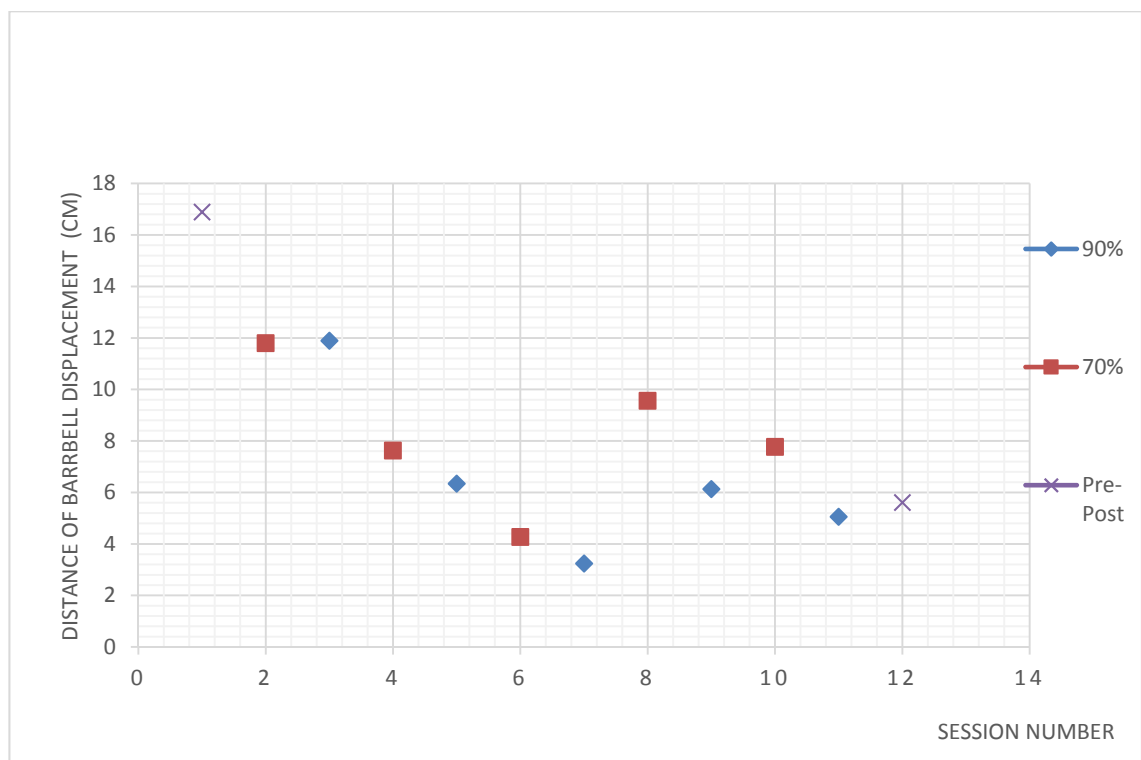The upper arm angle is seen in figure 4.3 above and table 4.4 below changed from 175° degrees in the pre-testing to 138° degrees in the post-testing session. Furthermore, this decrease in angle was more evident post training session 5 showing a difference of 25 degrees coinciding when the verbal task constraint was applied (Rule that the participant must make shoulder contact with the bar). During the following three sessions post the constraints implementation, sessions 5, 6 and 7 show exploration of state space with RMSE of between 8.3° to 12.0°. This varability shows large differences repetition to repetition indicating the participant searching to find the new solution to the verbal task constraint. Additionally, the RMSE moving from 12.0° to 4.0°, shows a progression from more variability in this measure to more stability; thus indicating learning a new movement and it becoming more embedded.

Table 4.4

Upper arm angle

Session		Pre	1	2	3	4	5	6	7	8	9	10	Post
Elbow	90%	175		172		178		153		148		131	138
	70%		176		146		161*		157		142		
	RMSE		5.7	7.4	3.0	2.9	8.3	12.0	9.5	3.3	6.3	4.0	

*Constraint present

Re-bending of the knees

The measurement of shin angle in relation to absolute horizontal changed positively from pre-testing 80° degrees to 73° post testing (seen in Table 4.5). Figure 4.4 below is a visual representation of this shifting of the knees back under the bar. This change indicated a shift in the participant movement from a single knee bend technique to the more advanced lifting technique of the double knee bend. Once again training session five is where these changes become more evident and in accordance with previous results the RMS is trending to more stability.

Table 4.5

Double knee bend

*Constraint present

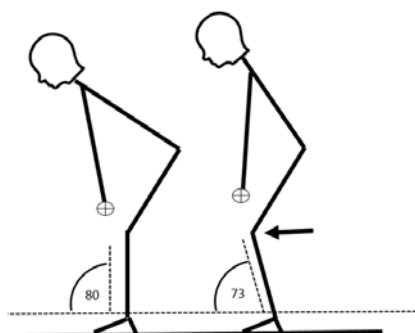|	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
Shin angle	90%	80		78		82		75.7		74.7		71	73
	70%		81.1		79.5		74.2*		74.3		70.1		
	RMS		2.1	1.4	1.8	2.2	1.4	1.3	1.2	0.5	1.9	0.8	

Figure 4.4 Double knee bend measure

Power clean 1RM

Comparison of the 1RM power clean pre was 97.5kg to post 112.5kg was a 15.5% improvement in power clean performance (seen in table 4.5 below). Furthermore, peak force during the pre 1RM lift changed improved from 3143N to 3515 N, indicting the new lifting technique to be much more efficient at producing peak force.

Case study two results

The chalk constraint was applied to bring the bar closer to their body and avoid a straight bar path. Participant two's bar path was straight and had no rearward direction from the floor as you can see from the figure 4.5 below.
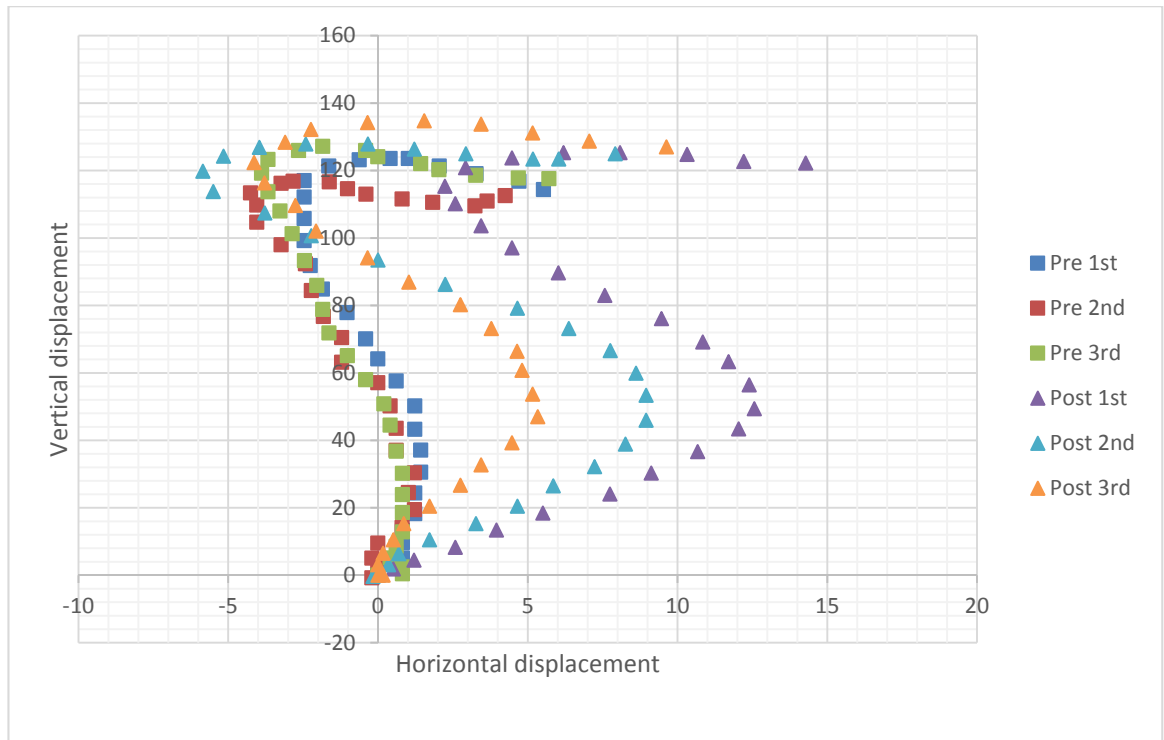
Figure 4.5 showing pre to post comparison of bar path where the pre-testing is very straight and the post is more S-shaped.

The change then in the rearward direction of the bar off the floor measured through DxR is evident ~0.82 cm pre-testing to ~7.14cm post. This change was expected with the chalk constraint where the participant brings the bar closer to their body off the floor. However, it is evident from the high degree of variability (as seen by the RMSE table 4.6) that the participant is still exploring the state space; as a new movement pattern not yet to be coupled with RMSE values pre 0.3 and post 1.8.

Table 4.6

DxR (horizontal displacement of the bar off the floor)

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
	90%	0.8		6.5		7.3		2.0		5.3		6.3	7.2
DxR	70%		9.9		10.1		8.5		9.3		10.2		
	RMS	0.3	1.9	0.9	1.8	2.0	1.7	1.2	1.2	0.2	2.6	0.3	1.8

Table 4.7

HxD (height of first defection point)

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
	90%	36.9		53.9		55.5		51.1		51.3		48.9	50.2
HxD	70%		62.8		61.6		59.2		62.8		56.8		
	RMSE	5.3	4.5	1.9	5.0	5.2	4.2	7.8	3.0	2.9	4.0	2.0	3.2

The height at which the bar makes contact with the participant's thigh was measured through HxD and the results of this measure are shown in table 4.7. Here it can be seen that this changed from 36.93~cm to 50.17~cm from pre-testing to post-testing. When this result is combined with the changes in DxR ~0.82 cm pre to ~7.14cm post. Indicate the bar path is now taking a more rearward direction towards the participant's hip and it now makes contact with the thigh. Whereas in the pre-test the bar never made contact with the body and had a very straight bar path as seen from the figure 4.5 above. These changes are expected with the chalk constraint showing bar path changes in the direction towards those of a more advanced lifting technique described in the literature review. The comparison of the 1RM power clean pre was 77.5kg to post 80 kg was a 3% improvement in power clean performance (seen in table 4.5 above). Furthermore, peak force efficiency for post-testing 77.5kg improved from 2703 N to 2669 N and a 10cm improvement in maximum barbell height 119cm to 130 cm at 77.5 kg. Indicating the new movement technique to be more effective at applying force.

Case study three results

Participant three jumped forward during their pre-testing lifts, which is indicative of not enough rearward force being applied to the barbell. Therefore, a cliff constraint was applied to promote the participant's jump backwards. This cliff constraint was an 8cm drop place in front of the participant's feet.
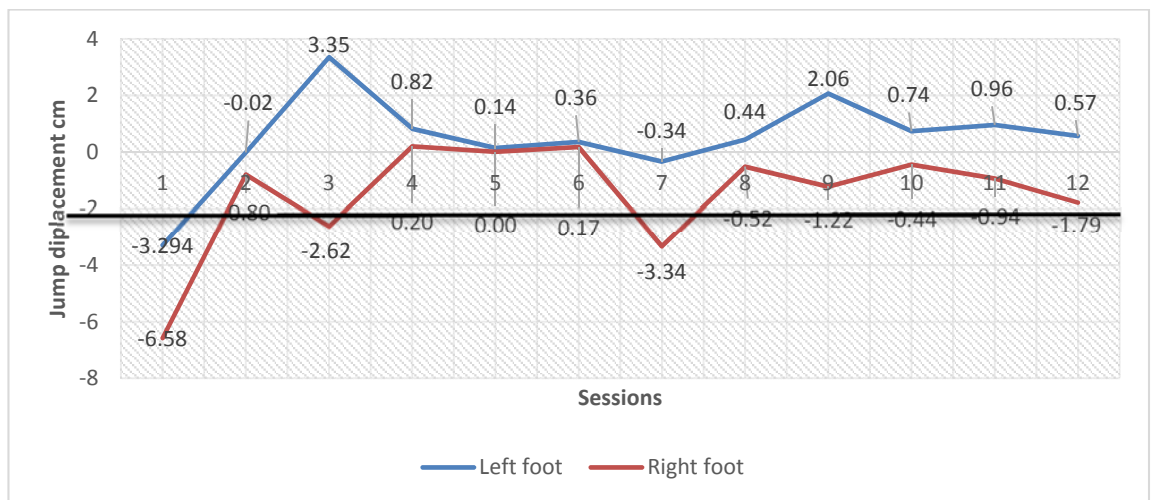
Figure 4.6 left, and right foot jump displacement relative to start position

The result of the cliff constraint on participant three's jump forward was an improvement in the left foot from jumping forward -3.29cm~ to jumping backwards 0.52cm~. This gave a combined difference of 3.81 cm from pre to post testing. In addition, there was less variability in jump distances repetition to repetition moving from pre 1.93 cm RMSE to 0.9 cm RMSE. The right foot measurement also moved a greater total distance of 4.79 cm. However as seen from the figure 4.6, the constraint was not completely successful in correcting the jump forward on the left foot with a post testing measure of -1.78cm nevertheless the constraint was still successful in changing the jump forward by an average 4.3 cm~ in the backwards direction. The right foot also trended to less variability measured by RMSE.

Table 4.8

Left foot displacement

*Constraint present

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
Left foot	90%	-3.3		3.4		0.1		-0.3		2.1		1.0	0.5
	70%		-0.02*		0.8*		0.4*		0.4		0.7		
	RMSE	1.9	0.4	2.5	1.2	0.4	0.3	0.7	1.1	1.8	1.1	1.1	0.9

Table 4.9

Right foot displacement

*Constraint present

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
Right foot	90%	-6.6		-2.6		0.0		-3.4		-1.6		-0.9	-1.8
	70%		0.8*		0.4*		0.2*		-0.5		-0.4		
	RMSE	4.5	0.7	1.9	1.2	2.1	0.8	0.4	0.9	0.9	1.1	0.8	3.5

The position of the participant's ear showed a trend to move towards a more rearward body position in the maximum rearward ear position (MREP seen in table 4.11 below). The more rearward ear position is Indicative of a more rearward force vector being applied to the bar resulting in the participant needing to jump backwards. Where the pre-testing measures had a much larger single measure rearward position than the training sessions however also had the largest RMSE indicating this session had the most variability and was not consistent. When the pre-test was compared to the post-test there was a 6.28 cm positive rearward difference with the post-testing session having one of the least amount of variability, indicating the new movement pattern is becoming more coupled. With the data from maximum forward ear position (seen in table 4.10 below), no clear trend was observed. The only implication drawn from the data was that there was times of significant movement exploration and variability in the measure. Despite improvements in movement behaviour which aligned with power clean literature, no improvement was seen in the comparison of the 1RM power clean pre to post performance.

Table 4.10

Maximum forward ear position

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
	90%	15.4		21.7		20.1		22.1		21.2		7.6	16.1
Forward (cm) (MFEP)	70%		17.4*		18.9*		19.6*		19.5		11.0		
	RMSE	2.0	0.7	0.9	1.2	0.4	5.0	1.3	2.2	1.4	2.5	2.2	1.6

*Constraint present

Table 4.11

Maximum rearward ear position

*Constraint present

	Session	Pre	1	2	3	4	5	6	7	8	9	10	Post
	90%	25.2		17.7		16.7		16.5	18.8	22.7			31.5
Rearward (cm) (MREP)	70%		15.5		15.6		15.5			23.5		26.7	
	RMSE	4.3	3.0	2.3	3.4	0.9	2.8	3.9	2.7	2.5	3.3	2.5	1.9

Table 4.12

Pre-test post-testing 1RM comparison

1RM	Case 1	Case 2	Case 3
Pre	97.5 kg	87.5 kg	122.5 kg
Post	112.5 kg	90 kg	122.5 kg
% improvement	15.4%	3%	0%

Chapter 5 Discussion

This discussion chapter will give a brief overview of the results from the 3 case studies and how these results support and add to the current literature in this area. Practical implications will then be discussed.

Summary of results

Case one the effect of the poles at constraining task space for the bar in order to bring the path closer to the body. The participant changed how far the barbell travelled away from their body during the lift from ~17 cm to ~6 cm. A secondary verbal task constraint was that the bar must make contact with the shoulder at the completion of the lift. The primary task constraint of the poles allowed a new movement to emerge where the bar position was closer to the body and opened up the new affordance of the bar to make contact with the shoulder at the end of the lift. The new affordance was seen by the upper arm angle changing from 175^0 to 138^0 comparing pre-testing to post-testing. Also, the participant showed a shift from a stable movement, through a period of instability and back to a new stable movement again. As described by Newell (2003) skill learning involves ebbs and flows of stability and instability to task demands. Seen through the root mean squared trending downward for all lifts from 2.32 cm to 1.24 cm in the horizontal barbell direction and changed from this 5.72^0 to 4.03^0 in the upper arm angle in the catch. The unexpected result of the pole constraint is there appears to be evidence of the emergence of a higher order double knee bend technique (Stone et al., 2006). The double knee bend was evident by the re-bending of the knees after they straightened from pulling the bar to the knee. This drastic movement change is evidence of a shift or bifurcation (Fink et al., 2000; Kelso, 1994; Kostrubiec et al., 2012). During pre-testing, the participant extended their knees to 10^0 off vertical and then never shifted the knee forward again until completion of the lift. In post-test, the participant re-bent their knees a further 19^0 off vertical demonstrating a second knee bend technique. These changes in movement resulted in a 15.4% improvement in the power clean performance from 97.5kg to 112.5 kg.

Case two the result of the chalk constraint on participant two's bar path. The chalk constraint resulted in changing the bar path to a more rearward direction of the floor and changed the bar to make contact with the upper thigh of the participant. The bar making contact was evident in the

results of the most rearward position of the bar from the floor to maximum hip extension changes from 0.82 cm to 7.14 cm. Additionally changes in the deflection point of rearward to forward horizontal bar path from 36.92 cm to 50.17 cm showed where the bar now makes contact with the thigh. These results show the constraint was successful at changing the technique to that described in the research from Winchester et al. (2005) where the bar should brush the thigh. Once again post constraint implementation, an increase in the variability was seen by the pre-post testing DxR root mean squared 0.29 cm to 1.81 cm post result. This higher variability is evident that the stability of the new movement behaviour was still not as stable as the original indicating the underlying attractor state may still be being searched for (Kostrubiec et al., 2012). This constraint resulted in a performance improvement of 2.5 kg on their power clean. Also, anecdotally again the following week post intervention the participant recorded another 2.5kg increase. The question is then raised of was the intervention perhaps not long enough considering the degree of variability in their movement still present.

Case three the result of the cliff constraint on participant two was a change in direction of their jump by ~4 cm on both legs. There was a change in the left foot from jumping forward -3.29 cm to jumping backwards 0.52 cm. The overall change on the right foot was greater than the left. However, their foot still moved forward, changing from -6.58 cm to -1.79 cm. There is evidence of success of the cliff avoidance reflex (Kretch & Adolph, 2013) from the constraint used. The result of the stimulus of the cliff on the visual system was evident through the participant's more rearward head position after full extension. Indicative of a more rearward pull on the bar from the participant changing from 25.17cm to 31.45cm. However, the pre-testing result had far more variability seen through the RMSE of 4.33cm whereas the post-test 1.92cm is indicative of a more coupled movement pattern. While this resulted in no performance increase during the testing session anecdotally this participant did record a 5 kg improvement two weeks post the end of the intervention.

Theoretical agreement or disagreement

When summarising the theoretical perspective behind the type of constraints used in this study. They are informed by Newell (2003) theory of transition information which is a category of augmented information. Augmented information or feedback is information not normally available in the performance environment. In this case each task constraint is a new augmented piece of

information that aids in the learner transitioning to a new co-ordination solution. This augmented information may be viewed as a control parameter, aiding in guiding the athlete to search different parts of the "perceptual-motor" landscape for task relevant coordination solutions.

In this study's example, the transition information in the three cases forced the participants to explore the space either closer to their body in case one, space behind their torso in case two and the space between the knee and their hip in case study three. This research manipulated the transition information requiring the participant to search through the motor perception landscape of these state spaces for a new attractor pattern to emerge. Hence, this searching of the motor perception landscape is seen through the variability in their movement measure through the RMSE calculation (Kostrubiec et al., 2012). This theory (Newell, 2003) supports the argument that some of the participants may still have been searching for a new attractor pattern as the post testing movement demonstrated more variability through the RMSE than the pre-testing movement. This implication is in agreement with contemporary skill acquisition theory (Newell & Yeou-Teh, 2012) that variability is to be seen as functional in the role of athletes exploring different motor patterns for effective skill execution (Vereijken et al., 1992).

This variability is also described in Nonlinear pedagogy theory (Chow et al., 2015) where a movement pattern is first stable then the coach manipulates key constraints in the performance context, thus causing instability in the system. This change in the system then forces the athlete to reorganise the many interacting subsystems (e.g., muscular, neural, skeletal) to form a new stable movement behaviour. This non-linear process to learning may have sudden and abrupt changes in the system's organisation, due to the intrinsic dynamic interactions taking place. Therefore, the variability seen in all of the participants in this study demonstrates the constraints were successful in facilitating signs of learning (Renshaw et al., 2010).

The result of each case was varied with participants achieving differing levels of success with the outcome of 1RM. In the case of participant one, a more drastic change in movement was seen. This learning process where a drastic change is seen has also been called a phase transition or bifurcation where the athlete has to undergo a complete shift in the movement behaviour to an entirely new skill (Kostrubiec et al., 2012; Newell & Yeou-Teh, 2012). In the first case, this was seen where the participant underwent a complete shift in the movement to a new re-bending of the knee technique.

The variance in the movement from each participant can also be described through a process of self-organisation, where to meet the task within the constrained state space the athlete needed to self-organise the many interacting parts. Hence, due to the non-linear nature of self-organisation, predictability about the result and time to result of reorganisation is impossible (Newell & Yeou-Teh, 2012; Newell et al., 2001). However what is predictable is a loss of stability. A loss of stability must occur for the reorganisation of the system (Kelso, 1994). In the case of participant one, he underwent a destabilisation of the movement pattern seen through failing one lift each session on the first two 90% training sessions. To then undergo a phase shift or bifurcation to a double knee bend technique resulting in session six shifting to a re-bending of the knee by 6^0 from baseline.

Practical applications

When drawing upon the results of this study strength and conditioning coaches need to be more aware of the non-linear nature of changing movement behaviour. When a coach is looking to change a movement pattern they may need to expect a deterioration in the movement. This deterioration is critical in the athlete's internal process of learning and self-organising. Coaches cannot expect to fix an error explicitly immediately, but rather reshape the task or the learning environment and allow time for the learning to occur. Also, the widespread use of explicit instruction by strength and conditioning coaches institutionalises the athletes to expect this when being coached (Dorgo, 2009; Hang et al., 2015). This became problematic for participants in the present study; some of whom were unsettled by not being told what to do. Examples being participant one commented, "I am just waiting for you to tell me how to do it." This participant also linked their confidence with the movement to explicit knowledge about the movement. They felt like they had not changed their technique because they did not have the explicit knowledge of how to perform the skill. Nevertheless, it was very evident from results that they had drastically changed their movement. Competence is one of the basic psychological needs of an athlete (Chow et al., 2015). Therefore, coaches applying a constraints-led approach need to make sure in some way that athletes experience an increase in feelings of competence. This competence could be developed through knowledge of performance provided by the coach. Knowledge of performance is information about how the movement was executed (Williams & Hodges, 2005). The roles of the coach do change now with this constraints-led approach. In order to now build the athlete's feeling of competence the coach could provide non-kinematic augmented feedback

about the athlete's movement. The coach now observes the performance and compares the performance against the athlete's desired outcomes. This now provides an external source of information from the coach not normally available to the athlete. In this way the athlete still gets some knowledge of the performance to help them believe they are improving towards their goal (Newell, 1991; Swinnen, Schmidt, Nicholson, & Shapiro, 1990). However again the challenge for traditional coaches is to still not provide copious amounts of feedback and develop a dependency for error detection (Williams & Hodges, 2005). The amount of augmented feedback given is also dependent on the athlete's level. The higher the athlete the more augmented feedbacks use should be decreased. Coaches coming from a traditional approach will find this shift of method very difficult as according to Salmoni, Schmidt, and Walter (1984) providing feedback on every single attempt will lead to an improved performance however is to the detriment on skill learning. This putting off the short term performance improvement for the long term skill development will be challenging. The delayed gratification will be a significant barrier for both coaches and athletes. As seen in other areas of human behaviour change such as obesity and substance abuse (Hoerger, Quirk, & Weed, 2011). What may help more traditional coaches adopt this approach is more research to strengthen the argument and more advocacy for the inclusion of skill acquisition within strength and conditioning education and resources.

As stated previously in the literature review, elite performers do not follow a recipe book to the perfect skill execution. However they are attuned to key information sources (high-level invariant information, or affordances) within the environment which shapes their movement. The movement behaviours are adaptable to different situations which may arise within the environment. Therefore, when coaching movement, it is not the replication of an idealised movement but a movement that displays functional variability to adapt when needed (Chow et al., 2015). In the case of the power clean every time the load on the bar changes, the centre of mass of the entire system (Kipp et al., 2011) or performer and bar changes. This inertial change needs to be perceived and their movement adapted, to reshape their body accordingly. As the coach, there needs to be an understanding for the little adjustments that need to be made rather than the focus on the overall "look" and replication of the skill. The different perceptual demands are why this study used loads of up to 90% to replicate the perceptual demands of lifting a heavier bar. This non-representation of practice is one of the main criticisms of previous research in this area

aiming to change technique but only using very light loads, which do not drive necessary configuration of the skill.

Understanding the learning process and time was a unique aspect of this research. The tracking of repetitions within all training sessions allowed the RMSE to show the amount of variability. The results provide support for the contentions of the non-linear learning process and the amount of time that is required for changes to occur and become more coupled. Strength and conditioning coaches need to gain a practical appreciation for this process and its time. Also, more emphasis needs to be placed on environmental factors that shape movement and less on organism-centred approaches.

The inclusion of expert coach's knowledge was important in the development of constraints as there is difficultly in determining the key performance lynchpin/s to improve. Utilising the knowing-how knowledge in identifying progressions and figuring out the next most important thing to fix. This aided in the justification of what constraints to apply and in which cases as the end performance needed to be in mind. Having the question of "What are we changing and how is this going to lead to a performance improvement? Alternatively, are we trying to change something that does not matter and does not change performance? The learning is understanding why you are changing what you are. The expert coach's knowledge was used to determine what needed to be changed and then the constraints-led method was applied successfully to change that variable.

The explicit/perfect model of technique demands that the coach corrects all aspects of the skill in line with the template or particular look. An unfortunate by-product of this approach is task decomposition gets favoured over task shaping. Whereas a constraints driven coach has more scope to focus on what is needed and effective. Additionally understanding the individualised nature of this method is critical as no performer/athlete are the same and nor will they respond in the same way or time. Hence, what is critical to performance is understanding the difference between allowable individual differences and the non-negotiables of performance.

Fundamental to a system based approach is not following a reductionist view seen in the task decomposition of the traditional research in strength and conditioning coaching of the power clean. Thus, when changing movement small changes may have big impacts on the entire system. In this way when solving case three it is not as simple as just not jumping forward but a

more complex organisation of many degrees of freedom to co-ordinate jumping backwards. Thus, the justification of why you are changing what you are needs to be of the utmost importance.

When comparing the result seen in this research to previous studies many of them have not measured if there was any change in 1RM (Sakadjian et al., 2014; Winchester et al., 2005) The studies that did measure post intervention 1RM Rucci and Tomporowski (2010) reported no significant differences between groups for 1RM and other power tests. Hang et al. (2015) using the hang power clean saw a 60-70% improvement but didn't report the actual numbers. These participants where naïve to the movement and would expect to see rapid improvements. Another unpublished masters research (Marriner, 2015) had a comparable intervention time frame 5 weeks and participants of a similar expertise level reported between 4.2% and 1.8% improvements in the power clean. When compared to the 15.4%, 3% and 0% change seen in this researches three studies.

This study has demonstrated a constraints-led approach may be an efficient and practical method for changing complex exercise skill related movements in the context of strength and conditioning implicitly. Through simple task constraints, all movements were changed in the expected direction. Practitioners can apply similar state space constraints to achieve movement exploration, searching and learning of complex total body exercises. Constraining task space is a very effective way of changing movement implicitly.

Limitations

The primary limitation of this research is the single case design, generalisation of results to other lifters and other sports should be undertaken with caution (Barker, McCarthy, Jones, & Moran, 2011). The evidence here is sufficient to justify longer studies with larger numbers that focus on a more limited range of outcomes. The constraints in this study were developed to meet the individual needs and lifting characteristics of each of the participants, and specific constraints utilised with one participant may not see the same results with others. However, a general practical application that could be taken from this study is the process of using expert coach knowledge to help determine the key variable to change. The choice of this variable will affect the end performance outcome, as manipulating specific constraints influences the learning direction that will occur. This constraint then needs to be shaping the movement in the right direction that being towards improved performance.

A second limitation is transferance to another movement as there was no measurement of transference, and one cannot assume that changes in the power clean movement will change any of the participants other exercise skills/movements such as the vertical jump. Future studies might consider vertical jump or other athletic performance tests as a viable transfer test.

Also, no retention test was taken, all measures were immediately post intervention. While results show changes in participant's movement, without additional testing session several weeks after the intervention period, we do not know how resistant to change the new movement was and how well they retained this. This is important given that the new attractor may not have yet stabilised and there is still a possibility of regression toward previous states

Future research

The future research in this area could draw upon the limitations of this study and look at the long-term effects of learning a skill from a constraints led method. This could involve research that looks at the possible retention of the skill in the short and long term. An examination if transfer has occurred to other movements, is also an area of future research. One of the primary goals of strength and conditioning is a transference of movements in training to athletic performance.

Therefore, an examination if a constraints-led approach increases the likelihood of transference to other athletic exercise skill related movements would be a good future research question.

Building upon the psychological aspects of the performers' and coaches' experience with this implicit approach. It was clear that the institutionalisation of a verbal approach was evident from the performers, however outside of the scope of this study.

Following on from the observations from the participants expecting to receive (constant) verbal feedback and instructions from the coach leads to questions about how the performers feel about a constraints approach with no verbal instructions/feedback given. In addition to this, it would also be worth exploring the coaches' perception of a more hands-off approach. It is a balance of allowing performers to learn is in conflict with feeling of needing to do something or say something. Research exploring the coaches' perceptions would aid in the development of coach education.

While this research has just looked at one common strength and conditioning lift, there is the scope to understand this approach with not only other lifts but also extend this approach to the rehabilitation context. There is a growing body of evidence of a constraints-led approach in some sporting areas, in particular with closed skills (Oudejans & Koedijker, 2010; Savelsbergh, Versloot, Masters, & van der Kamp, 2010; Scholhorn et al., 2010); there is still more to be known about its use and consideration with verbal instructions.

Conclusions

This study is a practical example of applying a constraints-led approach within the context of strength and conditioning. The challenge is not for coaches to now apply the constraints developed in the study; but rather understand the applied process of formulating constraints. In particular helping to direct the athlete/performer to search for a new attractor pattern through the shaping of the state space. This study provides a viable pedagogical alternative to the use of metaphors (Lam et al., 2009) when it comes to developing skills that are not grounded in explicit knowledge and consequently more robust under pressure. From the evidence of this study, strength and conditioning coaches could benefit from an increased appreciation for this nonlinearity of learning and allowing learning to emerge and self-organise. As predictability about linear learning are false and may go through phase shifts in movement as seen in case one.

Expert coach knowledge is useful in the processes for the development of constraints and the justification of what is most important to change.

This study has demonstrated a constraints-led approach is a practical method for changing complex exercise skill related movements in the context of strength and conditioning. Through simple task constraints, all movements were changed in the expected direction. Practitioners can apply similar state space constraints to achieve movement exploration, searching and learning of complex total body exercises.

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Appendix A

Constraint development process

Piloted constraint ideas

Activities for first pull faults

Lower the starting position of the lift, but having the participant stand on a slightly raised (20-40-mm) surface. This encourages the participant to push their knees further over the bar. The desired outcome is to slow down the participant during the first pull and encourage the participant to focus more on pulling the knees back and keeping the shoulders over the bar.

Two bars are set up; one with a lower/lighter load than the other. With the heavier bar, the participant performs a clean pull (power clean without the catch phase) and with the lighter bar, the participant performs a full power clean. This allows the performer to feel the heavier load pulling them forward out of position in the first pull then apply this feeling within the power clean.

Wooden boards set up to impose a rearward barbell direction (figure 5). If they hit the boards, the boards will fall over allowing the participant to come up with the own movement solution to achieve this rearward barbell direction.

Activities for second pull faults

Increasing and varying the load on the bar, which will encourage different muscle groups to be used; as a heavier bar will encourage more leg pushing/driving movements and less likely for the participant to try and pull the bar mainly with their arms.

Place lighting (weights) plates or use a wooden platform about 20mm to 40 mm either side laterally of feet to jump up and onto forcing greater need for extension to leave the ground.

Place a target foam pad just above the head of the participant; so that at the tallest position of the lift the participant can try and stand tall and have their head touch the target.

Activities for catch faults

Using different types of barbells (figure 6); some with more or less ability to spin in the participant's hand, so to draw their awareness to their elbow speed during the catch.

Have the participant perform the lift close to either wooden/rubber board that could fall over if the participant moved the bar out in front of them too far; this is to raise their awareness of the bar path during the catch.

Place small rubber training bands around the bar to alter the tension on for the participant during the lift. This will pull the bar down more at the top bar position, which encourages the participant to be faster at moving themselves under the bar at the catch.

Place a small block of wood/rubber/foam in front of the participant (figure 4). If their feet touch this object, it means they have stepped or jumped forward; and by placing a block there, it raises their awareness of the movement of their feet during the catch.

For example object restricting jumping forward such as a 40mm high small block of wood (Figure 4). This will promote optimal timing and bar path as a common error is jumping forward due to the bar path tracking away from the body.

Figure 4:

Figure 5: Barrier to bar path

Figure 6: Sand bag clean

For example changing of the bar to a sandbag (Figure 6) or a bar with no spin. Creating awareness in the catch position and about speed under the bar. Band tension could also be applied in the vertical plane increasing the need to be faster under the bar.

Figure 7: Box to promote lower hips

Changing of the force applied in a sagittal plane with band tension. Aiming to promote the double knee bend by increasing the performer's pull of the bar into the hip.

Figure 8: Band pulling the bar away

Refined list of Constraints

- Bars loaded to a heavy and a light weight.
- Deficit start to increase the difficulty of the start.
- Barrier to the bar path like jerk block or poles.
- Chalk on bar to make contact with the body and show where contact was made.
- Vary bar load.
- Tape on floor.
- Cliff in front to stop jumping forward.

Appendix B

A U T E C
S E C R E T A R I A T

1.1.1.1

Ethics 1 April 2015

Sarah Kate Millar
Faculty of Health and Environmental Sciences

Dear Sarah Kate

Re Ethics Application: **15/33 A constraints lead approach to acquiring the power clean lift.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 1 April 2018.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 1 April 2018;

- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 1 April 2018 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Wesley Verhoeff wesley.verhoeff@gmail.com