# EFFECTS OF THREE TYPES OF KINEMATIC FEEDBACK ON THE EXECUTION OF THE HANG POWER CLEAN

by

JOSHUA ANTHONY RUCCI

(Under the Direction of Phillip Tomporowski)

ABSTRACT

The type and quality of feedback provided during instruction influences motor skill learning. Little is known of the effects of feedback on discrete dynamic movements that are integral to strength-training programs. The effects of three types of feedback on a weight-lifting skill were evaluated. Participants' performance was predicted to benefit more from a combination of visual and verbal feedback cues than from visual feedback alone or verbal feedback alone. A mixed-model experimental design was employed to compare the effects of the three feedback conditions over 6 training sessions. Analyses of movement form indicated that with training participants in both the video+cues group and the verbal-only group improved while individuals in the video-only group did not. These results have implications for instructors seeking efficient methods of improving athletic performance.

INDEX WORDS: Hang power clean, Feedback, Dynamic movement, Weight-lifting

# EFFECTS OF THREE TYPES OF KINEMATIC FEEDBACK ON THE EXECUTION OF THE HANG POWER CLEAN

by

JOSHUA ANTHONY RUCCI

B.S. Ed., Bowling Green State University, 2006

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTER OF ARTS

ATHENS, GEORGIA

2008

EFFECTS OF THREE DIFFERENT TYPES OF KINEMATIC FEEDBACK IN THE

EXECUTION OF THE HANG POWER CLEAN

by

JOSHUA ANTHONY RUCCI

Major Professor: Phillip Tomporowski

Committee: Patrick O’Connor
Bryan McCullick

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

# Chapter 1

## INTRODUCTION

Strength and conditioning coaches as well as athletic team coaches look for ways to improve the efficiency and effectiveness of their training and practice programming. Research conducted in the field of motor control and motor skill acquisition shed light on effective means of structuring training and the type and quantity of feedback that is most beneficial when teaching novel motor skills or refining previously learned skills.

The hang power clean is a representative motor skill of particular importance to strength and conditioning coaches. The hang power clean is a movement in which an individual lifts a weighted barbell from mid-thigh height to clavicle height in one explosive movement. This movement is a staple of strength and conditioning coaches. The amount of power that can be generated during the movement very closely mimics many movements that occur in athletic events. The hang power clean can be broken down into three phases, which include the start phase, the pull phase, and the catch phase. The pull phase of the hang power clean has been shown in numerous studies to generate the maximum amount of power as opposed to other phases and variations of the movement (Garhammer, 1980).

Researchers in the field of motor control provide two interactive models to explain how movements are controlled and modified. The closed loop system typically applies to movements that are relatively slow and provide time for errors to be detected, error correction strategies to take place, and finally the initiation of the selected correction to occur (Schmidt & Lee, 2005). The closed-loop model of motor control relies heavily on intrinsic and extrinsic sensory feedback information (Schmidt & Lee, 2005). Sensory information, if time permits, can be used to detect error between the desired outcome and the actual outcome. The open-loop model applies to movements that are rapid and discrete. In this model, sensory information does not play a role in error detection; rather it serves as a trigger for the next aspect of the movement to occur (i.e., response chaining). When a movement is triggered it will run its course until all aspects of the movement chain have been completed. The open loop system is not sensitive to feedback and the response-chaining hypothesis predicts that attention is required only prior to the initiation of the movement; following initiation, the movement will run its course regardless of possible movement error (Schmidt & Lee, 2005). Applying these two models to the hang power clean, movements involved during the start phase of the power clean are under the control of the closed loop system and may change in response to both inherent and augmented feedback. The pull phase and the catch phase happen very rapidly and thus may be under control of the open loop system in which concurrent sensory feedback may not alter the movement.

The hang power clean is highly technique specific and takes practice and many trials to perform the exercise efficiently. Thus, this exercise requires extensive coaching and feedback for individuals to acquire and refine the motor skill. The typical method of coaching the hang power clean is through verbal instruction and demonstration that focuses on directing an individual's attention to the critical aspects of the performance of the movement. Despite the implementation of coaching feedback, relatively little is known of the impact of augmented verbal and visual feedback on young adults' acquisition of the hang power clean. Verbal feedback employed by coaches often ranges in specificity and may at times be too broad or general to benefit changes in the motor movement pattern. Further, while many coaches have begun to administer video feedback to young adults, its effects on learning are unclear. The few laboratory-based studies designed to assess the effects of feedback on the acquisition of weightlifting skills provide evidence to suggest that the relationship is complex. Young adults' gains in proficiency appear to depend both on components of the movement pattern learned and the type of feedback provided (Kernodle & Carlton, 1992). The relative impact of verbal feedback, video feedback, and the combination of video and verbal feedback on weight-lifting skills are understudied.

## Rationale for Study

The rationale for this study is to evaluate the role specific forms of augmented feedback has on young adults' improvement of a weight-lifting skill. Previous studies have focused primarily on determining the effects of feedback on movement outcomes (i.e., the amount of weight moved) rather than on the modification of movement patterns performed during the act of weight lifting (i.e., movement kinematics). The few studies that have used video feedback in conjunction with verbal feedback have not specifically evaluated the effects between kinematic verbal feedback alone, kinematic video feedback alone, or kinematic video feedback in conjunction with kinematic verbal feedback. Lacking are studies that focus solely on identifying optimal methods of administering kinematic feedback and their effects on movement production as opposed to movement outcomes. Kinematic feedback, which is feedback about the actual performance of movement (i.e., Knowledge of Performance (KP)), as opposed to feedback about the results of a movement (i.e. Knowledge of Results (KR)), is hypothesized to be particularly beneficial to acquisition of motor skills that involve complex interactions among limbs and body segments and that require complex temporal sequencing.

## Purpose of the Study

The purpose of this study was twofold: 1) to evaluate the effects of three types of augmented feedback on young adults' weight-lifting movement form and 2), to assess the effects of augmented feedback on measures of strength and power.

## Hypotheses

1. Video feedback with visual and verbal cues will enhance performance of the hang power clean to a greater extent than that of verbal or video feedback alone.
2. Verbal feedback will enhance performance of the hang power clean to a greater extent than video feedback alone.
3. Video feedback alone will show no improvements in performance.
4. Feedback conditions will differentially affect gains in strength and power, with greatest improvements observed in participants receiving video feedback with visual cues.

## Chapter 2

## REVIEW OF RELATED LITERATURE

The most notable thing that happens when people practice is that they demonstrate increased proficiency in performance and skill. A skill can be conceptualized as a task (e.g. throwing a baseball, kicking a ball) or it can be viewed as a level of performance proficiency that distinguishes a higher-skilled performer from a lower-skilled performer (Schmidt, 2004). While several definitions of skill have been proposed, Guthrie's (1952) definition captures the critical elements of skill that are espoused by the majority of contemporary researchers and theorists. He proposed that "skill consists in the ability to bring out about some end result with maximum certainty and minimum outlay of energy, or of time and energy." There are different types of skill; for example, motor skills, perceptual skills, and cognitive skills. Motor skills are those in which both the movement and the outcome of the movement are emphasized (Newell, 1991). There are three essential features of skilled movement: maximum certainty of goal achievement, minimum energy expenditure, and minimum movement time.

Motor skill acquisition is a process in which a performer learns to control and integrate posture, locomotion, and muscle activations that allow the individual to engage in a variety of motor behaviors that are constrained by a range of task requirements (e.g. athletic context) (Newell, 1991). As a learner acquires a skill, changes may be observed that reflect strategies that an individual uses to achieve specific movement outcomes. A learner may show a change in the spatial orientation of his or her body and body limbs as well as exhibit a change in the timing and sequencing of movements. Motor-skill acquisition follows a pattern in which learning accumulates with practice. Mathematically, the rate of change in learning due to practice follows a power function. Newell and Rosenbloom (1981) reviewed a number of studies and demonstrated a power function by plotting the logarithm of the time to perform a task against the logarithm of the trial number; it invariably yielded a straight line. The logarithmic relation between performance and practice reflects a central characteristic of motor-skill acquisition -- the rate of improvement at any point during practice is directly related to the current skill level of the learner and how much improvement is left to be made. Changes in performance that accompany practice are usually much greater and more rapid at first and systematically become smaller as practice continues.

## Theories of Skill Acquisition

Bryan and Harter (1899) were among some of the first researchers to study skill acquisition. They observed performance scores of telegraphers who received telegraphic messages and then translated the code into their native language. Bryan and Harter hypothesized that improvements in the telegraphers' performance, which was measured by the amount of words translated in minute, could not be due a sudden increase in knowledge of native language but rather an acquisition of higher language habits (Bryan & Harter,1899). Later, Snoddy (1926) provided a classic example of motor skill acquisition. He conducted a study that required subjects to perform a mirror tracing task that required them to learn to control hand movement speed and accuracy. Snoddy asked his subjects to trace a circuit of a 12-edge, star shaped path one fourth of an inch wide. The direct vision of the tracing instrument and the hands were obstructed by a screen and only an indirect mirror image of the tracing device and hands was available to the participants. The instruction to the participants was to move around the path as fast as possible and avoid making contact with the side of the tracing. Each trial consisted of completing one circuit, and performance was measured as the ratio of 1000 over the sum of tracing time (T) and number of contact made (E) within each trial [1000/(T+E)]. Analysis of participants' scores revealed that gains in performance follow a non-linear pattern in which improvement was rapid at first, but declined as training progresses and the number of trials increases. Snoddy (1926) hypothesized that the number of repetitions was the primary parameter that affected the course of learning. He explained motor-skill learning as a two-stage process which was comprised of an adaptation stage, in which the learner acquires the neuromuscular pattern required to perform the movement, and a facilitation stage, in which the efficiency of the movement pattern is improved.

Later, Henry and Rogers (1960) explained motor learning in terms of neuromotor memory. They hypothesized that humans possess a vast amount of unconscious motor memory which is stored in the form of innate motor coordinations that are essential to initiation of controlled motor actions. They modeled motor control processes in terms of a memory drum, a data storage device developed in the 1930's that was an early form of computer memory. For machines, the memory drum formed the working memory of the machine which allowed for data and programs to be loaded off the machine using punch cards. The memory storage drum in the human mind as proposed by Henry and Rogers is analogous to a memory drum in a machine in that programs are preprogrammed and stored for retrieval. Henry and Rogers hypothesized that the neural pattern for specific and well-coordinated motor acts are controlled by a stored program that when retrieved directs all of the neuromotor details of the performance (Henry & Rogers, 1960). In the absence of a stored program, a novel task will be carried out under conscious control and the execution of the movement will be poorly coordinated and awkward. Thus, the memory drum theory predicted that whenever a specific movement pattern is required; the stimulus causes the memory drum to 'play back' the particular learned neuromotor program.

The theory was consistent with the view that learning motor skills is specific, rather than general, and that there is little or no carry-over from one skill to another unless the skills are nearly identical. Practice was predicted to improve performance of a specific skill by the strengthening of the neuromotor program; further, the retrieval of the neuromotor program was predicted to occur more automatically and with less conscious awareness.

Most motor-skill acquisition theories have embraced a stage conceptualization of learning. Fitts (1964) and Fitts and Posner (1967) proposed a three stage process of motor learning that incorporated a cognitive stage, an associative stage, and an autonomous stage. During the cognitive stage of skill acquisition, the biggest challenge of the learner is to understand what is to be performed, while the biggest challenge for teachers is conveying to the learner what is to be done. During this stage, performance gains are usually quite large; however, these performance gains become smaller and smaller as a function of the number of trials.

The associative stage begins once the learner selects a movement strategy and actually performs the task, and based on feedback begins to modify how the movement is performed. This stage is of particular interest to researchers because feedback plays a crucial role in altering the movement pattern. In the associative stage, attention is allotted to improving the efficiency and timing of the movement. The rate of gain of learning in the associative stage is influenced by the nature of the relationship between environmental stimuli and developing motor responses. Stimulus-response compatibility refers to the extent of the association or “naturalness” between a stimulus and the response (Schmidt & Lee, 2005). Tasks are easier or more difficult to learn as a result of the pairing between specific stimuli and their respective responses (Kornblum et al., 1990).

The autonomous phase appears after extensive training and it is characterized by motor movements being performed automatically and requiring less attentional capacity to complete the skill. Schneider and Shiffrin (1977) conducted extensive research on automaticity and the goal of their research was to understand precisely the conditions under which attention limitations occur. Schneider and Shiffrin used a visual search task that involved presenting stimuli in a rapid succession of displays and the subject's goal was to judge whether a target stimulus had been presented. Stimulus display duration, memory set size, and consistency of target-distractor mappings were manipulated. Two conditions were used to evaluate attention and automaticity: consistent and varied mapping. On consistently mapped trials, the targets and distractors were distinguished by category (e.g. letters or numbers). In the varied mapping trials, targets and distractors were from the same category. Results showed that performance in the variable mapping condition was dependent on load and frame size, and performance in the consistent mapping condition was largely independent of load and frame size. Schneider and Shiffrin proposed two processes to account for their results: controlled search and automatic detection. Controlled search is a serial process in which a matching decision occurs after comparison of each item in the display to the memory set items; in contrast, that automatic detection operates in parallel and independent of attention. Automatic processes do not require attention and they do not use up short-term memory capacity; further, once initiated automatic processes are not easily modifiable (Schneider & Shiffrin, 1977). The findings have implications for motor skill acquisition: they demonstrate that cognitive load affects rate of skill acquisition, and that once learned, automatic movements are difficult to modify.

Adams (1971) was one of the first researchers to emphasize the role that cognition plays in skill acquisition. Early theories of motor skill acquisition were influenced by the views of behavioral psychologists who conceptualized learning in terms of the associations between stimuli and responses. Adams hypothesized that human motor-skill learning was not simply a behavior driven by neuromotor programs in response to a stimulus, but rather that motor behavior included a variety of cognitive processes as well as the development of strategies that can be used to complete a given motor task. A central component of Adams' (1971) theory of motor control was the manner in which feedback and error detection influences learning. Adams (1971) believed that learners possess a reference of correctness that specifies a desired outcome of the movement and a feedback mechanism that detects error between the learner's desired movement and the actual movement produced. Considerable research findings suggest that Adams' views hold true for movements that are relatively slow. Relatively slow movements provide the learner an opportunity to evaluate his or her performance as it is ongoing and to detect the error between the desired movement and the actual movement by way of a feedback mechanism. This type of processing has been termed closed-loop processing (Schmidt & Lee, 2005). Adams posited that movements produce internal feedback, which creates a perceptual trace of the movement that is laid down in the central nervous system. The more accurate the movement, the more useful the perceptual trace will be on subsequent trials. The feedback mechanism compares the feedback produced by the movement to the accumulated perceptual trace and detects any errors between the actual and expected feedback.

Adams' theory placed less emphasis on how ballistic, rapid, open-loop movements are learned and controlled, however. For open-loop movements, a motor plan needs to be structured in advance and executed without regard to the effects that they may have on the environment, which does not allow for feedback during the movement. Schmidt (1975) developed an important theory of motor learning that addressed directly how discrete motor movements are acquired and controlled. He proposed a schema theory that hypothesized that there are two states of memory: recall memory and recognition memory. Recall memory is responsible for movement production and recognition memory is responsible for evaluation of movement. Recall memory does not play a role in slow positioning movements. For slow movements, the recall state simply controls movements in small bursts with the movement terminating when the movement-produced feedback matches the reference of correctness. Schmidt proposed the idea of a generalized motor program; a structured plan of movement that is composed of invariant features and variant features. Invariant features are comprised of the components that remain the same in regards to the general movement being executed (overhand throw) and variant features are the parameters of the program that can be altered such as time and time and force (soft overhand throw versus hard overhand throw). Individuals do not learn specific movements; rather they construct a generalized motor program by exploring the rules of action (schema) and learning ways in which movements relate to outcomes.

Schmidt's theory explains how motor skills are learned. A general motor program depends on four types of information that are stored in short-term memory: 1) information about the initial conditions before the movement (variances in limb position or object size/weight), 2) parameters assigned to the general motor program (force, time), 3) augmented feedback about the movement (KR), and 4) sensory feedback (how the movement felt, looked, sounded) (Schmidt & Lee, 2005). These sources of information are interrelated and represent recall and recognition schemas. Learning occurs through the development of the recall schema as the number of trials of given task accumulate. After each adjustment of parameters, various sources of information are discarded from working memory; thus, all that remains is the movement rule, which represents the recall schema. The recognition schema forms in much the same way as the recall schema. The recognition schema is developed on the basis of information concerning the relationship between the initial conditions, the environmental outcomes, and the sensory consequences. Before a movement takes place, an individual can use a learned recognition schema to predict the sensory consequences that will occur if the correct movement outcome takes place. These expected sensory consequences are the basis for which to evaluate movement. Thus, augmented feedback plays a central role in schema development.

While there are differences among contemporary theories of motor-skill acquisition (e.g., Anderson, 1982), the notion that the learner progresses through a series of stages remains central to explaining the phenomenon.

## The Role of Cognition in Motor Learning

Several contemporary theories of motor learning have identified cognitive processes as being important to motor skill acquisition. Cognitive processes have been hypothesized to be crucial during the initial stages of skill learning. During the cognitive stage of motor-skill acquisition a large amount of mental involvement is required of the learner. The cognitive phase is characterized by conditions in which the learner must encode and integrate task instructions, become familiar with task goals, and formalize strategies for task accomplishment. Ackerman (1988, 1992) provided evidence that during this phase learners' performance is slow and error prone due largely to the need to formulate strategies and to test strategy effectiveness. During the cognitive stage considerable attention is directed towards understanding movement goals and the contextual factors that constrain movement. Performance during the cognitive stage is associated highly with general intelligence and verbal, spatial, and numerical abilities. During the associative phase of skill acquisition, the role of general intelligence abilities decline and perceptual-speed abilities become more highly associated with performance. In the autonomous stage, the influence of both general intelligence abilities and perceptual-speed abilities decline and performance becomes most associated with psychomotor abilities.

Ackerman and Cianciolo (2000) assessed procedural skill development via the Kanfer – Ackerman ATC task, which is a complex task that simulates air traffic control decisions and landing of aircraft planes on the basis of various procedural rules. Results obtained from the study demonstrated the predicted change in the contribution of general intellectual ability as performance improved and confirmed the importance of cognitive abilities early in skill acquisition.

There are many factors that influence the performance and learning of a motor skill. Verbal information in the form of instructions is one of the most important factors and also one of the first factors to be studied systematically. An early study conducted by Solley (1952) evaluated the effects of instruction on learning a lunge and stab movement under conditions that emphasized either movement speed, movement accuracy, or an equal emphasis on speed and accuracy. The results were quite dramatic. The group instructed to emphasize movement speed had the highest movement speeds, the group instructed to emphasize movement accuracy yielded the highest accuracy scores, and the group instructed on both speed and accuracy performed at intermediate levels on both speed and accuracy. These results indicate that specific information presented to learners can alter the way in which a movement is carried out as well as the outcome of the movement. Modeling a movement is another way to convey information to a learner. Modeling, or observational learning, is learning that occurs as function of viewing, retaining, and replicating a novel behavior executed by other individuals. Several factors influence the degree to which modeling influences skill acquisition: the properties of the model (e.g., expert versus non-expert), the nature of the task (complexity, number of degrees of freedom), observer determinants (comprehension of the demonstration), and feedback (Ferrari, 1996). Feedback in particular plays a critical role in determining motor learning and performance.

## **The Role of Feedback on Performance and Learning**

Feedback is information about behavioral actions that can be provided to an individual before the action, during the action, and after the action (Schmidt & Lee, 2005). During and immediately following an action, information is available to the learner through various sensory receptors; the learner perceives how the movement felt and sounded. This type of information has been termed movement-produced feedback.

Feedback comes in two forms -- inherent (or intrinsic) feedback and augmented (or extrinsic) feedback. Inherent feedback is available to the learner through multiple sensory channels and provides a basis for evaluating movement. Closed-loop movements allow the learner to use feedback to detect error in movement performance during and following action; whereas, open-loop movements require that the action be completed before the inherent feedback can be processed and used to modify subsequent actions. Adams and Bray (1970) suggest that for inherent feedback to be useful there must be a reference of correctness that must work in conjunction with inherent feedback for error detection to take place. Depending on the nature of the movement however, individuals may be unable to self-regulate or become aware of the reference of correctness, which leads to a need for an external source of information to aid in error detection.

As opposed to inherent feedback, augmented feedback comes from an external source. Augmented feedback can be provided in a variety of forms: visual feedback from a live model, video replay, or verbal feedback. Augmented feedback can be presented in two forms, knowledge of results (KR) and knowledge of performance (KP).

Knowledge of results is post-movement feedback that pertains to the outcome of a movement in terms of an environmental goal (Schmidt & Lee, 2005). This type of feedback can be qualitative or quantitative. Qualitative feedback is usually general feedback about the performance outcomes; e.g., the learner may be told that the movement was "right" or "wrong" or may include the description of the error such as "you to missed to the left" or "you missed low." Quantitative feedback informs the learner about the magnitude of the error; e.g., instead of simply saying "you missed to the left," quantitative feedback may sound like "you missed by four inches to the left." A prototypical experiment that evaluated the effects of qualitative and quantitative KR on motor skill acquisition was conducted by Magill and Wood (1986). In their study, subjects practiced a criterion task, which consisted of a pattern of six movements presented via a computer screen that subjects were required to replicate on a response board. A specified movement time criterion was associated with each response pattern. The outcome measures included the direction and magnitude of the response error. All subjects performed 100 trials and received either qualitative KR or quantitative KR after each trial. Subjects then performed 20 additional trials with no KR. Participants receiving quantitative KR performed the task when no KR was provided with less error than subjects receiving qualitative KR, suggesting that the precision of feedback is important for reducing movement variability.

Knowledge of Performance (KP) is feedback directed toward the movement pattern of the learner rather than the outcome of the movement. Typically, this form of feedback is directed toward correcting errors present in a specific motor pattern (Schmidt & Lee, 2005). Much of the published research conducted on the impact of feedback on motor-skill acquisition has focused on KR and relatively little research has been conducted on the impact of KP on learning. One reason for the relative paucity of research conducted on KP is that measurement of movement outcomes is technically less challenging to obtain than measures of movement patterns (Schmidt & Lee, 2005).

Young and Schmidt (1992) compared the effects of KP and KR on motor learning. A coincident timing task was used in which the participant's goal was to swing a lever at an appropriate time to intercept an incoming series of lights. This task was very similar to hitting a baseball with a bat except that the movement was restricted to just one limiting the degrees of freedom. Subjects in the study were assigned to four separate groups, each of which received different kinematic information. There was also a fifth condition which provided KR feedback. Kinematic information presented to the subjects included limb position, temporal information, and variability present in the movement. This kinematic feedback was presented in addition to KR, which is analogous to real world situations. Subjects performed two acquisition sessions on consecutive days consisting of 100 trials with KR following each trial as well as kinematic feedback appropriate to the group following every fifth trial. The retention test was given on the third day and consisted of 20 KR-only trials. Overall scores were taken as the main dependent measure and analyses of movement patterns were recorded to indicate the impact of kinematic feedback on movement performance during the acquisition phases. All groups that received kinematic feedback performed more proficiently then the KR-only group. These findings suggest that kinematic variables function as information feedback and enhance performance.

Schedules of KR have been researched extensively (Weeks & Kordus, 1998; Weeks, Zelaznik, & Beyak, 1993; Sparrow & Summers, 1992) and findings consistently show that decreases in the relative frequency of KR benefits learning. Weeks and Kordus (1998) evaluated the effects of the frequency of KP on learning. They used a soccer throw-in task in which participants performed a 30-trial acquisition phase and performed retention and transfer tests

5min, 24 hours, and 72 hours following training. During the acquisition phase, one group received 100% relative frequency and the other group received 33% relative frequency. The 33% relative frequency group was found to have higher form scores than the 100% relative frequency group. The authors concluded that reducing the relative frequency of KP eliminated participant's dependency on KP to guide performance acquisition.

KP is often presented in the form of verbal feedback or video feedback. Further, both verbal and video feedback can be used to provide kinematic feedback to the learner. Kinematic measures deal primarily with pure motion without regard to the forces that produce them and include information concerning position, time, velocity, and patterns of coordination (Schmidt & Lee, 2005). An advantage of kinematic feedback is that it can be used to direct the learner's attention toward specific aspects of the movement pattern that might otherwise not be perceived.

When a desired movement outcome depends on interactions among many segments, kinematic feedback has been demonstrated to be more effective than KR alone (Newell & Carlton, 1987; Schmidt & Lee, 1999). Newell, Quinn, Sparrow, and Walter (1983) performed two experiments to evaluate the relative contributions of KR and kinematic KP on the performance of an open skill. The first experiment contrasted three forms of kinematic feedback with traditional KR during a task in which the subject moved a lever forward to a given point with a designated movement time. Subjects were assigned to one of five feedback conditions: movement time, peak acceleration, time of peak acceleration, final velocity, and no KR. Each subject participated in six experimental sessions, one per day, each of which consisted of 3 blocks of 15 trials. Analyses of subjects' performance revealed that kinematic parameters were no more beneficial than KR for minimizing the duration of a single degree of freedom rapid arm movement. The second experiment differed from the first experiment in that a graphing machine was positioned in front of each individual in one group; the graphing machine provided a graphic velocity-time display. Subjects were assigned to three different feedback conditions: movement time, no- KR, and graphic display. Each participant participated in two experimental sessions, one per day, with 50 trials performed each day. Evaluation of the subjects' performance revealed that information feedback was effective in reducing movement time and that learning occurred over trials. Significant differences in the kinematic parameters were seen in the time of peak acceleration; the movement time group and the graphic display group had significantly lower times than the no-KR group. Results of experiment 2 indicated that participants' movement time performance was facilitated by kinematic information. These data were interpreted as evidence for the role that kinematic feedback plays in single degree of freedom tasks. The authors hypothesized that kinematic feedback would be most useful in movements that involve multiple degrees of freedom.

The initial large and rapid gains in skill acquisition have been explained in terms of cognitive involvement and the ability to construct cognitive representations of movements. The role of cognitive involvement in skill learning has received considerable research support. Carroll and Bandura (1987, 1990) evaluated how well subjects could create a cognitive representation of a movement. In their 1987 study, Carroll and Bandura had subjects observe a model perform a novel action pattern containing nine different response components, which varied in the spatial configuration and movement of the arm, wrist, and paddle. The particular movement was chosen because it required both temporal sequencing and patterning of actions. Subjects were assigned to two different groups, concurrent matching and separate matching. In the concurrent matching group, subjects first observed the modeled action pattern and then 26 seconds later they concurrently performed the modeled actions as they watched them being produced. Subjects in the separate-matching condition first observed the model and then performed it from memory, then saw the model again after their respective training; participants in each group were asked to reproduce the movement with no feedback. All of the subjects performed the experimental protocol four times and were also tested for reproduction accuracy on a final set of two trials without any aids. Following the second, fourth and sixth test trials, subjects were tested on their cognitive representation of the modeled action by a recognition test of component responses and a pictorial arrangement test of knowledge of the correct sequence of component responses. Correlational analyses showed that the better the cognitive representations, the more accurate the reproductions of the movement were.

Carroll and Bandura (1982, 1985, 1987, 1990) systematically evaluated the influence on observational learning on motor-skill acquisition; specifically, movement recognition and movement production. They proposed that a cognitive representation is developed initially via observation (modeling or video) and it then acts as an internal model used to guide movement and detect errors (Black & Wright, 2000). Information conveyed by model performances of a movement about the movement patterns is obtained by the learner through attention to spatial and temporal features (Carroll & Bandura, 1990). These features are then transformed into a cognitive representation by symbolic coding and cognitive rehearsal. Cognitive representations serve as a means of guiding motor movements and allows for error in the production of the movement to be detected (Carroll & Bandura, 1990). More recently, McCullagh and Weiss (2001) noted that observational learning permits the observer to form a cognitive framework that guides resulting actions.

The cognitive phase of learning is associated with dramatic gains in performance; however, performance is usually quite inconsistent. These inconsistencies have been hypothesized to be the results of the learner experimenting with different strategies in an attempt to ascertain the most efficient movement pattern to gain the desired outcome.

In summary, kinematic KP has been shown to be beneficial in the acquisition of a motor skill and may be more beneficial than KR depending on the nature of the task. The effects of KP on skill learning may be seen more clearly on complex multi-limb movements that characterize sport skills than on simple motor movements typical of laboratory-based studies.

## Knowledge of Performance: Multiple Degree of Freedom Movements

Mononen et al. (2003) suggest that real world movements that are defined in terms of multiple degrees of freedom may benefit more from KP than from KR. Much of the research conducted on feedback, particularly KR has been conducted using tasks that consist of a single degree of freedom in which the KR can specify all pertinent information about the positioning and timing of the movement (Newell, Quinn, & Carlton, 1987). In the case of multiple degree of freedom movements, Newell and Walter (1981) have hypothesized that kinematic information may be of more importance to learning than KR. If true, this finding would have implications for human performance applications in the athletic arena. There has been longstanding interest in instructional factors that are the most beneficial and efficient for improving skilled performance. Elucidating the effects of feedback, particularly kinematic KP, may lead to advances in instructional methods used by coaches to train and prepare athletes for competition.

Only a few studies have systematically evaluated the effect of kinematic feedback administered via video on sport skill acquisition. Studies conducted by Wieringen, Emmen, Bootsma, Hoogesteger, and Whiting (1989) and Guadagnoli, Holcomb, and Davis (2002) used similar protocols to evaluate the role of KP on sport skills. Wieringen et al. (1989) investigated the role of video feedback on improvement of the tennis service. Subjects in the study were classified as intermediate skill-level players. Subjects were randomly assigned to one of three experimental conditions: a video feedback training group, a traditional training group, or a control group. The control group did not receive any training at all, while both the video feedback and traditional feedback groups were trained twice weekly throughout a 5 week period. During each session, subjects practiced the tennis service for 30 minutes and then 10 minutes was spent evaluating their own service (video feedback group) or ground strokes and volleys of top level players (traditional feedback group). Both feedback groups showed increased performance in both outcome measures and form scores over the control group. There was however no differences between the two feedback conditions.

A more recent study conducted by Guadagnoli, Holcomb, and Davis (2002) sought out to better understand the efficacy of video feedback relative to verbal or self-guided feedback. Experienced golfers were assigned to one of three groups: a self-guided group that receives no KR, a verbal instruction group which receives verbal KR, and a video instruction group which receives video KR. The task included striking a golf ball with a 7-iron from an artificial turf mat and the outcome measures included both distance and accuracy. Subjects during the pre-test were required to strike 15 golf balls. Following the pre-test individuals participated in four, 90-minute training sessions on non-consecutive days. In the training sessions, the individuals in the feedback conditions received KR appropriate to their condition after each trial while the self-guided condition received no KR on any trials. Subjects then were required to perform two post-tests: one day after training sessions and two weeks following training sessions, both of which followed the same protocol as the pre-test. During the first post-test there were no significant differences between the three groups; however, during the second post-test the feedback groups were much more consistent than the self-guided group. Also, the second post-test showed that the performance of video feedback group was superior to the verbal feedback group. The results suggested KR presented via video may be more beneficial to performance than verbal KR.

Video replay may be an extremely useful tool to teach complex skills that involve multiple degrees of freedom movements (Kernodle & Carlton, 1992). Video feedback contains a record of an entire performance and it allows an individual an opportunity to detect errors in movement patterns and to formulate strategies to correct the errors (Schmidt & Lee, 2005). Early reviews of video feedback research suggest that video feedback may be an ineffective method of presenting KP to promote skill learning (Arnold, 1976, Newell, 1981). Rothstein and Arnold (1976) published a review of over 50 theses and dissertations, with a majority being unpublished, and 33 out of the 52 studies reviewed reported non-significant findings regarding video feedback alone as an instructional strategy. Several possible explanations exist for the lack of effectiveness of video feedback in these early studies. Video feedback may: 1) provide learners with overly complex information, 2) fail to provide information concerning specific aspects of the movement to be learned, and 3) not provide enough detail of the movement for the learner to recognize errors and make corrections (Schmidt & Lee, 2005).

Verbal attentional cueing, which involves directing or cueing an individual's attention to critical aspects of the movement, in conjunction with video feedback has been shown to benefit skills acquisition (Kernodle & Carlton, 1992). In their study, participants performed a multiple degree of freedom movement, the overhand throw executed with the non-dominant throwing arm. Subjects were assigned to a KR only group, KP via video-tape group, KP plus attentional-focusing group, or KP plus transitional information group. Subjects were instructed to throw the ball as far as possible. All subjects completed 12 practice sessions, 3 per week for 4 weeks. Each practice session consisted of 50 trials. Subjects in the KR group received verbal feedback after each trial regarding the distance thrown. Subjects in the KP groups did not receive any KR but did receive KP in the form of video replay of their previous trial before each subsequent trial. The KP plus attentional focusing and the KP plus transitional information groups in addition to video replay received a cue indicating where they should focus their attention while viewing the replay and transitional information which detailed what to change to improve distance respectively. The data were analyzed with respect to both movement outcome and movement form (Kernodle & Carlton, 1992). Participants who received KR alone or KP without additional information had smaller gains in throwing distances and had lower form ratings than KP plus attentional focusing. These results suggest that the KR alone or KP without additional information may not be sufficient to assist learners to refine multiple degree of freedom whole body actions. An unexpected outcome of the study was the lack of increased throwing performance by subjects in the KR and KP only groups. The results suggest that neither group received sufficient information to improve performance. Importantly, the increase in both performance and form rating by subjects who received KP with attentional cueing compared to performance of subjects who received KP only, indicates that attentional cueing may aid in the efficacy of video feedback. The group that showed the greatest change in both performance and form ratings was the KP plus transitional information group. These results suggest that this method provides the learner with information concerning how to make the appropriate changes in the execution of the motor action. It is possible that providing attentional focusing cues helps the learner focus his or her attention on the relevant aspects of the movement during video feedback. Thus verbal cues can aid in the decision and error correction process by reducing the number of responses from which to choose.

Landin and MacDonald (1990) showed that verbal cues that aid in the selection of appropriate responses can benefit both experts and novices. This type of information may be similar to feedback given to subjects in Kernodle and Carlton's study, the transitional feedback, which provided information about how to correct errors present in the movement pattern. The group that received video feedback with transitional information showed the largest increase in motor performance in their study even over the group that received attention cueing. Transitional information may be especially beneficial because of its ability help learners focus attention to errors in the movement pattern and to refine the cognitive representation that the learner has of the movement while also providing correction strategies. Providing transitional information gives the learner the proper correction strategies that may decrease the amount of variability of the performance of the movement from trial to trial. This may be the case for the reason that the learner does not have to test different strategies to determine the most appropriate correction. Kernodle and Carlton (1992) recommend that for the cues to be beneficial, transitional information must be appropriate for the movement being learned; further, experimenters who administer feedback should be experienced in evaluating the movement being learned. These recommendations are consistent with the views of Fowler and Turvey (1978), who suggested that learners' need information about how to correct errors rather than just pointing out the errors made in the previous trial.

In summary, the few studies that have assessed the effects of KP via video suggest a complex relation between the feedback condition and learner's skill acquisition. Methods that combine video feedback with verbal cueing appear to be beneficial to learning and refining complex motor behaviors typical of those used in sport context.

## Advances in Video Analysis Technology

With the advent of new video analysis technology, measuring movement patterns has become much more feasible than in the past and the technology provides the means for specific kinematic feedback to be administered. With the new video technology that has been recently developed, using video replay as a means of providing feedback has come into vogue. This type of feedback is thought to allow for more information about the actual movement to be presented. The use of video feedback was initially hypothesized to be of great benefit to the learner due to the ability to see a replay of ones self and pick up on any errors that may have been made during the execution of the movement. Research conducted by Rothstein and Arnold (1976) however, has provided evidence to suggest that video feedback alone may not be of benefit to a learner. The lack of feedback-produced benefits may be explained in terms of the quantity and quality of video feedback. Video feedback may provide too much information to the learner and, as a result, he or she is not able to focus on critical aspects of the movement.

The study conducted by Kernodle & Carlton (1992), described previously, addressed the possibility that video feedback alone provides the learner with too much information and fails to provide information concerning critical aspects of the movement to be learned. In both of these studies, the role of administering video feedback in conjunction with verbal feedback yielded increases in movement proficiency and learning.

## Movement Classification and the Hang Power Clean

Two approaches have been taken to categorize human movement. One approach classifies movements in terms of the type of actions involved. Movements are categorized as discrete, continuous, or serial. Discrete skills are skills that have a discernable beginning and end; examples being throwing and kicking a ball. Continuous skills are defined as movements that have no discernable beginning or end such as swimming or cycling. Serial skills are those skills that have a number of smaller discrete skills linked together to perform a skill as a whole such as learning a complex dance sequence in which parts of the dance are initially learned and then put together as a whole. A second approach classifies movements in terms of environmental predictability associated with the action or skills to be performed. Movements are categorized as open skills or closed skills. A closed skill takes place in a stable environment in which the environment is almost completely predictable such as bowling. Open skills are skills which require a skill to fit an unpredictable series of environmental factors which does not allow for the performer to effectively plan the whole movement in advance. An example of an open skill is driving on a busy road in which a general plan can be made about passing other cars, but this plan must be flexible in order to deal with unexpected actions of other cars on the road.

The hang power clean is classified as a serial, closed skill. The hang power clean is a variation of the clean and jerk exercise, which is a movement in which the lifter moves the barbell from the floor to chest level and then from chest level to overhead. However, in the hang power clean the lifter will hold the bar above the knees in the starting position, with knees slightly bent and shoulders in front of the bar (starting position). The lifter will then rapidly extend his or her hips, knees, and ankles propelling the bar upwards (pull phase) which is very similar to the mechanics seen in the execution of a vertical jump. Once the top of the pull phase is reached which is signaled by full extension of the hips, knees, and ankles, the lifter will rapidly move under the bar and catch the bar on the shoulders and clavicles (catch phase).

This hang power clean exercise has been found to produce high bar velocities, high ground reaction forces, and high power outputs (Garhammer, 1980). This exercise involves all of the major muscle groups of the body and is a technical lift which requires balance, coordination, timing and power (Garhammer, 1984). For these reasons the hang power clean has been used in athletic training for many years due to its ability to train athlete's muscles to produce power. Also the mechanics of this movement closely mimic and are specific to the demands placed on athletes in a variety of sports (i.e. hockey, football, basketball) in which being able to produce power is beneficial to performance.

The hang power clean is a movement that consists of multiple degrees of freedom and usually requires formal instruction for safe and efficient execution. The hang power clean is very technique specific and there are a variety of kinematic measures that can be evaluated throughout each phase of the movement (starting phase, pull phase, and catch phase). Specific kinematic measures during the starting phase include angle of torso relative to the ground, position of the bar relative to shoulders, and the position of the bar relative to the feet. Kinematic positions of importance in the pull phase are the angle of the body relative to the ground in full extension, position of the bar relative to the toe in full extension, and the time that the heels are out of contact with the platform. The final phase of the movement, the catch phase also has critical kinematic aspects including the time of elbow rotation under the bar, the knee angle during the catch, and the position of the hip relative to the feet. The outcome of this movement is simply the completion of the movement which is the end of the catch phase in which the bar comes to rest on the lifters' shoulders and clavicles. This outcome is highly reproducible and reasons for failure typically have to deal with the amount of weight that is on the bar rather than technical failure during execution. These characteristics make this skill a good candidate for research on augmented kinematic feedback. Also this skill is widely regarded as one of the best ways to develop power in athletes and it would be of great benefit to strength and conditioning professionals to understand the most beneficial way of giving feedback in an attempt to increase proficiency of the lift.

The hang power clean is a complex behavior that provides a model to evaluate the effects of various forms of augmented KP feedback on performance. Three forms of KP feedback were assessed in the present experiment: video+cues, verbal-only, and video-only. It was expected that 1) video+cues would enhance performance of the hang power clean to a greater extent than that of verbal or video feedback alone. 2) Verbal-only feedback will enhance performance of the hang power clean to a greater extent than video feedback alone. 3) Video-only feedback will show no improvements in performance.

# Chapter 3

# METHODS

## Participants

The research study included a volunteer sample of 26 female NCAA Division athletes ranging in age between 17 to 22 years, with an average age of 20 years. Participants were recruited from the University of Georgia volleyball team and soccer team. Recruited participants completed a questionnaire (Appendix A), which was used to evaluate each woman in terms of established exclusion criteria. An individual was excluded from participation if she had less than two months experience with the execution of the hang power clean, no prior completion of a one repetition maximal test (1-RM), or any medical contraindications to the performance of the hang power clean. One individual was excluded from participation. Anthropometric characteristics of the 25 participants who began the study are presented in Table 1. During the course of the study, 8 women withdrew from the study. Anthropometric characteristics of the 17 participants who completed the study are presented in Table 2. Withdrawal from the study was due to variety of reasons, which are described for each participant in Table 3.

## Research Design

A mixed-model research design was used in which the performance of individuals assigned to three groups was assessed prior to training, during 6 training sessions, and following training. Participants were stratified by height (greater or less than 67 inches) and by experience with the hang power clean (greater or less than 24 months) and then randomly assigned using a random number table to one of the three experimental groups: video-only, verbal-only, or video+cues. The video-only and verbal-only conditions each began with 8 subjects and the video+cues group began the study with 9 subjects.

## Instrumentation

The study was conducted in the weight room at the University of Georgia's sports training annex. Upon arriving, each subject read and signed an institutional review-board approved consent and completed a questionnaire. Participants attended 9 sessions, two per week (Monday and Friday), which was the normally scheduled weightlifting and conditioning time for each sport team. Participants also performed an additional strength training workout each Wednesday; the same format as Monday and Friday's workout was followed with the exception that the hang power clean task was not performed. All trials of the hang power clean were performed on 8 feet by 8 feet Powerlift lifting platforms that are specially designed for weightlifting and which house a barbell and weight plates. During the first and last sessions of the study, two platforms were used to conduct the 1-RM test and two platforms were used to conduct the power test. For the power test each platform was outfitted with a TENDO Weightlifting Analyzer (model V-104) that is used to calculate peak power and average power output during the execution of each repetition.

During each of the 9 trainings sessions, one platform was assigned to participants in each of the three treatment conditions. Platforms were separated by approximately 15 meters, which ensured the realtive isolation of participants in each feedback conditions. Each platform was equipped with a Panasonic digital video camcorder (model PV-GS300) mounted on a tripod set 11 feet away on the right side of the participant and positioned at a height 4 feet 8 inches. Platforms designated to the video-only and video+cues groups were also equipped with a Dell laptop (model Precision M-65) as a means of administering feedback. Feedback for the video-only and video+cues groups was administered using Dartfish© Advanced Video Analysis Software (version 4.0.9.0).

## Training and Measurement Procedures

At the beginning of the first session, the team's strength coach gave subjects general instructions for the session. Prior to beginning the prescribed exercises, participants assigned to the video-only group and those assigned to the video+cues group were asked to watch a video presentation of an expert modeling the hang power clean. Participants in the verbal-only group were asked to listen to a narration of the movement provided by an audio transcription via the Dartfish© software. (A sample text of the narration is found in Appendix B). Following the presentation of information, which took approximately 5 minutes, participants performed warm-up activities particular to their team. Upon completion of the warm-up, participants were asked to perform a 1-RM test of the hang power clean, which involves systematically increasing the weight lifted until the individual is capable of completing only one repetition of the lift. Participants in each team were assigned to one of eight platforms and were in groups of two to four participants per station. Proper safety protocols set forth by the National Strength and Conditioning Association were followed during the testing of the 1-RM test. Following a 2 to 3 minute rest period, participants were then asked to perform the muscular power test, which involved one set of 4 repetitions of the hang power clean using 70% of each individual's 1RM (~5 min duration). The test of muscular power for each participant took place at the same station that they were assigned to for the 1-RM test. The data were initially recorded by hand and then entered into a computer database. The total duration of each workout session was approximately 75 minutes for each team; and it required approximately 25 minutes to complete the experimental test protocol during each team's weight lifting session.

At the beginning of the second session, the team's strength coach again gave general instructions for the session. Following warm-up exercises, participants completed a series of the hang power clean repetitions. The weight moved by the participant during each lift was 75% of her 1-RM. The participant completed 4 sets of the hang power clean, (one set = 4 successive repetitions of the lifting movement). Participants in each team were assigned to one of four platforms equipped with a video camera and were in groups of 5 to 8. The video camera was turned on prior to the beginning of the experimental protocol and turned off once each participant's sets had been captured. Once the barbell was loaded with the designated weight (75% of 1-RM), participants were instructed to turn and face the camera prior to each set for identification purposes, prepare to execute the lift, and then execute the set. Following completion of each set, the participants placed the weighted barbell back in the weightlifting rack, helped adjust the weight on the barbell for the next participant, and then rested until their next turn (approximately 2 to 3 minutes). Digital images were recorded on a cassette, stored, and secured for later computer analyses. The total duration of the video-taping component of each team's experimental protocol was approximately 15 minutes.

The procedures employed for sessions 3 through 8 were identical to session 2. Following warm-up exercises, participants completed 4 sets (4 repetitions each) of the hang power clean. Participants in groups of 4 to 6 were assigned to one of three platforms that were equipped with a video camera. Lift performance was video taped throughout each experimental protocol and images were stored on a cassette, stored, and secured for later computer analyses. Once the barbell was loaded with the designated weight (75% of 1-RM), participants were instructed to turn and face the camera prior to each set for identification purposes, and then prepare to execute the lift, and then execute the set. Following completion of each set, the participant placed the weighted barbell back in the weightlifting rack, immediately proceeded to the assigned feedback station, received the appropriate feedback, and then rested until their next turn (approximately 2 to 3 minutes). Following each set, each participant assigned to the video-only condition was immediately shown video images of her lifting performance. The participant was allowed to view the video of her performance throughout the duration of one set (4 repetitions, approximately 45 seconds). Following each set, each participant assigned to the video+cues condition was immediately shown video images of her lift performance from the prior session with visual task relevant cues added to the video and was also given verbal feedback from the researcher concerning performance during the previous set. The task relevant cues not only drew attention to the movement aspects that were in most need of correction but also included information about how to correct the errors present in the movement (transitional information). Feedback was provided for approximately 45 seconds. Following each set, each participant assigned to the verbal-only condition received 45 seconds of verbal feedback typical of that provided by strength-training specialists. The feedback administered to the verbal only group and the verbal attention cues for the video+cues group can be found in Appendix C. The visual cues involved arrows and pointers to direct the subject's attention as well as the same cues that were given verbally but in written form on the screen. The cues corresponded to the 9 movement aspects that were analyzed in the study and can be found in Appendix D.

The total duration of the video-taping and feedback component of the participant's strength-training session was approximately 20 minutes. Digital images were stored on a cassette and secured for later software analyses.

During session 9, participants completed warm-up exercises and then performed the 1-RM test of the hang power clean and the muscular power test, which were measured in the same manner as during the first session of the experiment. The time required to complete both tests took approximately 30 minutes. At the end of the session, participants were debriefed which included a description of the intent of the study, and to provide answers to any questions posed by the participants.

## Data Reduction

Form Measures: During training sessions, movement performance of each participant was video recorded. Following sessions 2 through 8, all performances of each participant were entered into a computer for later analyses using the Dartfish© video analyses software. Nine movement indices were then analyzed using the Dartfish© video analyses software. These 9 indices can be found in Appendix D. Dartfish video analyses software allows for kinematic aspects of movement to be precisely measured. The methods in which each of the 9 indices were measured on the Dartfish© video analyses software can be found in Appendix D. An average score for each of the 9 indices was calculated by averaging participants' performance measured during second and third repetition of each of four sets. These measures were selected based on research conducted on the mechanics of the hang power clean, years of direct observation, and consultation with other strength and conditioning professionals. The feedback administered at the verbal-only or the video+cues stations, was directed toward aspects of the movement, most pertinent for subject's training. Once the subject demonstrated competence in a particular movement aspect, feedback regarding that aspect was withdrawn and the researcher evaluated another movement.

Outcome Measures: The outcome measures of interest in this study include the one repetition maximum test (1-RM) and the muscular power test. Scores on the 1-RM test indicate the maximum amount of weight that the individual could successfully lift for one repetition and was measured in pounds. This measure is important to the present study because increases in a 1-RM test are what athletes are typically evaluated on during testing and therefore athletes are trained to increase their 1-RM. Furthermore, if any significant changes are observed between groups on the 1-RM test it could indicate that one form of feedback is more beneficial in increasing an athlete's 1-RM. Scores for the 1-RM test were manually recorded and then were entered into a computer database. For the muscular power test, an individual's peak power output (Watt) was recorded for each repetition. This outcome measure is of importance because the hang power clean is used as a means to train an athlete to develop muscular power. Also, if any significant changes are observed between groups on the power test it could indicate that one form of feedback is more beneficial for increasing an athlete's power output. Power output scores were recorded manually after each rep and later entered into a computer database. Scores were averaged over four repetitions of the power test.

## Data Analysis

Each of the 9 form measure scores were analyzed separately via a mixed-model two-way ANOVA in which the three training conditions constituted the between-groups factor and participants' performance measures during each of the training session constituted the repeated-measures factor. Violations of sphericity were corrected by adjusting degrees of freedom according to the Huyhn-Feldt test. An alpha of 0.05 was used for all ANOVAs. Estimates of effect size ($\eta_p^2$) were reported for significant main effects and interactions.

The form measures were further analyzed to test the reliability of the scoring procedure. A rater, who was unaware of participants' assignments to training conditions, was taught the methods of data collection using the Dartfish© video analysis software and was instructed to conduct the analysis process for three subjects in each of the three feedback conditions. The scores obtained from the blind rater and the scores obtained by the primary researcher were correlated. The stability of scores measured during successive training sessions was determined by assessing the performance of participants assigned to the video-only treatment group. An intraclass correlation (ICC) using a two-way random consistency model was computed on participants' scores across the six training sessions. Intraclass correlations were computed separately for each of the nine movements.

Outcome measures included the 1-RM test scores and the muscular power test scores. The scores of each outcome measure were analyzed separately via a mixed-model two-way ANOVA in which the three training conditions constituted the between-groups factor and participants' performance measures on the first and last session constituted the repeated-measures factor.

**Table 1. Population Demographics**

| | (N) | Height (in) | Experience (months) |
|---|---|---|---|
| Subjects | 25 | 67.68±2.65 | 20.64±18.5 |
| Video-Only | 8 | 67.38±2.45 | 15.75±10.6 |
| Verbal-Only | 8 | 67.75±2.96 | 20.13±19.3 |
| Video+Cues | 9 | 67.88±2.85 | 25.44±23.5 |

**Table 2. Subject Demographics**

| | (N) | Height (in) | Experience (months) |
|---|---|---|---|
| Subjects | 16 | 68.06±2.32 | 18.68±16.17 |
| Video-Only | 5 | 67.8±2.28 | 15±11.02 |
| Verbal-Only | 5 | 67.4±1.34 | 21.6±20.05 |
| Video+Cues | 6 | 68.83±3.06 | 19.3±18.52 |

**Table 3. Participant Withdrawal**

| Subjects ID# | Group | Reason for Withdrawal |
|---|---|---|
| #3 | Verbal-Only | Did not complete all sessions |
| #4 | Video+Cues | Could not complete final testing |
| #9 | Video-Only | Injury |
| #12 | Video-Only | Injury |
| #21 | Video-Only | Did not complete all sessions |
| #24 | Verbal-Only | Injury |
| #25 | Video+Cues | Did not complete all sessions |
| #26 | Video+Cues | Did not complete all sessions |

## Chapter 4

## RESULTS

The data obtained in this study were of two types. *Form measurements* yield indices of the characteristics of the movement of interest. *Outcome of movement measurements* yield indices of the extent to which a given movement achieved a specific goal.

### **Form Measures**

**Start Phase**

1) Torso Inclination Relative to the Ground

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed-model ANOVA conducted on the torso inclination relative to the ground measure scores did not yield a main effect among groups $F_{(2,14)} = .239$, $p > .05$ or Time $F_{(5,70)} = 1.389$, $p > .05$. There was a significant Group X Time interaction $F_{(8.191,57.338)} = 4.170$, $p < .05$, $\eta_p^2 = .373$. Post hoc tests conducted on scores measured during each of the six training failed to find difference among groups. The ICC for the video-only group was 0.944. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 1.

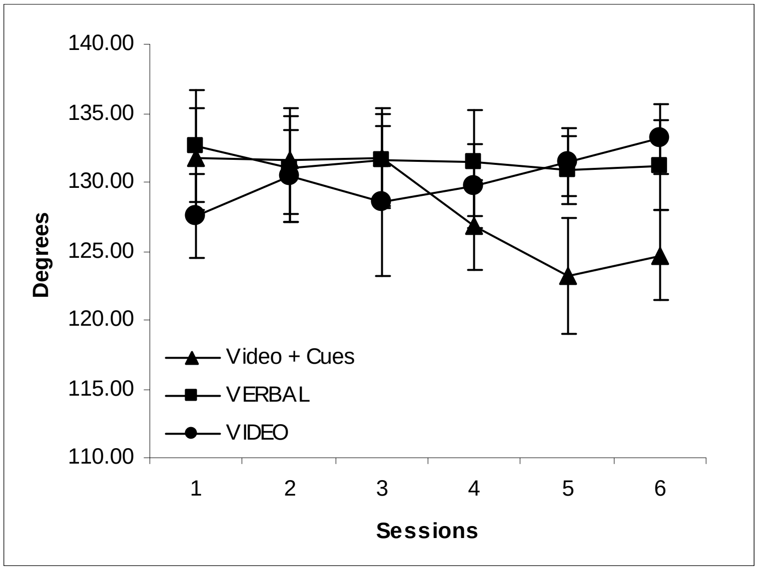


**Figure 1. Torso Inclination Relative to Ground**

2) Distance Ears are in Front of the Bar

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA on the distance ears are in front of the bar measure scores did not yield a main effect among Groups $F_{(2,14)} = .240$, $p > .05$ or Time $F_{(5,70)} = 4.160$, $p > .05$. There was a significant for Group X Time interaction $F_{(7.165,50.135)} = 2.842$, $p < .05$, $\eta_p^2 = .289$ with degrees of freedom adjusted using the Huynh-Feldt test to correct for violation of sphericity. Post hoc tests conducted on scores measured during each of the six training failed to find difference among groups. The ICC for the video-only group was 0.981 Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 2.

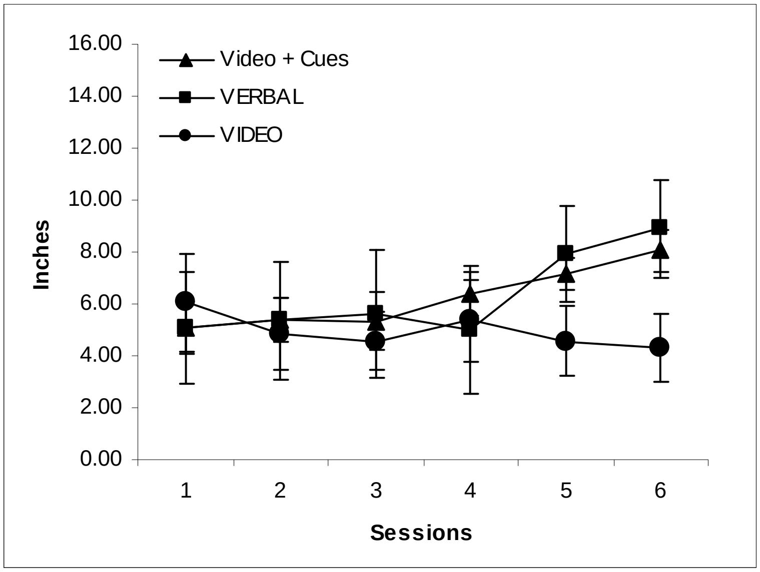


**Figure 2. Distance Ears are In Front of Bar**

3) Position of Bar Relative to Toe

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the position of bar relative to toe measure scores did not yield a main effect among Groups $F_{(2, 14)} = .441$, $p > .05$ or Time $F_{(5,70)} = 1.339$, $p > .05$. There was marginal effect for Group X Time interaction $F_{(9.544,66.81)} = 1.850$, $p = .071$, $\eta_p^2 = .209$ with degrees of freedom adjusted using the Huynh-Feldt test to correct for violation of sphericity. The ICC for the video-only group was 0.955 Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 3.

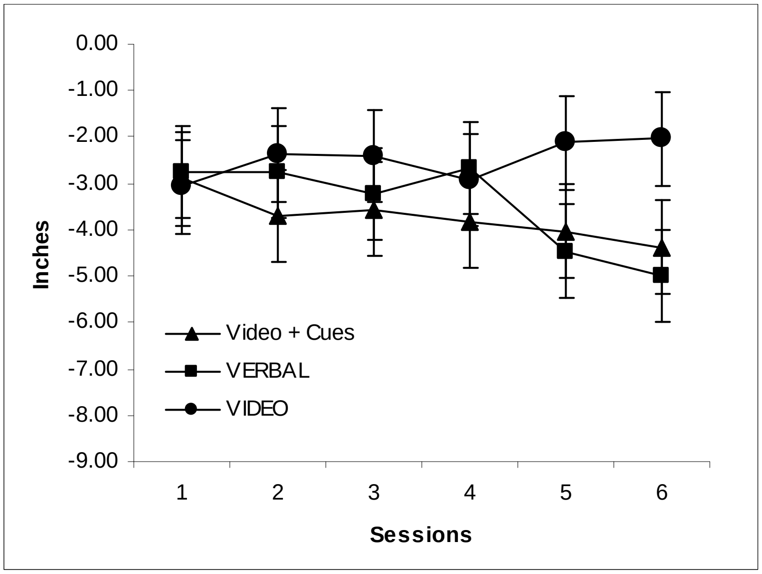


**Figure 3. Position of Bar Relative to Toe**

**Pull Phase**

1) Angle of Body

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the angle of body measure scores did not yield a main effect among Groups $F_{(2,14)} = 1.627$, $p > .05$. There was a main effect present for Time $F_{(5,70)} = 4.857$, $p < .05$, $\eta_p^2 = .258$. There was a significant Group X Time interaction $F_{(10,70)} = 4.273$, $p < .05$, $\eta_p^2 = .379$. Post hoc tests indicated that the three groups differed during session 5 $F_{(2,14)} = 4.338$, $p < .05$. The Video + Cues group differed from the Verbal only group with a mean difference of 2.75 at $p < .05$ but did not differ from the Video only group. There was no difference present between the Verbal only group and the Video only group during session 5. The ICC for the video-only group was 0.988. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 4.

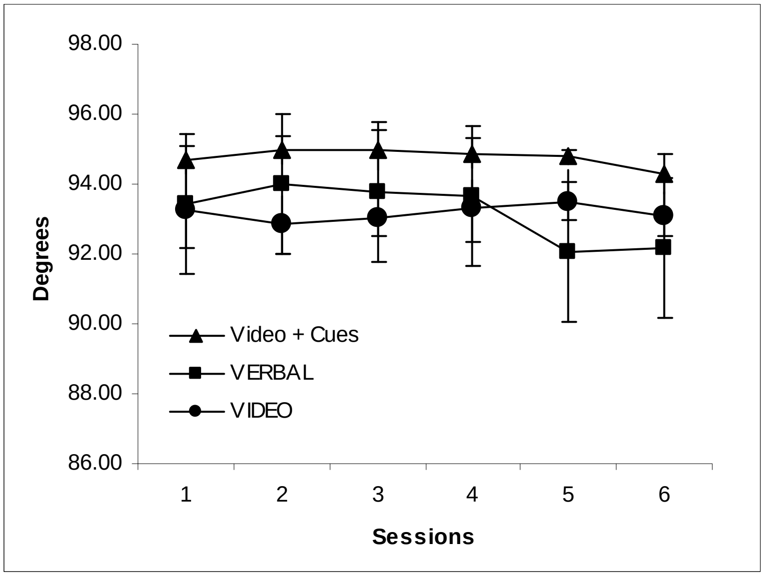


**Figure 4. Angle of Body**

2) Bar Relative to Toe in Full Extension

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the bar relative to toe in full extension measure scores did not yield a main effect among Groups $F_{(2,14)} = .649$, $p > .05$ or Time $F_{(5,10)} = 1.477$, $p > .05$. There was a significant Group X Time interaction $F_{(9.153, 64.07)} = 2.568$, $p < .05$, $\eta_p^2 = .270$ with degrees of freedom adjusted using the Huynh-Feldt test to correct for violation of sphericity. Post hoc tests showed marginal effect for session 5 $F_{(2,14)} = 2.961$, $p = .085$ and marginal effect for session 6 $F_{(2,14)} = 2.795$, $p = .095$. The ICC for the video-only group was 0.981. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 5.

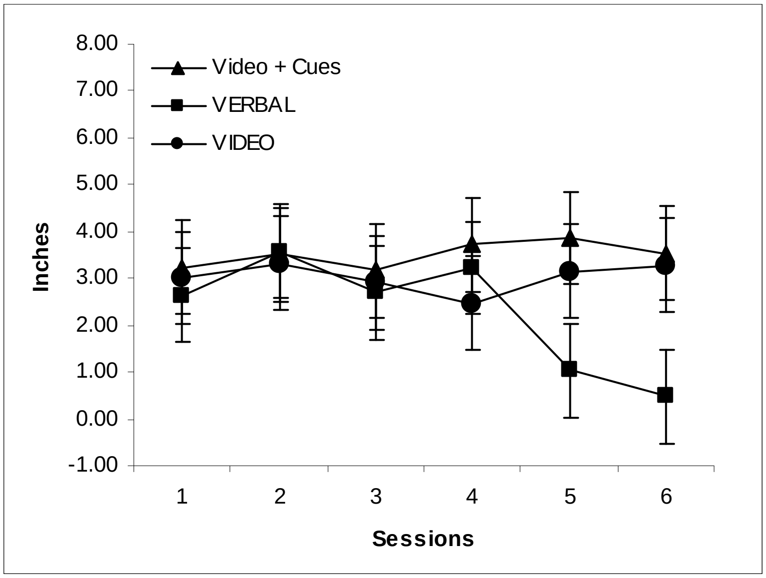


**Figure 5. Bar Relative to Toe in Full Extension**

3) Time Heels are Out of Contact with Platform

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on time heels are out of contact with platform measure scores did not yield a main effect among Groups $F_{(2,14)} = 1.018$, $p > .05$, Time $F_{(5,70)} = .652$, $p > .05$, or Group X Time interaction $F_{(10,70)} = .403$, $p > .05$. Mean scores for the three groups over each of the 6 feedback sessions are seen in Figure 8. The performance for all three groups did not change as a function of training. The ICC for the video-only group was 0.980. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 6.

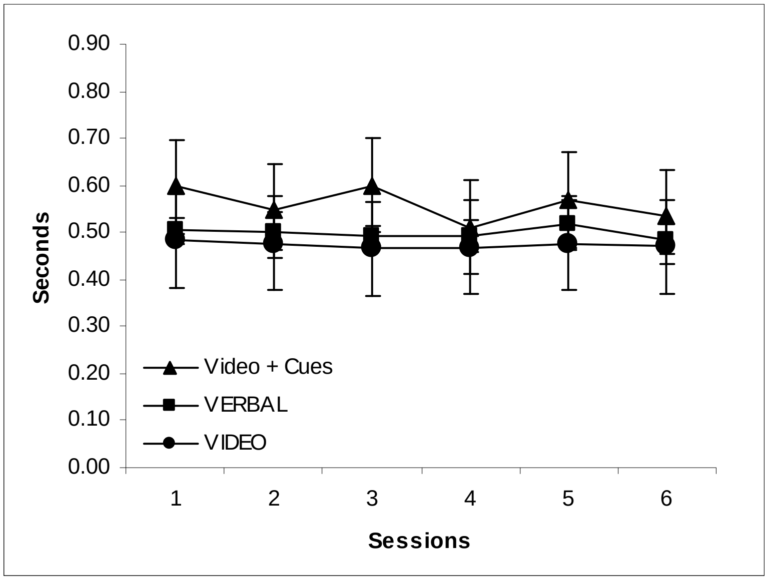


**Figure 6. Time Heels are Out of Contact with Platform**

**Catch Phase**

1) Time of Elbow Rotation Under the Bar

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the time of elbow rotation under the bar measure scores did not yield a main effect among Groups $F_{(2,14)} = .390$, $p > .05$. There was a marginal effect for Time $F_{(3.225,32.882)} = 2.451$, $p = .071$, $\eta_p^2 = .149$ with degrees of freedom adjusted using the Huynh-Feldt test to correct for violation of sphericity. There was no Group X Time interaction $F_{(10,70)} = 1.117$, $p > .05$. The ICC for the video-only group was 0.997. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 7.

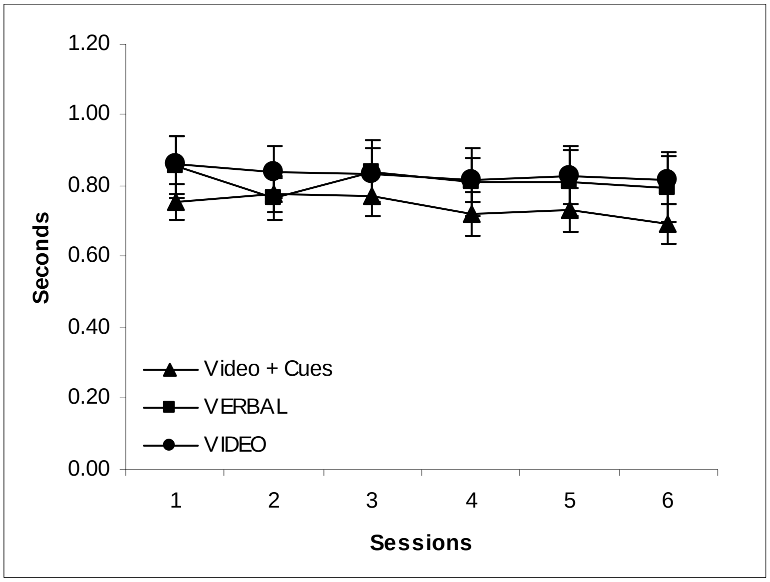


**Figure 7. Time of Elbow Rotation Under the Bar**

2) Knee Angle

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the knee angle measure scores did yield a main effect among Groups $F_{(2,14)} = 3.9$, $p < .05$, $\eta_p^2 = .358$. The Video+Cues group differed from the Video only group (mean difference of .027, $p < .05$); the Verbal Only group differed from the Video only group (mean difference of .029, $p < .05$); the Video + Cues group did not differ from the Verbal only group. There was no main effect for Time $F_{(5,70)} = 1.7$, $p > .05$, $\eta_p^2 = .108$. There was no Group X Time interaction $F_{(10,70)} = .66$, $p > .05$. The ICC for the video-only group was 0.995. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 8.

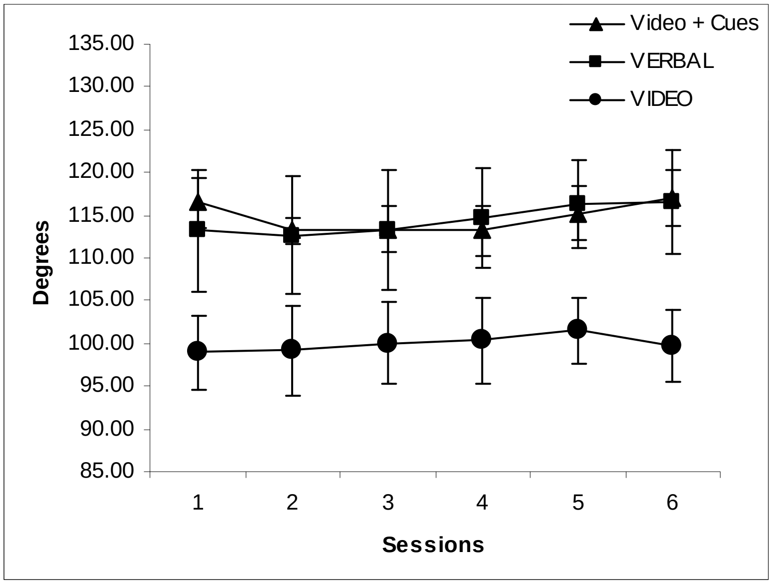


**Figure 8. Knee Angle**

3) Center of Hip Relative to Toe

The 3 (Group: Video, Video+Cues, Verbal) X 6 (Time: 6 Feedback Sessions) mixed model ANOVA conducted on the center of hip relative to toe measure scores did not yield a main effect among Groups $F_{(2,14)} = 2.962$, $p > .05$. There was a main effect present for Time $F_{(5,70)} = 2.443$, $p < .05$, $\eta_p^2 = .149$. There was significant differences in time found between session 2 and 6 (mean difference of -.711 $p < .05$) and sessions 4 and 6 (mean difference of -.682 $p < .05$). There was no Group X Time interaction $F_{(10,70)} = .282$, $p > .05$. The ICC for the video-only group was 0.980. Mean scores for the three groups and error bars representing standard error over each of the six feedback sessions are seen in Figure 9.

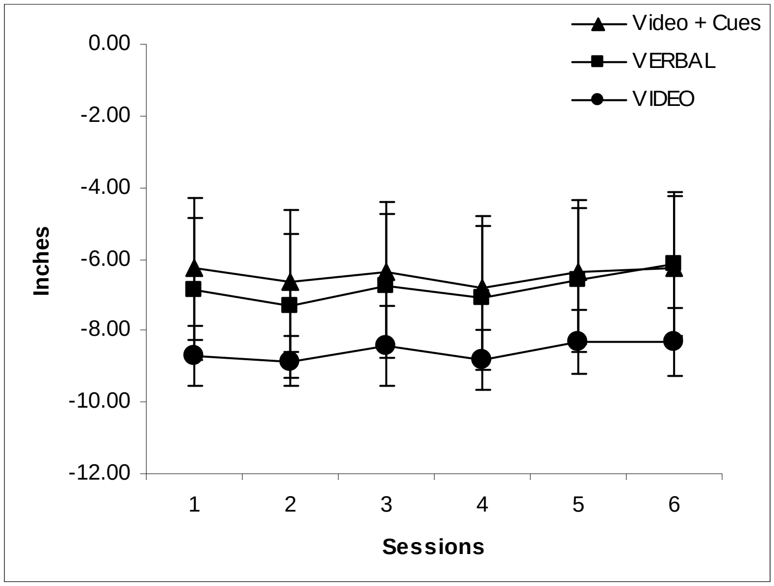


**Figure 9. Center of Hip Relative to Toe**

## Outcome of Movement Measures

### One repetition maximum (1-RM) Test

The 3 (Group: Video, Video+Cues, Verbal) X 2 (Time: Pre, Post) mixed-model ANOVA conducted on the one-repetition maximum (1-RM) scores did not yield a main effect among Groups $F_{(2,14)} = .037$, $p > .05$. There was a main effect observed for Time $F_{(1,14)} = 22.275$, $p < .05$, $\eta_p^2 = .614$. There was no Group X Time interaction $F_{(2,14)} = 1.385$, $p > .05$. Mean 1-RM performance scores for the three groups before and following training are seen in Figure 10. The performance of participants in all three groups improved similarly as a function of training.

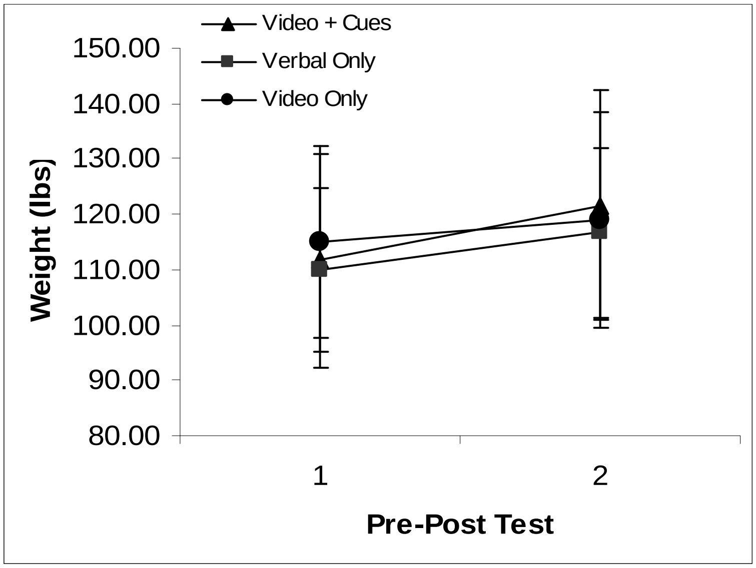


**Figure 10. One Repetition Maximum (1-RM) Test**

**Muscular-Power Test**

The 3 (Group: Video, Video+Cues, Verbal) X 2 (Time: Pre, Post) mixed model ANOVA conducted on the muscular-power test scores did not yield a main effect among groups $F_{(2,14)} = .081$, $p > .05$. There was a main effect observed for time $F_{(1,14)} = 14.69$, $p < .05$, $\eta_p^2 = .512$. There was no Group X Time interaction $F_{(2,14)} = .220$, $p > .05$. Mean power test performance scores for the three groups before and following training are seen in Figure 11. The performance of participants in all three groups improved similarly as a function of training.

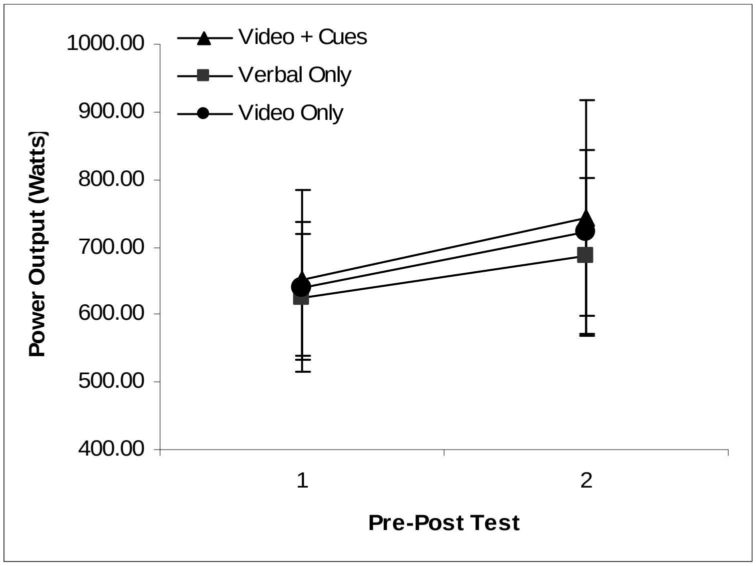


**Figure 11. Muscular Power Test**

## Inter-Rater Reliability Analysis

The scores obtained by the primary researcher and the blind rater on three participants, one from each group, were correlated (Pearson r) test. Using the Dartfish© video analysis software, raters scored each participant's movement proficiency on two repetitions and then averaged. The agreement between raters ranged between 0.94 and 1.0. Results for each movement aspect are provided in Table 4.

**Table 4. Inter-Rater Reliability**

| Movement Aspect | Pearson (r) Correlation |
|---|---|
| Torso Inclination Relative to the Ground | 0.98 |
| Distance Ears are in Front of Bar | 1.0 |
| Position of the Bar Relative to the Toe | 1.0 |
| Angle of Body | 0.99 |
| Bar Relative to Toe in Full Extension | 1.0 |
| Time Heels are Out of Contact with Platform | 0.94 |
| Time of Elbow Rotation Under the Bar | 0.99 |
| Knee Angle | 0.99 |
| Center of Hip Relative to Toe | 1.0 |

## Chapter 6

## DISCUSSION

This experiment was designed to evaluate the effects that three forms of augmented knowledge of performance (KP) feedback have on young adults' acquisition of a weight-lifting skill. Skill was evaluated in terms of form measurements, which yield indices of the characteristics of the movement of interest. Outcome of movement measurements were also evaluated, which yield indices of the extent to which the given movement achieved a specific goal.

The impacts of three different types of augmented KP feedback were compared: video+cues, verbal-only, and video-only. The video+cues group received video replay that included both visual task-relevant cues as well as verbal-task relevant cues. The cues given both visually and verbally for the video+cues group directed the participant's attention towards the most critical corrections needed, and also provided information about how to make the proper corrections. The verbal-only group received verbal cues that were the exact same as the verbal cues presented to the video+cues group; however, this group was not presented video feedback or video cues. The video-only group received video replay of their previous performance, but did not receive any verbal or visual cues in regards to their performance.

The movement of interest, the hang power clean, was chosen based on the multiple degrees of freedom exhibited during execution as well as the technical specificity required to properly execute the movement. The hang power clean has three distinct phases: the start-phase, the pull-phase, and the catch-phase. Each phase contains three distinct movement aspects. A summary of the effects of each form of KP feedback on participants' movement form is presented in Table 5 (improved movement pattern = +; no change in movement pattern = -).

**Table 5. Effects of Feedback Conditions on Movement Form**

| | Video+Cues | Verbal Only | Video Only |
|---|---|---|---|
| **Start Phase** | | | |
| Torso Inclination Relative to Ground | + | + | - |
| Distance Ears are In Front of Bar | + | + | - |
| Position of Bar Relative to Toe | + | + | - |
| **Pull Phase** | | | |
| Angle of Body in Full Extension | - | + | - |
| Bar Relative to Toe in Full Extension | - | + | - |
| Time Heels are Out of Contact with Platform | + | + | - |
| **Catch Phase** | | | |
| Time of Elbow Rotation Under the Bar | - | - | - |
| Knee Angle | - | - | - |
| Center of Hip Relative to Toe | - | - | - |

### Effects of Augmented KP on the Three Phases of the Hang Power Clean

The results provide partial support for the predictions that: 1) video+cues feedback would yield greater changes in performance compared to verbal-only and video-only conditions, 2) verbal-only feedback would yield greater changes than video-only conditions, and the 3) video-only feedback would yield no changes in performance.

The Start Phase. The results obtained for the start phase of the hang power clean did not support the prediction that participants in the video+cues feedback group would perform movements better than participants in the video-only group; however, the results do support the prediction that participants in the video+cues feedback group and participants in the verbal-only feedback group would perform better than the video-only group. The start phase of the hang power clean includes three movement aspects: 1) torso inclination relative to the ground, 2) distance ears are in front of the bar, and 3) position of bar relative to toe. Statistical analyses of movement form scores revealed that video+cues feedback and verbal-alone feedback conditions improved two movement aspects: 1) torso inclination relative to the ground, and 2) distance ears are in front of the bar. While not statistically significant, visual inspection of the data suggest that position-of-the-bar relative-to-toe-scores benefited from both the video+cues and verbal-only feedback conditions. Thus, it appears that both verbal KP and video+cues KP are sufficient to improve select movements that constitute the power hang clean. As predicted, participants in the video-only group evidenced no gains in performance.

<u>The Pull Phase.</u> The results obtained for the pull phase of the hang power clean failed to support the prediction that participants in the video+cues feedback group would perform pull-phase movements better than participants in the video-only group. Indeed, participants in the verbal-only group performed two movements better than subjects who received video+ cues or video-only feedback. The pull phase of the hang power clean consists of three movement aspects: 1) angle of body relative to ground in full extension, 2) position of bar relative to toe in full extension, and 3) time heels are out of contact with the floor. Statistical analyses revealed that two of the three movement aspects were influenced by feedback: 1) angle of body relative to ground in full extension and 2) position of bar relative to toe in full extension.

<u>The Catch Phase.</u> The catch phase of the hang power clean consists of three movement aspects: 1) time of elbow rotation under the bar, 2) knee angle, and 3) center of hip joint relative to toe. None of the movement aspects changed as a function of training. The movements that

occur in the catch phase happen rapidly and ballistically. The catch phase movements may provide only limited intrinsic feedback and, thus, may not allow for a precise cognitive representation to be formulated.

Prior research has shown that kinematic video feedback with attention cueing (e.g., transitional information) is more beneficial for performance than verbal or video feedback alone Kernodle & Carlton, 1992). This was not the case in the present study, as the participants in the video+cues group did not increase performance more than the verbal-only group. It may be the case that the verbal cues used in both feedback conditions were sufficient to direct participants' focus to critical aspects of the movement and to provide the participant with information concerning the appropriate corrections. Kernodle and Carlton (1992) observed that kinematic feedback given verbally with cues that contained transitional information; outperformed video replay coupled with cues that did not contain transitional information and simply focused the performer's attention to parts of the movement that contained errors. Both feedback conditions (i.e., verbal cues with transitional information and video replay with attentional focusing cues) enhanced the learning of complex movements more than verbal KR-only feedback or, video KP-only feedback. In the present study, both verbal and visual feedback conditions contained transitional information and the results of the present study suggest that the form of the feedback, (i.e., video vs. verbal) may be of less importance on performance than transitional information presented.

In summary, the effects of augmented kinematic KP on complex multiple segment actions appear to be complex. Augmented KP may benefit some, but not all, movement components of the hang power clean. It is clear, however, few if any performance gains are realized when augmented feedback is limited to simply allowing a learner to view a video display of his or her performance.

### Effects of Augmented KP on Muscular Strength and Power Outcome Measures

The second goal of the present study was to determine if kinematic feedback would influence muscular strength and power outcome measures. The results of training are important for practical application by strength and conditioning personnel. Comparison of participants' performance before and following training revealed that both muscular strength and power increased in each of the training conditions. Feedback, regardless of the method of administration, appears to play a role in improving the performance of a highly technique specific weightlifting skill. It is the case, however, that the increase in participants' outcome measure scores could also be due to the strength training regimen the subjects were involved in during the study. During the course of the study individuals were also required by their respective strength coaches to adhere to a strength and conditioning program designed to increase muscular strength and power. The programs administered utilized other exercises that are aimed at increasing muscular strength and power. The additional exercises could have played a role in the increases observed, and thus the increases in muscular strength and power are not solely a result of the experimental protocol.

## Limitations of the Study

There are several limitations of results obtained in the present study. Participant withdrawal led to small sample sizes. The small sample size is known to influence statistical power. As such, the small sample size yielded less sensitive statistical tests of hypothesized relations between feedback conditions and participants' performance.

An additional limitation was the lack of stringent experimental control typical of laboratory-based studies. The present study was conducted under training conditions typical for competitive athletes and it was designed for practical application in the strength and conditioning arena. Strength coaches very rarely have control of their athletes' training conditioning. The methods used to recruit participants also limits generalizations that can be made from the results obtained. The participants were university athletes with extensive histories of sport-specific training. It is unknown whether the results obtained in the present experiment would be similar for a sample of young women who were not competitive athletes. Non-competitive young women with the same amount of experience with the hang power clean would be expected to yield the same results for form measures. However, there may be greater changes in the movement outcome measures. Competitive athletes are required to undergo rigorous training for their respective sport and as a consequence typically exhibit fitness levels much higher than the general non-competitive population of young women. Young, non-competitive women may begin with a lower level of muscular strength and power and as a result may show increased gains in strength and power over competitive young women.

While all participants were competitive athletes, individual differences exist that may have influenced study outcomes. First, participants were selected from two different athletic teams (volleyball and soccer), and each sport has different demands and therefore require slightly different methods of strength training. The metabolic demands of soccer and volleyball are quite different due to the nature of play in each sport. Soccer stresses a wide variety of metabolic systems and demands that training focus on short, powerful sprinting as well as long, endurance running. Volleyball on the other hand does not require as much endurance training as soccer and focuses more on short burst metabolic demands and training that increases heart rate recovery.

Also, volleyball strength training may focus more on power development due to the amount of jumping and explosive movement present. These slight differences in training may have had an effect on the movement outcome measures but is unlikely that they had an effect on the form measures.

In addition, the study was limited to athletes with prior weight-training experience. While all participants had previously participated in strength training using the hang power clean exercise, the amount of previous experience with the hang power clean varied among athletes and could have possibly affected the study outcomes. The young athletes in the present study may have been in different stages of learning the hang power clean and these differences may have affected how the different types of feedback influenced performance improvements. Individual differences in strength training experience are common in many Division-1 athletic teams.

However, while the physical demands of each sport differs, increasing muscular strength and power is a primary goal of strength trainers for each sport and the exercises prescribed to each team may have varied but the goals were the same. Every effort was put forth to ensure that the training regimens of each team did not greatly differ. Efforts included insuring that both teams were in their off-season, both teams were in the same training stage, and that outside activity was comparable between teams. The inability to monitor outside activity and the intensity of voluntary practices may have impacted form measures and movement outcome measures. Increases in unsupervised activities could have led to abnormal amounts of fatigue which may have an impact on both form and movement outcome measures.

## Conclusions

The results of the present study corroborate those obtained in several other studies showing that simply providing a learner with video feedback without additional cues has little effect on skill acquisition (Arnold, 1976; Newell, 1981). Improvements in skilled performance necessitates that some form of cued feedback. However, the effects of cued feedback on dynamic multiple segment actions appear to be complex. Knowledge of performance may benefit some, but not all, movement components. It is unlikely that any one form of KP, in and of itself, will lead to improvement in all aspects of movements that underlie the complex behaviors seen in sporting events. Nevertheless, more research is needed that examines the acquisition of complex multiple degree of freedom movements and how types of feedback influence performance and learning. Additional information will provide the basis for developing a component specific approach to athletic skill training. It will be important for both researchers and strength trainers to analyze the components of sport-related movements and to identify components that may be differentially influenced by different types of feedback. In the present study, video replay plus verbal feedback was not found to differ from verbal-only feedback conditions. However, the participants in the study were young athletes with prior experience in weight lifting. It remains to be determined if video feedback may aid novices who may be able to use video information to develop cognitive representations involved in planning movements. Strength and conditioning professionals should be aware that regardless of whether KP feedback is administered verbally, visually, or in combination, it is important that the feedback does not simply direct an individual's attention to the aspect of the movement that is in error, but also the feedback provides information concerning how movement error can be reduced.

## REFERENCES

Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3,* 111-150.

Adams, J.A., & Bray, N.W. (1970). A closed-loop theory of paired-associate verbal learning. *Psychological Review, 77,* 385-405.

Ackerman, P.L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117,* 288-318.

Ackerman P.L. (1992). Predicting individual differences in complex skill acquisition: Dynamics of ability determinants. *Journal of Applied Psychology, 77,* 598-614.

Ackerman, P.L., & Cianciolo, A.T. (2000) Cognitive, perceptual-speed, and psychomotor determinants of individual differences during skill acquisition. *Journal of Experimental Psychology: Applied, 6,* 259-290.

Anderson, J.R. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369-406.

Bernstein, N.A. (1967). *The co-ordination and regulation of movements*. Oxford: Pergamon Press.

Black, C.B., & Wright, D.L. (2000). Can observational practice facilitate error recognition and movement production? *Research Quarterly for Exercise and Sport, 71,* 331-339.

Bryan, W.L., & Harter, N. (1899) Studies on the telegraphic language: The acquisition of a hierarchy of habits. *Psychological Review, 6,* 345-375.

Carroll, W.R., & Bandura, A. (1982). The role of visual monitoring and motor rehearsal in observational learning of action patterns: Making the unobservable observable. *Journal of Motor Behavior, 14,* 153-167.

Carroll, W.R., & Bandura, A. (1985). Role of timing of visual monitoring and motor rehearsal in observational learning of action patterns. *Journal of Motor Behavior, 17,* 269-281.

Carroll, W.R., & Bandura, A. (1987). Translating cognition into action: Theo role of visual guidance in observational learning. *Journal of Motor Behavior, 19,* 385-398.

Carroll, W.R., & Bandura, A. (1990). Representational guidance of action production in observational learning: A causal analysis. *Journal of Motor Behavior, 22,* 85-97.

Ferrari, M. (1996). Observing the observer: Self-regulation in the observational learning on motor skills. *Developmental Review, 16,* 203-240.

Fitts, P.M. (1964). Perceptual-motor skills learning. In A.W. Melton (ed.), *Categories of human learning* (pp. 243-285). New York: Academic Press.

Fitts, P. M., & Posner, M.I. (1967). *Human Performance*. Belmont, CA: Brooks Cole.

Fowler, C. A., & Turvey, M. T. (1978). Skill acquisition: An event approach with special reference to searching for the optimum of a function of several variables. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 1-40). New York: Academic Press.

Garhammer, J. (1980). Power production by Olympic weightlifters. *Medicine and Science in Sports and Exercise, 12,* 54-60.

Garhammer, J. (1984). Power: Kinesiological evaluation. *NSCA Journal,* 60-63.

Gentile, A.M. (1972). A working model of skill acquisition with application to teaching. *Quest, 17,* 3-23.

Guadagnoli, M., Holcomb, W., & Davis, M. (2002). The efficacy of video feedback for learning the golf swing. *Journal of Sport Sciences, 20,* 615-622.

Guthrie, E.R. (1952). *The psychology of learning*. New York: Harper & Row.

Henry, F.M. & Rogers, D.E. (1960). Increased response latency for complicated movements and a “memory drum” theory of nueromotor reaction. *Research Quarterly, 31,* 448-458.

Janelle, C.M., Barba, D.A., Frehlich, S.G., Tennant, L.K., & Cauraugh, J.H. (1997). Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport, 4,* 269-279.

James, W. (1890). *The principles of psychology* (Vol. 1). New York: Holt.

Kernodle, M.W., & Carlton, L.G. (1992). Information feedback and the learning of multiple-degree-of-freedom activities. *Journal of Motor Behavior, 24,* 187-196.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility – a model and taxonomy. *Psychological Review, 97,* 253-270.

Landin, D. (1994). The role of verbal cues in skill learning. *Quest, 46,* 299-313.

Landin, D.K., & MacDonald, G. (1990). Improving the overheads of collegiate tennis players. *Journal of Applied Research in Coaching and Athletics, 5,* 85-90.

Magill, R.A. & Wood C.A. (1986). Knowledge of results precision as a learning variable in motor skill acquisition. *Research Quarterly for Exercise and Sport, 57,* 170-173.

McCullagh, P., & Weiss, M.R. (2001). Modeling: Considerations for motor skill performance and psychological responses. In R.N. Singer, H.A. Hausenblas, & C.M. Janelle (Eds.), *Handbook of sport psychology* ($2^{nd}$ ed.) (pp. 205-238) New York: Wiley.

Mononen, K., Vitasalo, J., Konttinen, N., & Era, P. (2003). The effects of augmented kinematic feedback on motor skill learning in rifle shooting. *Journal of Sport Sciences, 21,* 867-876.

Newell, K.M. (1981). Skill Learning. In D.H. Holding (Ed.), *Human Skills.* New York: Wiley.

Newell, K.M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213-237.

Newell, A., & Rosenbloom P.S. (1981). Mechanisms of skill acquisition and the law of practice. In J.R. Anderson (ed.), *Cognitive skills and their acquisition* (pp. 1-55). Hillsdale, NJ: Erlbaum.

Newell, K.M., & Walter, C.B. (1981). Kinematic and kinetic parameters as information feedback in motor skill acquisition. *Journal of Human Movement Studies, 7,* 235-254.

Newell, K.M., Quinn, J.T., Sparrow, W.A., & Walter, C.B. (1983). Kinematic information feedback for learning a rapid arm movement. *Human Movement Science, 2,* 255-269.

Newell, K.M., & Carlton, M.J. (1987). Augmented information and the acquisition of isometric tasks. *Journal of Motor Behavior, 19,* 4-12.

Newell, K.M., Quinn, J.T., & Carlton, M.J. (1987). Kinematic information feedback and task constraints. *Applied Cognitive Psychology, 1,* 273-283.

Poulton, E.C. (1957). On prediction in skilled movements. *Psychological Bulletin, 54,* 467-478.

Rothstein, A.L., & Arnold, R.K. (1976). Bridging the gap: Application of research on videotape feedback and bowling. *Motor Skills: Theory Into Practice, 1,* 35-62.

Salmoni, A.W., Schmidt, R.A., & Walter, C.B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95,* 355-386.

Schmidt, R.A. & Lee T.D. (2005). *Motor control and learning: A behavioral emphasis*. Champaign, IL: Human Kinetics.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1-66.

Small, A.M. (1990). Foreword. In R.W. Proctor & T.G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. v-vi). Amsterdam: Elsevier.

Snoddy, G.S. (1926). Learning and Stability: A psychophysical analysis of a case of motor learning with clinical applications. *Journal of Applied Psychology, 10,* 1-36.

Solley, W.H. (1952). The effects of verbal instruction of speed and accuracy upon the learning of a motor skill. *Research Quarterly, 23,* 231-240.

Sparrow, W.A., & Summers, J.J. (1992). Performance on trials without knowledge of results (KR) in reduced relative frequency presentations of KR. *Journal of Motor Behavior, 24,* 197-209.

Thorndike, E.L. (1931). *Human Learning*. New York: Century

Schmidt, R.A. & Wrisberg, C.A. (2004). *Motor learning and performance*. Champaign, IL: Human Kinetics.

Weeks, D.J., Zelaznik, H., & Beyak, B. (1993). An empirical note on reduced frequency of knowledge of results. *Journal of Human Movement Studies, 25,* 193-201.

Weeks, D.L. & Kordus, R.N. (1998). Relative frequency of knowledge of performance and motor skill learning. *Research Quarterly for Exercise and Sport, 69,* 224-230.

Wieringen, P.C., Emmen, H., Bootsma, R.J., Hoogesteger, M., & Whiting, H.T. (1989). The effect of video-feedback on the learning of the tennis service by intermediate players. *Journal of Sport Sciences, 7,* 153-162.

Young, D.E. & Schmidt, R.A. (1992). Augmented kinematic feedback for motor learning. *Journal of Motor Behavior, 24,* 261-273.

# APPENDIX

## Appendix A

Questionnaire

## Previous Experience Questionnaire

Name: ______________________ Sport: ______________________

Height: ______________________ Dominant Hand: ______________________

Academic year in College: ______________________

Years playing current sport? ______________________

Years involved in weightlifting? ______________________

Years/Months performing the Hang Power Clean Exercise? Years: Months: ______________________

Have you performed a maximal test for the Hang Power Clean? Yes / No

Rate your performance on the Hang Power Clean.
(Circle Choice) Excellent Fair Poor

Rate your perceived exertion when performing a maximal test of the Hang Power Clean (Circle Choice)

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 10+ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nothing At All | | | | | Heavy | | | | | Almost Maximal | Maximal |

Do you feel comfortable performing the Hang Power Clean? Yes / No

# Appendix B

Hang Power Clean Narration

## Hang Power Clean Narration

After loading the bar with the appropriate weight, you will grab the barbell with hands approximately shoulder width apart and move away from the rack to prepare for the execution of the hang power clean.

Stand with your feet approximately hip width apart with your toes straight ahead or slightly turned out. After adjusting your feet, make sure to stand with your chest puffed out, head focused straight ahead and in neutral alignment with the spine.

Upon properly adjusting yourself in the initial position, you will then maintain a strong posture and lower the bar through flexion of your hip, not your knees, to just above your knees. Throughout this motion your arms should remain straight and the bar should remain close to the body. Wrists should be curled slightly under the bar and your shoulders should move out in front of the bar.

When the barbell reaches the point just above your knees the bar should still be close to your body with arms straight still. At this point you will begin to forcefully extend your hips, and knees into full extension. When your hip and knees reach full extension your shoulders should shrug straight up and your heels should leave the ground through flexion of your ankles.

After you reach full extension the bar will be moving upwards and should remain close to your body. As the bar approaches mid-chest you should rotate your elbows under the bar rapidly until your upper arms are parallel with the ground. Your heels should reach the ground as you catch the bar and the bar should be caught with flat feet. When catching the bar your weight should go back to cushion the catch with your butt and not your knees.

## Appendix C

Cues

**Cues**

| Initial Position | Cue |
|---|---|
| Chest puffed up and out. | "Back tight, Big Chest, Get Tall" |
| Head focused straight ahead | "Look straight ahead" |
| Head in neutral alignment with spine. | "Head in line with body" |

| Getting Into the Start Position | Cue |
|---|---|
| Strong posture. | "Keep your posture strong" |
| Lowering of bar through hip flexion. | "Lower the bar only by pushing your hips back" |
| Arms stay straight. | "Keep your arms long" |
| Bar remains close to body. | "Keep the bar against your body" |
| Wrists curled under the bar. | "Curl your wrists under the bar" |
| Shoulders are in front of bar. | "Bring your shoulders in front of bar" |

| Power Shrug / Full Extension | Cue |
|---|---|
| Bar remains close to body. | "Keep the bar close throughout the movement" |
| Full extension of hip, knee, and ankle. | "Extend your ankles, knees, and hip and get your head high" |
| Shoulders shrug straight up. | "Bring your shoulders to your ears" |
| Heels do not leave ground until full hip extension. | "Keep your heels down until your hip fully extends" |

| Catch | Cue |
|---|---|
| Bar remains close to body. | "Keep the bar close throughout the movement" |
| Elbows rotate under bar rapidly. | "Shoot your elbows out rapidly" |
| Upper arms parallel with ground. | "Elbows up" |
| Lands with flat feet. | "Land with a flat foot" |
| Feet land at same time bar lands. | "Feet and bar hit together in the catch" |
| Bar caught with weight back. | "Push your butt back when catching the bar" |

## Appendix D

9 Movement Aspects/Indices

# 9 Movement Aspects/Indices

## Starting Position (Starts just prior to pull phase)

Torso inclination relative to ground. (degrees)

*Measure from ear to iliac crest to mid-foot.*

Distance ears are in front of the bar. (in)

*Drop vertical line down from ear & measure to barbell.*

Position of bar relative to toe. (in)

*Drop vertical line down from bar & measure to toe.*

## Pull Phase (Ends at full extension)

Angle of body relative to ground in full extension. (degrees)

*Measure from ear down to point of foot/floor contact & out horizontal.*

Position of bar relative to toe in full extension. (in)

*Drop vertical line down & measure to toe.*

Time heels are out of contact with the platform. (sec)

*Time from heels leaving ground to contacting ground.*

## Catch Phase (Begins at the end of full extension & ends with bar resting on body)

Time of elbow rotation under bar. (sec)

*Measure time from end of full extension to catch.*

Knee angle. (degrees)

*Measure from iliac crest to lateral malleolous at end of phase.*

Center of hip joint relative to toe. (in)

*Drop line down from iliac crest & measure to toe at end of phase.*