Video Analysis as a Form of Feedback to Improve Sport Performance

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or partially, been submitted at any university for the purpose of obtaining a degree.

Signature Date

Abstract

Feedback is critical for motor skill learning. Knowledge of performance (KP) in the form of verbal feedback is the most commonly used type of augmented feedback. Advances in technology have made it possible for coaches to utilise video-supported feedback with athletes with the intention of accelerating the learning process. The use of videotape replay has been an effective aid under some circumstances. Recent commercially available products offer digital analysis that may be even more successful than ordinary video replay in this regard.

The purpose of this study was to determine the effectiveness of knowledge of results (KR) and verbal KP with video-support in improving the learning of the tennis serve, when compared to KR with verbal KP only. A total of 18 adults (10 women and 8 men) were assessed on their serving technique (6 kinematic variables), accuracy (2 variables) and speed (1 variable). Technique analysis was completed using a commercially available analysis programme. For a short intervention period, one group (n = 10) received KR with verbal feedback only, while the other group (n = 8) received KR plus verbal feedback with video support. The subjects were tested after the intervention to see what changes had occurred with regards to the speed, accuracy and technique of their serves. No significant differences were found for any of the variables, leading to the conclusion that the amount of time spent in the intervention programme must be extended in order to possibly achieve significant effects on performances.

Opsomming

By die aanleer van motoriese vaardighede is *terugvoer* van kritiese belang. Verbale terugvoering is die mees algemene vorm van kennis oordraging aan die uitvoerder. Verbetering in tegnologie het dit nou moontlik gemaak vir afrigters om video-ondersteunde terugvoer met atlete te gebruik, met die doel om die leerproses te versnel. Die gebruik hiervan is in sekere situasies 'n effektiewe hulpmiddel. Kommersiële produkte wat tans beskikbaar is bied die moontlikheid van digitale ontledings, wat dalk meer suksesvol kan wees as slegs die terugspeel van 'n video aan die uitvoerder.

Die doel van hierdie studie was om die doeltreffendheid van kennis van resultate (*knowledge of results*) en verbale terugvoering met video-ondersteuning in die verbetering van die tennis afslaan te meet, en dit dan te vergelyk met kennis van resultate waar net verbale terugvoering verskaf is.

'n Totaal van 18 volwassenes (10 vroue en 8 mans) se afslaantegniek (6 kinematiese verandelikes), akkuraatheid van afslaan (2 verandelikes) en die spoed van die afslaan (1 verandelike) is nagegaan. Tegniekontleding is met die gebruik van 'n komersieël beskikbare analise-program gedoen. Een groep (n = 10) het kennis van resultate en verbale terugvoer gekry vir 'n kort intervensie periode. Die ander groep (n = 8) het kennis van resultate en video-ondersteunde verbale terugvoer, ook vir 'n kort intervensie tydperk ontvang. Die deelnemers is na afloop van die intervensie tydperk getoets om te bepaal watter veranderinge met betrekking tot spoed, akkuraatheid en afslaantegniek plaasgevind het.

Geen beduidende verskille is in enige van die verandelikes gevind nie. Dit gee aanleiding tot 'n gevolgtrekking dat die duur van die intervensieprogram verleng moet word om 'n beduidende effek op uitvoering te kry.

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Chapter One

Setting the Problem

Feedback is essential to the acquisition of skills (Rose, 1997). Augmented feedback (feedback from a source external to the performer) has been shown to enhance the performance of a variety of skills (Magill, 2001). Verbal feedback is the most commonly used form of augmented feedback in motor learning situations, and usually takes the form of a coach/teacher providing a performer with information intended to help him/her become more skillful (Rose, 1997). In recent years, technology has played an increasingly more important role in sports performance. Many coaches, athletes, sport scientists and sport enthusiasts have begun using various forms of technology in an attempt to gain more precise information about individual and team performances. This information is often used as part of the augmented feedback given to performers.

There have been numerous studies involving the use of technology in the learning of skills (Emmen, Wesseling, Bootsma, Whiting & van Wieringen, 1985; Rikli & Smith, 1980; Guadagnoli, Holcomb & Davis, 1996). The various types of technology used focus on different aspects of the sports performance, which include technique analysis (Lees, 2002; Messier & Cirillo, 1989; Rikli & Smith, 1980), tactical analysis and motor learning (Kernodle & Carlton, 1992). These researchers have shown that many individuals and sports teams have been able to gain advantages over opponents that have resulted in success through the use of technology.

Hughes (no date) has described coaching as a qualitative effort. It has been suggested that technology provides the tools that allow coaches to better analyse sport performance and thus deliver more accurate and meaningful feedback to performers (Hughes, no date). Rikli and Smith (1980) provided videotape feedback to groups at different stages of the instructional cycle while learning the tennis serve The results of this research showed that videotape feedback led to better results than verbal augmented feedback only. Messier and Cirillo (1989) also demonstrated that technique improved through the use of videotape feedback. Their study looked at changes that occurred in the technique of novice female runners as a result of verbal and videotape feedback. The results of the experiment showed that certain technique characteristics improved more with the videotape feedback than with verbal feedback only.

The tennis serve has become a tremendous weapon in the professional game, with male tennis players serving in excess of 220 km/h (Noffal, no date). This emphasis on the serve has filtered down to the lower levels. It stands to reason that the sooner a player can master the serve, the sooner that player can implement the weapon with positive results. Due to the fact that the tennis serve is the only stroke in the sport that is under the control of the performer, and is not directly influenced by the opponent, it is considered a closed skill (Rikli & Smith, 1980; Elliott, 1988). Advanced competitors display very consistent kinematics in the skills that they perform, and consistency in a correct movement pattern is the performance goal of closed skills (Gentile, 1972).

There are certain critical biomechanical elements that need to be adhered to when trying to perform the tennis serve (Elliot, 1988). This means that instruction, including feedback, must focus on the technique of the serve as a matter of utmost importance. Rikli & Smith (1980) suggested that information about the movement pattern (knowledge of performance) would be the most appropriate type of feedback to give to players. Videotape replay is a method of helping coaches analyse technique as well as a means for providing knowledge of performance (KP) to players.

Purpose of the Study

The purpose of this study was to compare the effectiveness of two forms of augmented feedback on the speed, accuracy and technique of the serve in tennis:

- Verbal knowledge of performance (vKP), with KR available in the form of accuracy and speed scores announced after each serve.
- Video-supported verbal (v/VideoKP), with KR available in the form of accuracy and speed scores announced after each serve.

This study was similar to that of Rikli and Smith (1980). However, there were several important differences. First, this study used a digital computer-based video programme that allowed subjects in the v/Video KP group to receive KP while simultaneously viewing their pretest serves immediately at courtside, prior to attempting to implement the augmented feedback received on the posttest. Secondly, the study was structured in a kind of coaching clinic format, i.e. players' pre- and posttest performances were assessed during the same practice session, with augmented feedback delivered in between the testing opportunities. The Rikli and Smith study assessed the impact of verbal vs. video feedback delivered in a series of practice sessions stretched over a period of a few weeks.

The focus in the current study on the immediate effects of the two forms of augmented feedback, was intended to provide insight for professional coaches who conduct short clinics and training camps. The technology used in this study was a commercial digital video analysis programme that is supposed to help coaches accelerate the learning process (Dartfish®). The v/Video KP made possible by the programme should help players recognise those critical elements of the tennis serve which need correction more easily than if verbal feedback only is available. Whether or not changes in performance can be effected immediately is not certain. The current study attempts to assess the usefulness and practicality of the Dartfish® programme as video support, applied in the format of a one-hour individual coaching session.

Significance of the Study

This study tries to bridge the gap between research and learning/performance by exploring the use of the commercial digital video analysis programme, Dartfish®, as a means of providing KP to players attempting to improve a closed skill, i.e. the serve in tennis. By bringing video-based qualitative analysis into the sphere of coaching, this study also seeks information about the limitations on the technology in assisting coaches in making better and more well-informed decisions with regards to a particular sport skill. It is thought that the quality of the augmented feedback given to a performer will be enhanced through the use of the Dartfish® technology. However, not much research has been completed regarding the use of commercial technology products aimed at everyday use by coaches and athletes (Page & Dawkins, 2003).

This study was also designed to ascertain whether the use of technology can make an immediate and significant improvement in the learning of the tennis serve. The results may be able to define the lower limits of the effective use of the technology. If participants' serving accuracy, speed and/or technique improves significantly after a one-hour session when technology is used to support feedback (v/Video KP), then it is indeed a powerful tool for promoting learning. If there is no significant difference between the participants' receiving v/Video KP compared to those receiving vKP, then the length of the coaching intervention must be expanded in order to determine how long a period of time is needed to gain the benefits of vKP and/or v/Video KP.

Research Questions

1. Will there be any changes in the technique, speed and/or accuracy of the tennis serve, of subjects who experience the verbal KP (vKP) only intervention?

2. Will there be any changes in the technique, speed and/or accuracy of the tennis serve, of subjects who experience the verbal with video-supported KP (v/VideoKP) intervention?

3. Will there be any significant differences in technique, speed and/or accuracy of the tennis serve, among subjects who experience the vKP only intervention compared to subjects who experience the v/Video KP intervention?

Limitations

The following limitations must be kept in mind when considering the outcomes of this study:

1. The subjects were volunteers. They may have been more motivated to gain from the instructional experience than typical subjects.

2. The subjects had previous experience with the tennis serve as they had completed two practical modules in tennis as prescribed courses during their undergraduate degree. This means that they knew the skill. The subjects also had a background in the analysis of movements, having completed a module in biomechanics, again as prescribed study for their degree. This may have made them more receptive to the

kind of technical information made available by the videotaped feedback, and more interested in general about the quantitative measures of serving accuracy and speed, than typical subjects.

3. The subjects involved in the study do not represent the full continuum of levels of skill tennis. They represent only the advanced beginner and intermediate level. Thus the results that were found as a result of this study will not necessarily hold true for either absolute beginners or more advanced players.

4. This study also looked at the immediate effects of the feedback given to the subjects, and did not examine the long-term effects of feedback conditions.

5. The tennis serve is a highly complex and coordinated movement pattern (Elliot, 1988), thus allowing for a wide range of different styles and interpretations of what constitutes the perfect serve. Empirical evidence shows that not all coaches and experts agree on what parameters are more important than others, but there seems to be certain aspects that do constitute a technically sound service action (Elliot, 1988; Behm, 1988). The critical elements of the serve in this study were chosen by the investigator based on experience in coaching tennis as well as personal contact with a wide variety of expert sources.

6. An important consideration that must be noted is the software package that was used for the analysis of the service technique. This commercial product is aimed at the coach and/or athlete and is thus not a complicated or precise as some of the equipment used in laboratory settings by sport scientists. This means that the reliability of the results depends on the user's mastery of the technology.

7. Only two-dimensional analysis of the serve was done, thus it is possible that the results are not 100% accurate. With regards to the software product being used, it is necessary to mention a few factors regarding its operation. In order to do a three dimensional analysis of a skill using the Dartfish®, it is necessary to digitize the images. This is a long and complicated process requiring yet more technology. Due to the fact that only two-dimensional images were used, angles cannot be 100%

accurate as the orientation of the subject's body with regards to the position of the camera will influence the angle being measured. When measuring distance, the distance being measured must be in the same plane as the one metre reference. Thus it would not be useful to compare the distance that is further away from the camera to one that is closer to the camera.

Definitions

The terms used for this study will be defined according to the Dictionary of Sport and Exercise Sciences (Anshel, 1991).

Kinematics

"Area of mechanics concerned with the position, velocity and acceleration (angular or linear) of a system without reference to the forces causing motion" (p. 83).

The Dartfish® programme made it possible to digitally analyse the kinematics of the tennis serve.

Qualitative Analysis

"Evaluation of movement in non-numerical terms relative to some criterion" (p. 123).

The investigator in this study compared what he observed in serving techniques, then compared that observed image to his mental image of an ideal serve. Feedback was made to subjects based on this subjective comparison.

Qualitative Knowledge of Results

"The form of external, informative feedback that is categorical, relative or imprecise (non-numerical)" (p. 123).

Qualitative knowledge of results is labeled KP in this study. This KP was qualitative knowledge of performance about performance technique or mechanics.

Quantitative Analysis

"Evaluation of a movement in numerical terms describing the mechanical variables influencing the outcome of the movement" (p. 123).

In addition to the serving test and use of the radar gun to determine serving speed, The Dartfish® programme made it possible to assign numerical values to selected biomechanical features of the tennis serve, thus allowing the statistical analysis of any change in technique from the pre- to posttest.

Quantitative Knowledge of Results

"The form of external, informative feedback that conveys the numerical amount or degree of error" (p. 123).

The KR delivered in this study was quantitative knowledge of results in the report of speed of serve (kph) and accuracy of serve (number of points on the skills placement test).

Summary

This research is an attempt to mobilize sport science to study the practical use of technology in the provision of video feedback to enhance the speed, accuracy and/or technique of the tennis serve. The results of this study will help determine if this software package will be of practical use to coaches and athletes. This research looks at the tennis serve in particular and aims to provide a method for improving this vital skill in tennis. Due to the rapid movement and dynamic nature of the tennis serve, videotape replay may help the coach to see all the parts of the serve as the coach may look at other parts not looked at in the live situation. Replay may also assist the player in seeing his/her own errors and thus promote the recognition and correction of those errors.

Chapter Two

Review of Literature

This chapter will provide a review of research completed on the topic of augmented feedback, including sections on feedback and skill acquisition, feedback content and the timing for the delivery of feedback. An additional section is focused specifically on knowledge of performance (KP) since that is the type of feedback delivered via the digital video intervention tested as part of this research. The final section presents information about the kinematics of the tennis serve. Because this was the skill used in this study, it was necessary to identify the critical performance indicators that might serve as the template for providing feedback to subjects, as well as to generate qualitative criteria for assessing subjects on their pre- and post-intervention progress in tennis serving technique.

The Role of Augmented Feedback in Skill Acquisition

Magill (2001) has provided clear definitions that can be used to understand feedback and motor skill learning. He defined augmented feedback as information about performance that has been added to the situation by some external agency. There are two general types of content that characterise augmented feedback:

1. Knowledge of Performance (KP)

   This is information about the characteristics of a movement that led to the outcome of the performance.

2. Knowledge of Results (KR)

   This is information about the outcome of the performance of a skill or about the achievement of an objective of the performance.

There is also a timing issue in the delivery of feedback:

- Concurrent feedback is feedback that is given while the subject is performing a skill.

- Terminal feedback is feedback that is given after the subject has finished with the performance of a skill or movement

Magill (2001) also defined two roles that augmented feedback play in the acquisition of a skill. It provides information about the performance of the skill. The learner uses this information to discover what he/she is doing correctly and incorrectly. It also helps to motivate the learner to continue to try to achieve a goal. The learner uses augmented feedback to compare his/her own performance to the performance objective in order to assess how close he/she is to success.

In a specific skill learning situation, it is necessary to establish how important augmented feedback is in facilitating skill acquisition. This is done by looking at the characteristics of the skill being learned and the characteristics of the person who is attempting to learn the skill.

Augmented Feedback as Essential for Learning

In certain situations, augmented feedback is essential to skill learning. These situations include:

- When the task intrinsic feedback is not available or cannot be used. In some situations critical sensory feedback is not available to the person. For example, due to injury or disease, a learner may not have the sensory pathways needed to detect critical task intrinsic feedback.

- When task intrinsic feedback cannot be used. An example would be when performing rapid movements. In these situations, it has been shown that augmented feedback, especially knowledge of results, is essential to learning.

Augmented Feedback as Helpful for Learning

In other situations, augmented feedback is helpful for learning. Some skills can be learned more quickly or be performed at a higher level of skilfulness when augmented feedback is given during practice. One situation where this is applicable involves relatively simple skills. Research has shown that in such situations, augmented KR during practice helps to enhance the level of performance (Salmoni, Schmidt & Walter, 1984). The other type of skill that is enhanced with the use of augmented feedback is a complex skill that requires the person to acquire an appropriate multi-limb pattern of co-ordination. The achievement of a performance goal can be speeded up with the use of augmented KP that provides information about the crucial components of the co-ordination pattern. Wallace and Hagler (1979) showed that through the use of the one hand basketball set shot that this is the case. One group was given KR and verbal KP about the problems with the stance and limb movements during the shot while another group received KR and verbal encouragement only. The KP group first showed an improvement, then the verbal encouragement group "caught up," then the KP group improved again, but the verbal encouragement group did not. The KP group showed higher performance levels when performing with verbal withdrawal than the verbal encouragement group. They also reached superior levels by the end of the acquisition phase and their improvement continued after KP was withdrawn. The verbal encouragement group did not show this trend.

Augmented Feedback as Non-essential for Learning

There are situations in which augmented feedback may not be needed for skill learning. These situations are usually when the motor skill provides sufficient intrinsic feedback, i.e. feedback that occurs within the performance situation that can be detected by the learner without any external assistance (Magill, 2001). Intrinsic feedback occurs when learners use their own sensory feedback systems to ascertain whether or not they are performing the correct actions and to make the necessary adjustments for future performances. During a coincidence-anticipation skill experiment, Magill, Chamberlin and Hall (1991) found that receiving augmented KR during the practice of some skills did not lead to faster learning than practising augmented KR. Motor skills that do not require a person to have augmented feedback to learn have an important characteristic: a detectable external reference in the environment that the performer can use to determine the appropriateness of the action, thereby making the verbal KR redundant.

Augmented Feedback as a Hindrance for Learning

In some situations, augmented feedback can actually hinder the learning of a skill. One situation where this can occur is when concurrent augmented feedback is provided. Performers tend to neglect the important task intrinsic feedback and pay attention to the augmented feedback delivered during their performance. The performer does not develop an internal sense of the movement, and becomes dependant on the augmented feedback (Magill, 2001). This dependency limits the learning process.

Another situation in which augmented feedback may hinder performance is when terminal augmented feedback is provided after every practice trial. This also leads to dependency because learners "wait" until after a skill is completed to discover from an outside source if they have bee successful or not. When learners must later perform without augmented feedback, the task-intrinsic feedback alone may not be enough for them to perform the skill successfully (Janelle, Kim & Singer, 1995).

A third situation where augmented feedback has been shown to hinder skill acquisition is when erroneous augmented feedback is provided to someone in the early stages of skill learning. The performer often chooses to use the augmented feedback (erroneous information) rather than the task intrinsic feedback because they are not sure how to use or interpret the task intrinsic feedback (Magill, 2001).

The Content of Augmented Feedback

The information that is provided in the feedback must be such that it brings about a positive, immediate and significant effect on the performance. This will help in correcting many errors. There are various issues that must be considered when deciding on the content of augmented feedback, including information about errors vs. correct aspects, KR versus KP, qualitative vs. quantitative information, performance bandwidths and the problems associated with the delivery of erroneous information.

Errors vs. the Correct Aspects of Performance

Research has shown that providing of information about the errors in performance is an effective way to promote skill improvement (Kernodle & Carlton, 1992). This means that augmented feedback should include both correct performance and error-based information. Magill (2001) suggested that there may be an optimal combination of these two kinds of information, and that further research is needed.

Knowledge of Results vs. Knowledge of Performance

Kernodle & Carlton (1992) used videotape replays and verbal statements about technique performance as a form of KP, and found that it led to greater improvement in throwing technique and distance than KR. Zubiaur, Oña & Delgado (1999) found similar results when studying the volleyball serve. An interesting finding that the authors discovered was that one of the subgroups showed decreased retention when KP was presented first and KR later.

Experiments by Brisson and Alain (1997) and Silverman, Woods and Subramanium (1999), both showed the effectiveness of KR and KP as augmented feedback. However, these experiments did not give a definitive answer to the question of whether KR and KP influence the learning of a skill in different or similar ways. They did show, however, that both forms of augmented feedback can be valuable during the learning of skills.

Magill (2001) presented four hypotheses to explain how/why both KR and KP are beneficial for skill learning, based on the conditions in which these forms of augmented feedback are delivered:

> KR is beneficial to skill learning when learners use KR to confirm their own assessment of the task intrinsic feedback.
>
> - Learners may need KR because they cannot determine the outcome of performing the skill based on the available task intrinsic feedback
> - Learners may use KR to motivate themselves to continue practising a skill.
> - Practitioners may want to provide only KR in order to establish discovery learning practice environment in which learners are encouraged to engage in trial and error as the primary means of learning to perform a skill.
>
> KP is beneficial to skill learning when skills must be performed according to specified movement characteristics.
>
> - Specific movement components of the skill that require complex co-ordination must be improved or corrected.

- The goal of an action is a kinematic, kinematic or specific muscle activity.
- KR is redundant with the task intrinsic feedback.

Qualitative vs. Quantitative Information

Qualitative augmented feedback is descriptive and gives the learner an indication of the quality of the performance. Quantitative augmented feedback consists of numerical values that are related to performance characteristics or the outcome of performance. A study by Magill and Wood (1986) showed that qualitative KR was more useful in the early stages of skill learning. However, quantitative KR proved to be more effective once the skill had been learned. When learning a skill, the quantitative KR would be of little use to the performer because he/she would not understand the meaning of the information in the context of the skill and would not know how to use it to change his/her performance. The authors concluded that the quantitative information helped the more advanced learners to refine the action to make it more effective for achieving the action goal.

Performance Bandwidths

An important factor when providing feedback is to determine the number of errors or the magnitude of the error(s) that must occur before augmented KR or KP is effective. This is a matter of deciding on a "performance bandwidth." In the context of augmented feedback, a bandwidth is a range of performance error that is deemed acceptable. Augmented feedback is only given when the performance exceeds this limit. An experiment by Sherwood (1988) supported the performance bandwidth theory. Three groups performed an elbow-flexion task. One group received KR after every trial, while the other two groups only received KR when performance error was greater than 5% and 10% of goal achievement time. The group that received KR only when they exceeded the 10% bandwidth condition received KR less than the other two groups, but showed more consistency during 25 transfer-test trials. Thus the reduced frequency of KR improved the consistency of movement.

Performance bandwidth can help address the issue of how to tell learners when they are performing correctly, without making them dependent on a coach or teacher. Butler, Reeve and Fischman (1996) showed that when using the bandwidth procedure and only giving feedback about errors, subjects knew that no feedback meant that the performance was correct. The group receiving "no feedback" for correct performance showed an improvement in learning.

Erroneous Augmented Feedback

Research completed by Beukers, Magill and Sneyers (1994) provided an explanation about why erroneous KR affects learning, especially for beginners. The authors performed two experiments where beginners had to perform the same anticipation task. Feedback conditions were manipulated with subjects either receiving correct KR, erroneous KR or no KR, with varying combinations and frequencies. The results of the study showed that subjects used the KR provided regardless of whether or not it conflicted with the task intrinsic feedback. They stated that because beginners are uncertain about what the task-intrinsic feedback is telling them, they rely on augmented feedback rather than their own perceptions of their performance. The importance of this research is that instructors must realise that most beginners will use augmented feedback when it is available, whether it is correct or not. This is particularly true when task-intrinsic feedback is difficult for beginners to interpret and use.

The Timing of Augmented Feedback

There are three issues that need to be considered when deliberating about the timing of augmented feedback. The first issue is the determination of when the augmented feedback should be given – during (concurrent feedback) or after (terminal feedback) the performance of the skill. The second involves the determination of the length and content of the intervals prior to and following the provision of feedback. The final issue is the determination of how frequently augmented feedback should be given.

Concurrent Feedback

By providing augmented feedback concurrent to the skill performance, task-intrinsic feedback may be enhanced. Magill (2001) provides various examples of situations when concurrent augmented feedback is helpful:

- When the skill requires movement accuracy, provision of a visual or audible signal during performance tells the performer when a movement is off- or on-target.
- When bimanual co-ordination tasks are performed, a computer can be used to calculate and display displacement characteristics to the performer while performing the task.
- When tasks in which the performer is expected to produce a specific force-time curve, the performer can be shown a curve with the assistance of a computer or oscilloscope.
- When tasks that require the learner to use a physiological feature or process in a specific way, various forms of biofeedback can be used as concurrent feedback.

Effects of Concurrent Augmented Feedback

There appears to be two types of effects on learning motor skills if concurrent augmented feedback is provided. The first is a negative learning effect. Van der Linden, Cauraugh and Greene (1993) demonstrated this negative learning effect. In their study, researchers compared concurrent and terminal augmented feedback in the learning of a 5-second isometric elbow-extension force production task. One group of subjects were given concurrent kinetic augmented feedback by seeing the force produced during each trial. Another two groups received terminal augmented feedback after each trial. One of these two groups saw this information after each trial, while the other group only saw it after every other trial. The concurrent augmented feedback group performed better during practice than either of the two groups that received terminal augmented feedback. However, on a retention test taken 48 hours later, the concurrent augmented feedback group's performance deteriorated to the point where their scores were the lowest of all groups.

The second effect of providing concurrent augmented feedback on learning motor skills is positive. In other words, concurrent augmented feedback can enhance skill learning. Brucker and Bulaeva (1996) used concurrent electromyography (EMG) biofeedback on al elbow extension task with 100 patients with spinal cord injuries that were C6 or higher. The subjects saw the amplitude of the integrated EMG on a colour monitor as they extended their elbow. The results of the testing showed that the subjects were able to increase their voluntary muscular contraction.

When to Use Concurrent Augmented Feedback

There has been some research that assists in the determination of when to use concurrent augmented feedback. Annett (1959) proposed that information value should be used when the delivery of augmented feedback is considered, which he related to the "informativeness" of augmented feedback in relation to the task-intrinsic feedback. When the task-intrinsic feedback has a low information value, but the augmented feedback has a high value, he proposed that the use of concurrent augmented feedback would lead to a dependency on the part of the learner on that augmented feedback.

Van der Linden et al. (1993) completed research using tasks that had low task-intrinsic information values. The study required participants to discern proprioceptive feedback in a manner that is not common to most people. This resulted in the subjects' dependence on concurrent augmented feedback. In the situations when attention was directed away from the critical features of the motor skill, no significant learning occurred. Significant learning did occur when concurrent augmented feedback directed attention to the critical factors of the task. The authors concluded that the concurrent feedback was effectiveness in those situations where the task did not inherently provide the learners with enough information about their performance.

Terminal Augmented Feedback

There are two intervals of time that are created between a trial of a motor skill and the delivery of terminal feedback: the feedback-delay interval and the post-feedback interval. The feedback-delay interval is the time between the completion of the performance and the provision of the augmented. The post-feedback interval is the time between the provision of the augmented feedback until the start of the next trial. Two variables influence the relationship between these intervals and their effect on skill learning: the time of and the nature of the activity during these intervals. Research about this topic has focused on using KR rather than KP.

Length of the KR-Delay Interval

Research on animal learning favours giving terminal augmented feedback immediately after completion of a performance (Adams, 1987) has been done to support this proposal. However, delays in the provision of feedback do not always have a negative affect the learning of skills. There seems to be "window of opportunity" after the performance of a skill when terminal feedback is quite effective. This was demonstrated by Swinnen, Schmidt, Nicholson and Shapiro (1990) in two experiments. In the first, subjects were required to move a lever using a two-reversal movement pattern in order to obtain a specific movement-time goal. The second experiment required participants to co-incidentally move a lever in time with the presence of a target light. For experiment one, one group was given KR immediately following the completion of the task, while the other group received it eight seconds after completion. In experiment two, KR was given 3.2 seconds after completion of the task. The results showed that receiving KR immediately upon completion of the task had a negative learning effect. The reason given for this was that the subjects in the group receiving immediate feedback, had not had the chance to engage in their own analysis using the task-intrinsic feedback, which is necessary for them to develop error-detecting abilities. They suggested that there are learning benefits in the delay of terminal feedback that must be investigated as a situation-specific variable, and in relation to the amount of intrinsic feedback available to the performer.

Activity During KR-Delay Interval

Activity during KR-delay interval may hinder skills learning, although this effect does not appear to be common. One type of KR-delay interval activity that has been shown to have a negative effect on learning is the estimation of the movement-time error of someone else's movement, which was performed during the KR-delay interval. This was found by Swinnen (1990) who had participants learn to move a lever a specific distance, involving two direction reversals, in a criterion time. There were also two other groups. One did no activities during the interval, while the third group performed a non-learning task. The results showed that those that were involved in the movement estimation group performed worst on a retention test.

There may be some activities performed during the KR-delay interval that could enhance learning. Evaluating own performance has demonstrated this effect consistently.

Two approaches to the use of this phenomenon have been shown to be effective. One requires the estimation of the outcome of the movement, while the other requires evaluating the movement-related characteristics of the performance. Liu and Wrisberg (1997) had subjects throw a ball with the non-dominant arm at a target, without viewing the target. KR was given on each trial with the subjects seeing where the ball had landed on the target. Two groups, one receiving immediate KR and one receiving delayed KR, rated each throw on a 5-point scale, including the angle of release, the appropriateness of the force and the trajectory of the thrown ball and then estimated the throw's point value on the target. Two other groups, one receiving immediate KR and one receiving delayed KR, did nothing during the KR interval. It was found that the two groups that used the estimation strategy during the interval performed better on a retention test, for throwing accuracy and estimation of error, than the two groups that did not use this strategy.

An experiment performed by Anderson, Magill and Sekiya (1994) found an interesting correlation to the subject performance estimation strategy in what is called the trials-delay procedure. Here, KR for a certain attempt is given only after a later trial. In this experiment, subjects had to perform an aiming test while blindfolded. One group received KR about error in distance after each trial, while another group only received this KR after completing another two trials (the trials-delay procedure). During practice, the group that followed the trials-delay procedure did not perform as well, but they had better performance, in terms of accuracy but not consistency, on the retention test performed 24 hours later. It is suggested that this method helps to improve performance because it forces the subject to focus on the task-intrinsic information of that trial.

It appears to be important that activity during KR-delay intervals can benefit learning, including activities that encourage the learners to analyse their own performance. This strategy may help learners subjectively evaluate the task-intrinsic feedback in relation to his own performance as well as motivate the learner.

Activity During the Post-KR Interval

The effects of activity during the post-KR interval seems to mirror the effects of the KR-delay interval: activity can enhance learning, have no effect on learning or it can interfere with learning. It has been postulated that learners develop a plan of action for the next trial during the post-KR interval. Planning happens at this time because the learner now has the augmented feedback necessary to add to the task-intrinsic feedback. If this interval is used to process critical information with regards to the learning of a skill, it can be expected that there should be a minimum length of time for this interval. Gallagher and Thomas (1980) used post-KR interval delays of three, six and 12 seconds, and found that this interval can be too short. The subjects in the study showed that a three second post-KR delay interval was detrimental to KR and that a 12 second interval was most helpful. Research has yet to establish an upper limit to the interval.

Activity in the post-KR interval often has no effect on the learning of a skill. Lee and Magill (1983) found this in an experiment where the subjects practised an arm movement through a series of three wooden barriers in 1050 milliseconds. Three groups were separated. On group did no activity during the post-KR interval, one performed a motor activity, while the final group was involved in the guessing of numbers (cognitive activity). The groups that had engaged in activity during the post-KR interval showed poorer performance than the no-activity group. However, on a retention test that provided no KR, there was no difference between the groups.

Benedetti and McCullagh (1987) did find that activity during the post-KR interval can hinder learning. Subjects were required to perform a task that involved the movement of the hand in a certain manner in a specified time. Subjects estimated their movement time, then, depending on the assigned group, were given KR about actual movement time after a 10 or 15 second delay. Two of the groups were then involved in either five or 10 mathematical problem-solving activities before performing the next trial. The result of the study showed that the overall error was higher in the subjects that performed the interpolated task than thee overall error of those who did nothing during the post-KR delay interval.

Frequency of Augmented Feedback

The final question with regards to the timing of augmented feedback in helping to optimise learning, is how often feedback should be given. The traditional view was to provide feedback after each trial, as it was believed that no learning took place in the absence of augmented feedback. Winstein and Schmidt (1990) disproved the traditional theory. Subjects in their experiment had to move a lever on a tabletop to manipulate a cursor on a computer monitor. Participants practised for two days and either received KR

100 percent of the time or 50 percent of the time. In one of their experiments the fading technique for the 50 percent of the time feedback was used. This involves systematically decreasing the KR frequency. For the first 22 trials of each day, KR was given after each trial, the subjects then performed eight trials with no KR. The frequency was then systematically decreased from eight to two trials for the remaining eight-trial blocks of each day. The faded 50 percent groups showed better retention performance than the 100 percent group in a no-KR retention test performed one day later. In another experiment by the same authors, a 12 trial KR retention test was performed a day later and provided similar results to the previous experiment.

Two conclusions were arrived at in research by other authors (Lai & Shea, 1998; Wulf, Schmidt & Deubel, 1993). First, a reduced frequency of augmented feedback may not benefit learning of all motor skills. Second, the optimal level of relative frequency differs from skill to skill. These conclusions lead to questions about which skill-related factors might predict the relative frequency effects. Wulf, Shea and Matschiner (1998) believed it was the complexity of the skill. Their research led them to the conclusion that decreased augmented feedback frequency appears to be better than, or at least as effective as, 100 percent frequency, mainly for simple tasks. Their findings led them to conclude that the opposite held for complex tasks.

Frequent feedback can cause problems for learning. There can be an overload of attention capacity, due to too much information having to be processed, if augmented feedback is given after every trial. Salmoni, Schmidt and Walter (1984), as well as Winstein and Schmidt (1990) proposed the guidance hypothesis that states that when providing feedback after every trial, learners are 'guided' into correct movement learning. However, they caution that this may lead to a dependence on the augmented feedback, which ultimately could lead to poorer performance.

Techniques to Reduce Frequency of Augmented Feedback

Reduced frequency of augmented feedback may encourage learners to use other strategies to improve. Practical ways to decrease the frequency with which feedback is given have been found in the literature.

- **Performance-Based Bandwidths**

Instructors can decide to provide feedback based on performance bandwidths, thereby reducing the frequency of feedback. Lai and Shea (1999) found that using a 15% error bandwidth led to more effective learning of a complex spatial-temporal movement than either switching halfway from 15% to zero percent bandwidths or using a zero percent bandwidth.

- **Self-Selected Frequency**

With this technique, learners themselves decide when augmented feedback is given. This approach allows learners to more actively determine the format of the practice. Janelle, Kim and Singer (1995) gave evidence that this strategy can improve motor skill learning. Subjects threw a golf ball underhanded at a target on the ground. KP was given with regards to ball force, ball loft and arm swing. Five groups were used, with one being the self-controlled feedback group. The other groups received KR 50% of the time, summary feedback after five trials, no KP or were yoked with the self-controlled group. The self-controlled groups showed better throwing accuracy on the two retentions tests.

Janelle, Barba, Frehlich, Tennant and Cauraugh (1997) used two forms of augmented feedback, namely videotape replay and verbal KP to demonstrate a similar effect. In their study, the authors had four groups. One group controlled the provision of KP themselves, one received summary KP, one group was a yoked control group (yoked to the self-controlled group) and the last group only received KR. The yoked control group was used to determine if it was only the decreased frequency of the feedback that was the reason for improved performance. The results showed that the groups receiving KP showed an improvement, but the self-controlled group learned the skill better than the others. They also retained the information longer. Interestingly, the self-controlled feedback group only asked for feedback 11.15% of the time (which is similar to the findings of 7% by Janelle, Kim & Singer, 1995). This led the authors to the conclusion that learners did not need the guidance of feedback to learn the skill. They also adopted a learning strategy that enhanced their information processing capabilities.

- **Summary Augmented Feedback**

  A technique known as summary augmented feedback also helps to decrease the frequency of feedback. This involves giving feedback after observing a certain number of attempts, in order to identify the most commonly recurring characteristics of a learner's performance. Boyce (1991) gave a practical example of this in his study of the learning of target shooting with rifles. One group was given KP after every shot, while another group only received KP after every third shot. No difference was found between the two groups. This demonstrated that summary augmented feedback was just as effective an instructional tool as feedback after every trial.

  Guadagnoli et al. (1996) gave evidence that the optimal length of time before providing summary augmented feedback depended on the experience of the learner with the task/skill. They suggested that it may be better for the learning of simple skills to have longer KR summaries, and to have shorter summaries for complex skills. They also contended that for beginners, shorter KR summaries were more beneficial than long ones, and that the opposite applies to experienced performers.

  Sidaway, Moore and Schoenfelder-Zohdi (1991) argued that it is the reduced frequency of augmented feedback or the time delay associated with providing summary feedback that leads to benefits in learning, and not the number of trials summarised itself (which is a question of feedback content).

A Focus on Knowledge of Performance

Knowledge of Performance is given more often than KR by people who instruct motor skills (Magill, 2001). It is thus important to understand how various types of KP influence the learning of a skill. More non-verbal forms of KP are becoming possible as movement analysis technology becomes more readily available. Specific characteristics of KP are explored in the following sections because the mode for the delivery of KP is the unique variable studied in this research.

Verbal Knowledge of Performance

Verbal KP is easy to deliver since it usually takes the form of comments delivered by a teacher or coach. However, it is not always easy to know what content to include in this feedback. The reason for this is that movement patterns for many skills are complicated and KP must relate to specific features of a skill performance. It is critical that the instructor choose the most appropriate and effective features as KP. Magill (2001, p. 256) has recommended the following process:

1. The instructor must perform a skill analysis that identifies the various parts or components of a skill.

2. Each component should then be prioritised in terms of how critical that component is for performing the skill correctly.

3. When observing performance, the instructor must go through the list of prioritised components in his/her mind in order to determine the critical components that require feedback for the learner being observed.

4. The instructor next must choose between delivering descriptive or prescriptive KP. Descriptive KP is a verbal statement that only describes the error that the subject made during the skill performance. Prescriptive KP is a verbal statement that describes the errors made and states what must be done in order to correct the mistakes.

Magill (2001) has suggested that prescriptive KP is more effective for beginners because it helps them to learn about the components of the skill and how they should be performed. For advanced subjects, descriptive KP will often be sufficient.

Videotape as Augmented Feedback

Although technology has improved dramatically over recent years, the use of videotape feedback is not new. Research has provided guidelines for the use of videotape replay as augmented feedback (Jambor & Weeks, 1995; Darden, 1999).

Guadagnoli, Holcomb & Davis (2002) compared the use of videotape feedback during practice to that of verbal feedback and self-instruction. Using the golf swing, it was found that the augmented feedback groups performed worse on the immediate post-test than the self instructed group. However, on the two week delayed post-test, the video feedback group performed better than the verbal feedback group, who in turn performed better than the self instructed group. This led the researchers to the conclusion that video feedback is an effective method of practice, but it may take some time before the positive effects can be seen.

Darden (1999) identified four stages that learners go through with regards to videotape feedback.

Stage 1: Shock – Learners experience an anxiety, with some negative feelings towards seeing themselves on video.

Stage 2: Error detection – Learners begin to watch the video replay more critically with the aid of information that directs their attention to important cues and techniques.

Stage 3: Error correction – Learners start to make a connection by understanding what causes the errors and making corrections independently. Prescriptive feedback still needs to be provided during this stage to help learners make the connection.

Stage 4: Independence – Learner can actively and independently correct their own errors.

Kernodle and Carlton (1992) conducted research into the benefits of having instructors point out the key elements to the learner during observation of the videotape replay. The experiment involved subjects throwing a soft, spongy ball for distance. One group received specific technique-related cued of what to look for on the videotape replay of each attempt. The second group received the same with the addition of a verbal prescriptive statement aimed at improving technique. The third group only watched the videotape replay. A fourth group was provided with verbal KR about the distance of the throw. The subjects in the two groups that received specific technique-related cues threw the ball further with better technique than the other two groups.

Starek and McCullagh (1999) used videotape replay as augmented feedback to demonstrate the self-modeling theory. They showed two groups of adult beginning swimmers, three-minute video sequences of swimming performances. One group watched four clips of correct performance, and four clips of sessions in which they made mistakes. Another group viewed a skilled performer performing the skill correctly. It was found that the swimmers who viewed their own videotape performances, experienced more skill improvement than those who viewed someone else performing the skill. This is referred to as self-modelling, which combines modelling as a form of instruction with modelling as a form of augmented feedback.

Movement Kinematics and Augmented feedback

Another tool that can be used to provide augmented feedback about performance is a graphic kinematic representation of performance. Computer software can now analyse the kinematics of performances. There is little empirical evidence available to provide insight into the effectiveness of movement kinematics as augmented feedback, although it has been noted that there is a need to study the learner's stage of motor learning in relation to the effectiveness of kinematic information as augmented feedback. Beginners may not be able to use kinematic information in the same way in which more advanced performers can.

Swinnen, Walter, Lee and Serrien (1993) performed a laboratory-based study that used kinematic analysis as augmented feedback. Subjects were required to move two levers at the same time, each with different spatial-temporal movement patterns. The angular displacement of each arm was superimposed over the criterion displacements. In many of the experiments performed in this study, kinematic feedback was compared to other forms of augmented feedback. The results proved the effectiveness of the kinematic information as augmented feedback.

Wood, Gallagher, Martino and Ross (1992) found that kinematic feedback transferred to the learning of sport skills. Test subjects performed a golf swing with a 5 iron. A computer monitored the kinematics of the swing as the club moved over light sensors on a platform. The computer assessed the velocity, displacement and trajectory path of the swing. All this information was displayed for the learners, who had been separated into groups. One group viewed the kinematics of their swings along with a template of the optimum swing pattern. The second group viewed their own swings, but did not see this template. A third group received kinematic information verbally, and the fourth group did not get any augmented feedback. The group that received both the kinematics and optimal swing pattern information, performed best on a retention test, which was administered one week later without augmented feedback.

The Serve in Tennis

The tennis serve is a highly complex and co-ordinated movement pattern. For effective and efficient performance the tennis serve requires the correct sequence and timing of the muscles involved in the action. In tennis, the serve is the only shot in which the time of execution and the timing among the components of the movement, are under the complete control of the athlete, thereby classifying it as a closed skill (Elliott, 1988).

In order to make the analysis of the serve easier, it is usually divided into various component parts. Numerous researchers (Elliott, 1988; Behm, 1988; and Rose, Heath & Megale, 1990) compartmentalized the parts of the serve into different performance stages, but the performance of the stages do overlap. Each of the researchers differed on the compartmentalizing of the serve but there are components that are common to each of the authors (see Figure 1). Before looking at the various stages of the tennis serve, it is important to note that without the correct rhythm between the parts, the serve will be ineffective (Schmidt & Lee, 1999) and performance may even lead to injuries (Cook, 2003).

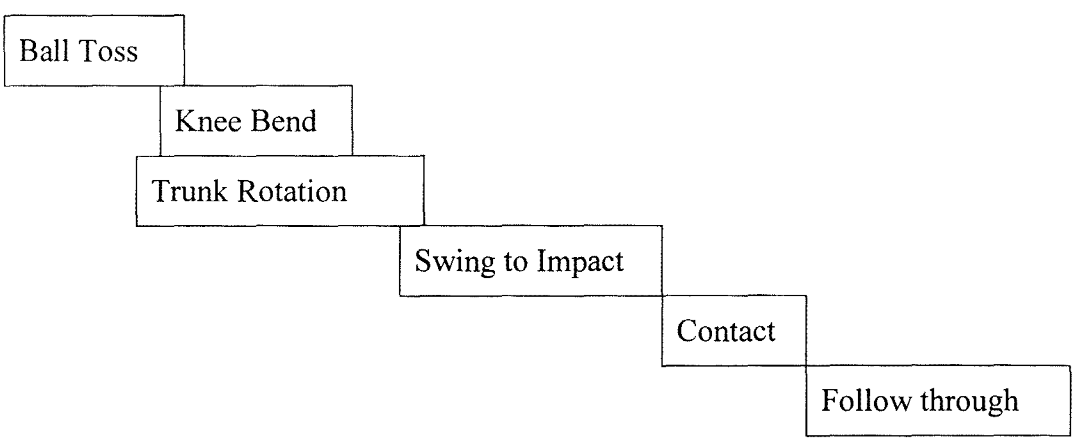


Figure 1

Typical representation of the component parts of the tennis serve.

Ball Toss

Before discussing the tossing motion, it is important to first ensure that the ball is correctly gripped before tossing it into the air. It is recommended that the ball be held in the fingertips and not the palm so that the contribution of the wrist is decreased (Behm, 1988). The ball toss needs to be a well-controlled motion and, with this in mind, it is recommended that the ball be pushed into the air using one of two methods.

- The straight forward and up method, where the tossing arm is parallel with the plane of the body and goes straight up in front of the server's head.
- The rotary style requires the arm to move to a position parallel to the baseline before going up. This method improves the rotation of the trunk, but the toss is more difficult to control.

During the motion of the toss, both hands start together and move down towards the front thigh (Behm, 1988). Upon reaching the thigh, the tossing arm reverses its direction as the shoulder flexes. The tossing arm elbow remains fully extended. When the hand of the tossing arm reaches approximately eye-level, the hand opens to release the ball. The momentum of the arm should be used to get the ball in the air and the wrist should remain fixed. By flexing the wrist, control of the ball becomes difficult and an accurate and consistent ball toss is rarely achieved.

The hitting arm continues in its path and one of two methods may be used. The full backswing occurs when the hitting arm continues past the rear thigh. The classical style of down together, up together is no longer recommended (Elliott, 1988). The overwhelming majority of experienced servers use the method in which the hitting arm lags slightly behind the tossing arm. The abbreviated backswing occurs when hitting arm takes a more direct path to the power position. This is achieved through a combination of shoulder abduction, horizontal abduction and flexion, while the elbow flexes (The type of backswing used by the subjects was not monitored as it is a matter of personal preference and should not have an impact on the effectiveness or efficiency of the serve). It must, however, be noted that Elliott (1988) found that the abbreviated backswing had more potential of leading to shoulder injuries.

Knee Bend and Trunk Rotation

The flexion of the knees is recommended to start just after the ball is released from the hand (Tiley, 2003). The knee bend is important in helping to reduce the occurrence of injuries, especially in the shoulder (Elliott, 1988; Elliott, et al. 2003). This is so because it helps to start the movement of the body and decrease the amount of force that the upper body needs to produce in order to achieve the objective of a powerful serve (Elliott, 1988). Knee flexion also helps the server in his/her attempt to reach up to the contact point (Elliott, 1988). The higher the contact point, the better the server's chance of achieving the objective of the serve – a powerful, accurate serve. The knee bend is also important for the creation of power. The large muscles of the legs are loaded during the eccentric knee bend, ready to be transferred through the trunk to the upper body and eventually to the racket.

At the same time as the knee bends, rotation of the trunk takes place, thereby stretching the rotational muscles of the trunk. This movement is important to allow the body to generate more power and also to take some stress off the shoulder. During the knee bend phase, the server must attempt to establish the power position. This position is so termed because from this position, the server can explode up and into the ball to produce a powerful serve (Tiley, 2003).

- This position is characterised firstly by a tilted shoulder alignment, caused by the lag of the hitting arm.

- This alignment is closer to vertical than it is to horizontal, which allows internal rotation of the trunk and shoulder to produce racket-head speed at contact (Elliott, 1988).

- The hitting shoulder has abducted further since the tossing phase so that the tossing shoulder, the hitting shoulder and the hitting elbow form a straight line (Elliott, 1988).

- The hitting elbow is flexed to approximately 90° when the knee bend is at its deepest, with the trunk flexing away from the court (Tiley, 2003).

- Trunk flexion helps to stretch the trunk muscles so that they can contract more forcefully and at higher speed to produce more power (Tiley, 2003).

Swing to Impact

From the power position, it is the legs that initiate the upward movement towards contact. The transfer of power is rhythmically transferred from the ground up through all the muscles that have been stretched. According to Elliott (1988), the sequence is:

- Leg drive and trunk rotation.
- Followed by shoulder elevation and flexion.
- Then by elbow extension, pronation and internal rotation of the shoulder.
- With wrist flexion being the final movement.

The extension of the knees forces the shoulder into external rotation and the racket initially moves away from the contact point (Elliott, 1988). This movement is contrary to the "backscratch" teaching method which recommends that the racket moves into a position against the server's back. This method is no longer used when teaching the serve as it does not comply with the principle of the stretch shortening cycle and does not lead to a more powerful serve (Elliott, 1988). The movement of the racket away from the contact area serves to stretch the muscles of the chest and shoulder (Elliott, no date). The elbow then leads the racket up to contact with the racket still lagging behind the forearm with the wrist abducted (Bolletieri, 2001). The trunk rotates as the hitting shoulder moves forward and up in a shoulder over shoulder motion. Just prior to contact, after all preceding segments have unloaded and transferred momentum to the hitting arm, the elbow extends and radio-ulnar joint pronates, while the shoulder undergoes internal rotation. This then leaves only the wrist to flex at contact (Elliott, 1988).

Contact

Elliott (1988) noted that expert server's impact the ball just after it has begun to drop. He also suggested that the coach teaches the learners to hit up into and through contact. This motion is necessary to produce some forward rotation on the ball, which will help it to dip into the court.

At contact the body is fully extended (Elliott, 1988) and it is flexed laterally to the left (for right-handed players). It is recommended that the angle between the torso and the arm as a result of this lateral flexion should be between 90° and 100° (Ellenbecker in Noffal, no date). This places less stress on the shoulder and prevents possible injury (Ellenbecker in Noffal, no date). The left arm tucks into the body so as to act as a brake to prepare the body for deceleration and to create a whip-like effect for the hitting arm (Bollettieri, 2001).

Follow-through

There is a natural pronation and internal rotation of the hitting arm post-contact, due to the high racket head and arm speeds produced (Elliott, 1988). This action in the arm is necessary in the slowing down of the hitting arm so as not to induce any injuries (Elliott, 1988). The advanced server propels the body into the court. This is a combination of the toss that is tossed in front of the body as well as the explosive power that is created from the extension of the legs after the knee bend. The hitting arm continues on its arc, across the body's sagittal plane (Elliott, no date) and finishes on the left hand side of the body (for a right-handed player). During this phase almost all of the muscles undergo an eccentric contraction.

Conclusion

Augmented feedback (both KR and KP) has a critical role to play in the learning of skills. The content and time of augmented are factors in determining its effectiveness.

- This study will make identical KR available to subjects in order to remove that consideration from the analysis.
- The time of feedback will be terminal and presented in a period in-between pre- and post-tests of their serves. No intervening activities will be permitted.

Technological advances have added the dimension of the mode for delivering feedback as another critical variable. Videotape feedback has provided mixed results to date in the research. This study will attempt to utilise the more sophisticated option of digital video as part of an augmented feedback intervention designed to impact upon the technique, speed and accuracy of the tennis serve. Providing augmented KP on the tennis serve presents the coach with a difficult task because the skill is very fast, dynamic and difficult to analyse. This study will utilise video feedback not only to determine its effectiveness in helping the coach deliver meaningful feedback to a performer, but also as a means for the biomechanical assessment of the serve, when processed by a commercial programme, Dartfish®.

Chapter Three

Methodology

This study followed a pretest-posttest randomized-groups design (Thomas & Nelson, 2001). The purpose of this design is to determine the amount of change brought about by the treatment, which in this research was the support of verbal KP with video technology. Group 1, who received KR and verbal KP only, served as the control group. Group 2, who received KR and verbal KP with video technology support, served as the experimental group.

Selection of Measurement Instruments

Two measurement instruments were used to provide quantitative data about the accuracy and speed of each subject's serve. A computer software package was selected to process digital video recording of each serve. This information was used in two ways. First, the video feedback was used as KP for the experimental group. Second, the data analysis capacity of this software was used later to provide quantitative data for the measurement of changes in the serving technique of all subjects.

Accuracy of the Serve

The current study adapted the testing protocol of the Hewitt Tennis Achievement Test developed by Hewitt in 1966 (Strand & Wilson, 1995). Only the service placement test was used for the purpose of the study. In this study, the deuce court service box was demarcated into various sections. Each section had a point assigned to it, which the subject was awarded if the serve landed within this section (see Figure 2). The test consisted of the following sequence of events:

1. The subject took his/her place to the right of the centerline behind the baseline. He/she was instructed to try to ignore the camera and radar gun placed on the court, and was assured that both pieces of equipment were protected and could not be damaged if hit by the ball.

2. When ready, the subject served the ball to the deuce court, aiming for the maximum number of points. When ready for the next trial, the subject served the ball again to the deuce court, again aiming for the maximum number of points

3. This self-paced sequence was repeated until the accuracy and speed of 10 serves were recorded. Serves that hit the net and went over were repeated.

Each of the serves was scored on a scale of zero to six, depending on where in the service box the serve landed. Balls that landed on the line received the higher point. The accuracy score was the total of the 10 recorded serves. Sixty points constituted a perfect score.

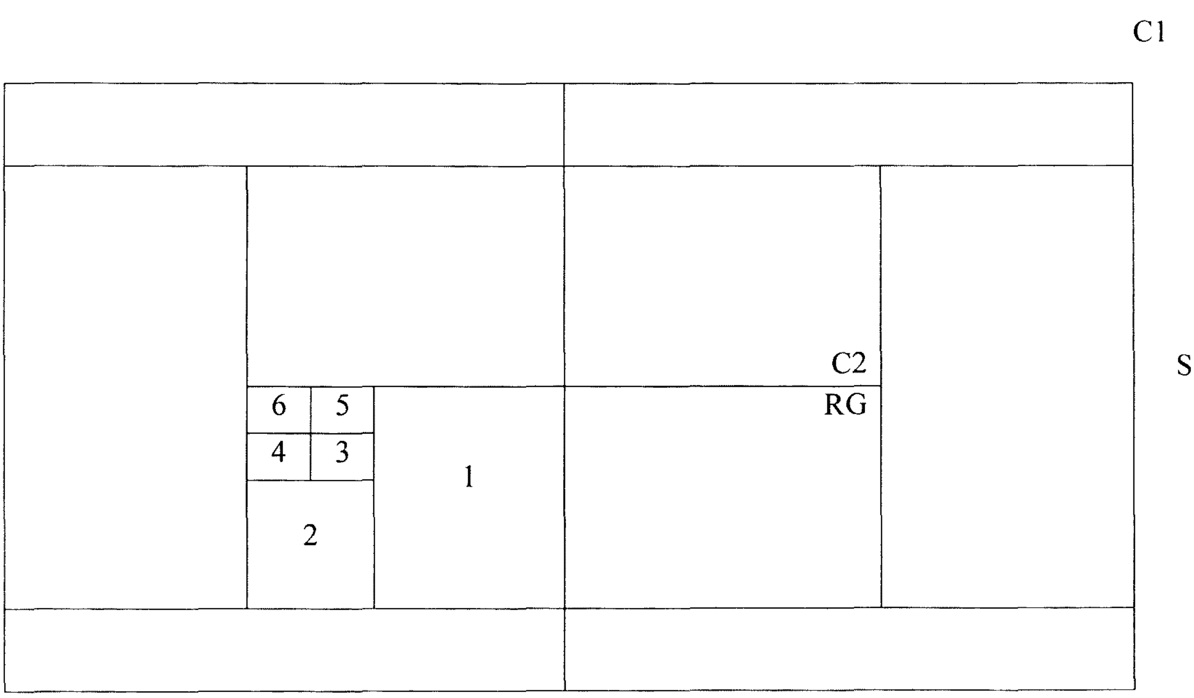


Figure 2

Scoring for the various zones in Hewitt's test for serving accuracy (Strand & Wilson, 1995) with locations indicated for positions of camera 1 (C1), camera 2 (C2), radar gun (RG) and subject (S).

All testing was done on the same outdoor court at the university's tennis complex during favourable weather. Second hand balls were used for the warm up and new balls were used for the testing. Two test assistants used to judge accuracy points were students in the Department of Sport Science at Stellenbosch University. All assistants were briefed prior to the commencement of testing to ensure consistency and reliability of the results. For scoring accuracy, assistants stood behind the receiving court baseline.

Speed of the Serve

The speed of each subject's serve was measured using a radar gun. The radar gun used in this study was the Sports Pro radar gun (US Radar, Inc.), which was powered by a Bescor MM-7 rechargeable battery. The test administrator operating this device had extensive experience with the radar gun during previous research projects. In order to measure speed, the manufacturer recommended that the gun be positioned alongside the camera that was placed in front of the server at point RG (see Figure 2). The speed of each serve was taken as the ball went over the top of the radar gun. This position was selected because it was the one position that consistently produced a reading from the radar gun. The sensitivity of the radar gun was set to approximately 75% of full sensitivity.

Movement Analysis Software

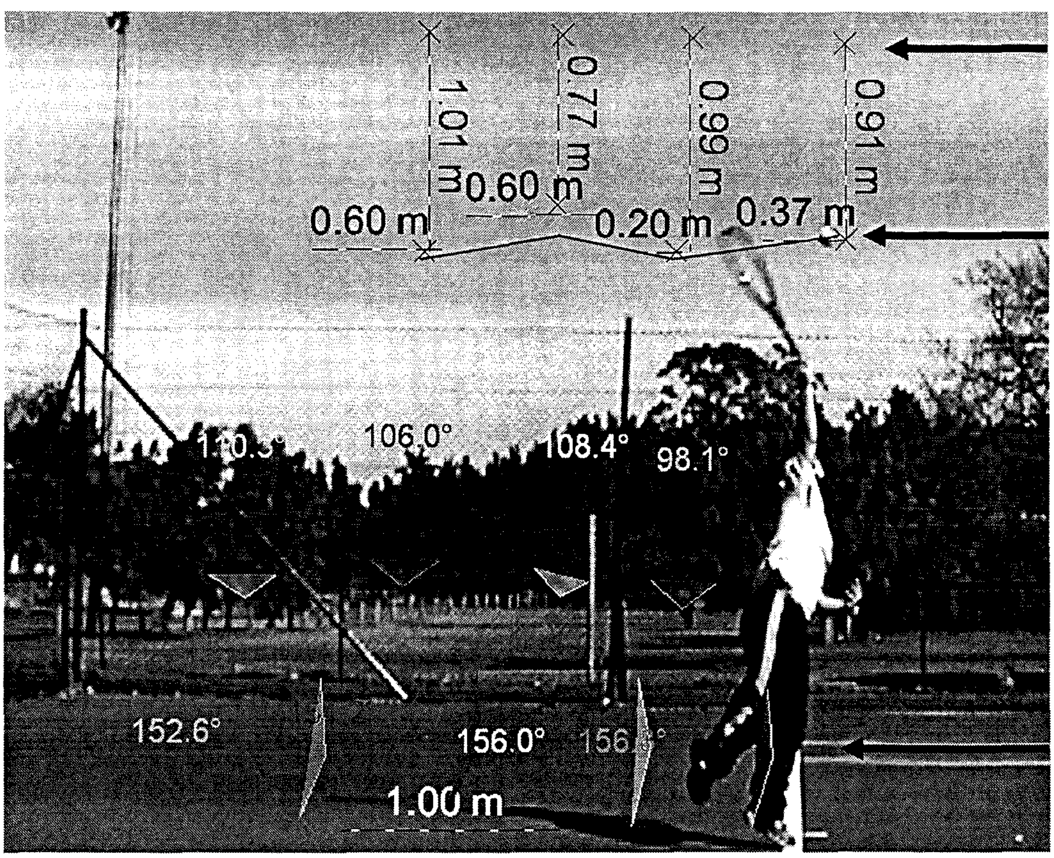
Two digital video cameras were used. Both were Panasonic NV-DS30 digital video cameras mounted on tripods.

- One camera (C1) was placed in line with the baseline 10.10m away from the centerline. This camera was used to capture the full height of the toss. This camera was mounted on a tripod that stood 108cm high.

- The second camera (C2) was placed in front of the server in the service box directly in front of the server on the subject's side of the net. This camera was 110cm from the service line in the direction of the net and 50cm from the middle line. The camera was mounted on a tripod that stood 73cm high.

Following the pretest of each subject in the v/Video group, the 10 video clips of that subject's serves were downloaded onto the Compaq Presario 2700 (on which the DartTrainer Professional Suite 2.0, Dartfish® was installed) using the DV import mode. The clips were then replayed to those in the verbal feedback with video support group using the playback mode. The test administrator used the "slo-motion" feature when providing KP to subjects in order to make observation of the errors easier.

The advantage of the Dartfish® programme is that it also supports a basic biomechanical assessment of any image recorded. This feature enabled the investigator to digitize, calculate key points in the technique of each serve. Figure 3 is an example of the quantification of four different variables on four different serves.



Ball Drop

Ball Position

Elbow Angle

Knee Angle

Figure 3

Capabilities of the Dartfish® programme to support the measurement of four different variables on four different serves.

Procedures

The following procedures were followed in this research.

Recruitment of Subjects

The subjects in this study were volunteers from the Department of Sport Science at Stellenbosch University. Eighty-five potential subjects were briefed on the nature of the research project, the testing procedures and the time commitment involved, before the investigator asked for volunteers. Eighteen subjects made the decision to volunteer for the study. There were 8 male participants and 10 female participants. Volunteers then signed a letter of consent indicating their willingness to participate as subjects in the research.

The subjects were randomly assigned to Group 1 (verbal FB only) or Group 2 (verbal with video-supported feedback). A timetable for the pretest, intervention and posttest sessions was created. Subjects confirmed their availability with the investigator. There were 17 right-handed players and one left-handed player. All participants in the study had at least a limited background in tennis. They all had completed two modules in tennis (24 lessons taught by a registered professional tennis instructor), as part of the sport science curriculum. The evaluation of these modules includes knowledge of the mechanics of the serve. All subjects also had some knowledge about the biomechanical assessment of skills in general, because all had successfully completed an undergraduate theory module in biomechanics.

Equipment Setup

The equipment (Radar gun and two digital cameras) was placed consistently in the same location for every test session so that there would be reliability in the results. This set-up is described in the previous section on measurement instruments and is illustrated in Figure 2. Camera 1 was moved to the opposite side of the court for the left-handed subject.

Warm up

For the warm up, the subjects prepared the body for dynamic movement by performing a series of dynamic stretches focusing predominantly on the shoulder region. The subjects were then allowed to hit some practice serves for a period of five minutes, after which the testing began.

PreTest, Intervention and Post-Test Sessions

The pretest, intervention and posttest session for each subject occurred during a single visit to a selected University tennis court. The duration of each individual session was approximately 60 minutes. The sequence of events during each session was identical, with the exception of the intervention period where the two different approaches to the delivery of KR were provided (see Table 1).

Table 1. Comparison between the sequences of events for the KR & KP (verbal only) group and the KR & KP (verbal plus videotape) group during the research project

Group 1 **KR and Verbal KP**	**Group 2** **KR and v/Video supported KP**
Court setup	Court setup
Equipment setup & confirm working order	Equipment setup & confirm working order
Briefing of subject	Briefing of subject
Warm-up	Warm-up
Start cameras	Start cameras
Self-paced serving test (10 recorded)	Self-paced serving test (10 recorded)
• Subject hears speed reported for each serve (KR)	• Subject hears speed reported for each serve (KR)
• Subject can see where each serve lands (KR)	• Subject can see where each serve lands (KR)
Stop recording after 10th serve	Stop recording after 10th serve
Investigator downloads and views replays of serve (± 4 minutes) without allowing subject to watch	Investigator downloads and views replays of serve together with subject
Instructor provides corrective feedback to performer (v KP)	Investigator replays serves in slow motion and provides corrective feedback to subject (v/Video KP)
Subject allowed practice period to try to incorporate feedback – Investigator gives additional verbal FB if asked	Subject allowed practice period to try to incorporate feedback – Investigator gives additional verbal FB if asked
When subject feels ready, posttest begins	When subject feels ready, posttest begins
Start recording	Start recording
Repeat pretest protocol exactly	Repeat pretest protocol exactly
Stop recording	Stop recording
Investigator provides positive closing comment to subject about his/her serve before subject leaves	Investigator provides positive closing comment to subject about his/her serve before subject leaves

- **Pretest and Posttest Details**

An assistant was used to record the results of each serve. This assistant stood at the opposite end of the court to the subject, near the service box that had been demarcated. The assistant first recorded the accuracy of the serve based on the point system as discussed earlier. The test administrator then called out the speed of the serve. This procedure was repeated until 10 serves had been recorded. (see Figures 4 and 5 for examples of score cards for subjects X and Y. Snapshots from the Dartfish® programme have been inserted in these Figures to indicate when video-replays were available for viewing).

After the intervention period, the subjects of both groups were given the opportunity to attempt to implement the suggested changes in a self-paced practice period. The test investigator was present and available if the subject requested additional feedback.

After the practice period, the subjects then served again. The test administrator again took up the position next to camera two. The assistant took up a position next to the service box to which the subject was serving. The assistant first recorded the accuracy of the serve before recording the speed of the serve, as called out by the other test administrator. This procedure was repeated until there were 10 recorded serves.

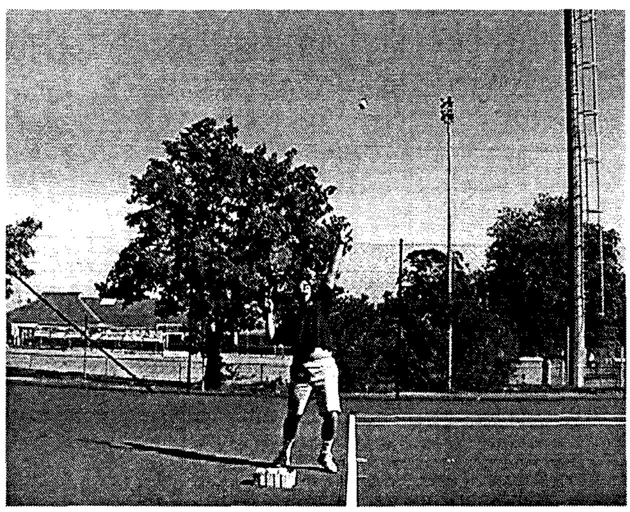
- **Intervention (Feedback) Details**

Upon completion of the 10 recorded serves, the test administrator viewed the videotape replay so as to ascertain what the errors were that the subject was committing. On-court feedback was then given to the subject based on group to which the subject had been assigned. Knowledge of results was given to the subject immediately post testing. The one group received the traditional verbal feedback where the test administrator discussed the most common and frequent

PRE-INTERVENTION

Average Speed	122.8	Fastest Speed	129
Slowest Speed	111	Accuracy Points	19

Variable	1	2	3	4	5	6	7	8	9	10
Knee flexion	126.3	128.3	120.5	126.2	116.7	137.6	119.6	126	124.5	120.9
Torso vs arm	121.6	110.8	117.5	120.8	116.1	119.5	122.7	125.5	118.9	123.4
Elbow at cocked	68.8	69.4	69	63.8	66.3	67.5	68.8	70.7	62.9	72.9
Arm extension	167.5	156.8	165.2	170.6	164.5	160.6	164.2	161.3	158	166.4
Ball toss drop	95	82	77	81	102	108	112	101	99	106
Ball toss position	41	50	53	40	52	51	58	59	75	49



INTERVENTION – FEEDBACK GIVEN

Use deeper knee bend to explode up to the ball
Rotate hips and shoulder more during the toss phase

POST INTERVENTION

Average Speed	121.3	Fastest Speed	130
Slowest Speed	116	Accuracy Points	5

Variable	1	2	3	4	5	6	7	8	9	10
Knee flexion	116	116.3	111	117.7	128	119.2	117.4	120.9	117.9	118.3
Torso vs arm	121.6	118.7	116.6	117.2	115.9	120.7	118.4	112.2	123.2	126.5
Elbow at cocked	68.5	74.4	65.2	63	66.8	69.9	66.5	66.7	68.5	71.1
Arm extension	168.5	168.9	145.5	168.6	172.5	171.3	166.5	164.8	170.2	160.7
Ball toss drop	78	83	83	80	90	73	77	77	86	72
Ball toss position	56	49	50	42	54	42	65	59	55	44

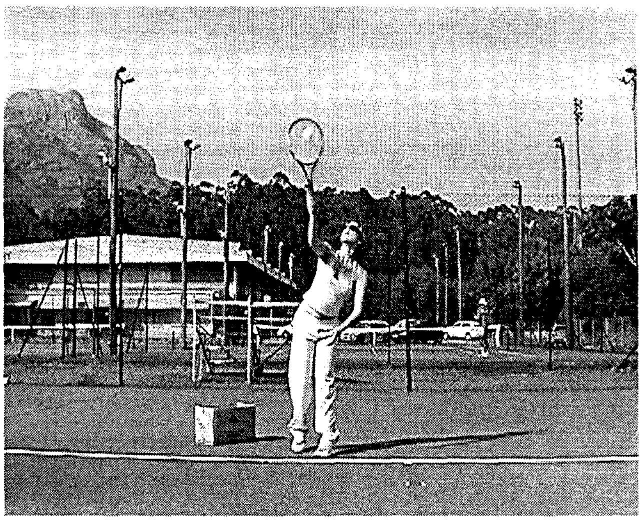
Figure 4

Scorecard with Feedback for Subject X.

PRE-INTERVENTION

Average Speed	60.2	Fastest Speed	74
Slowest Speed	55	Accuracy Points	14

Variable	1	2	3	4	5	6	7	8	9	10
Knee flexion	155.3	160.1	163.8	162.3	164.7	163.2	159.1	166	165.7	160.9
Torso vs arm	88.5	100.8	113.9	106.3	117.1	120.7	102.5	114.5	107.5	112
Elbow at cocked	129.9	142.4	118.4	137.9	124	126.5	129.9	126.3	126.9	131
Arm extension	132.6	148	142.4	137.4	133.2	143.1	132.6	142.1	150.7	133.8
Ball toss drop	109	90	126	109	87	117	144	141	104	118
Ball toss position	9	17	1	9	12	11	40	-13	4	3



INTERVENTION – FEEDBACK GIVEN

Keep racket up during cocked position
Don't let ball drop too much – use legs to extend up into contact
Get body moving in direction of target

POST INTERVENTION

Average Speed	60.4	Fastest Speed	67
Slowest Speed	55	Accuracy Points	11

Variable	1	2	3	4	5	6	7	8	9	10
Knee flexion	159	173.5	161.7	156.7	176.1	167.8	162.8	156.9	159.4	166.7
Torso vs arm	94.4	100.8	110.3	102.5	155.6	109.1	138.2	121.6	111.9	114.4
Elbow at cocked	116.9	122	139.7	134.1	126.1	130.4	133	129.5	138.6	126
Arm extension	152.3	139.1	141.1	148.6	145.3	140.6	162.3	139.1	145.5	142.8
Ball toss drop	162	158	115	145	195	129	171	149	102	142
Ball toss position	7	1	1	25	-11	-44	20	-7	5	11

Figure 5

Scorecard with Feedback for Subject Y.

mistakes being made by the subject. The second group received videotape replay feedback. This group sat with the test administrator and viewed the replays of the serve on a laptop computer (Compaq Presario 2700). The video clips had been downloaded onto the computer and put in the commercially available software analysis package DartTrainer®. The subject then received feedback with regards to the most common and frequently occurring errors while viewing the replays. Slow motion playback was used to better illustrate/distinguish more rapidly the errors being made. Some of the feedback given to the subjects suggested specific distance changes. The subjects were able to understand and attempt to implement these changes as they were all student of the Sport Science department at their University and had completed a course in biomechanics.

Feedback was given based on a template designed by the author, which highlighted the key elements of the service action. The elements that were looked at were:

1. PREPARATION
    - Balanced position, hands close to body
    - Body not parallel to baseline
    - Grip: Continental or Eastern Forehand

2. BALL TOSS
    - Ball held loosely in hand
    - Smooth, co-ordinated movement, arm straight
    - Ball released at approximately eye level without wrist flexion
    - Not too high, not too low
    - In front of body and slightly to side of hitting arm

3. KNEE FLEXION
    - Front knee bends and track in line with toes
    - Horizontal rotation of shoulders and hips
    - Shoulder tilt with staggered arm position (tossing shoulder higher than hitting shoulder)
    - Power position: Tossing, shoulder, hitting shoulder and hitting elbow in straight line; approximately 90° at hitting elbow with racket up (wrist not hyperextended); Trunk leaning away from court

4. SWING TO IMPACT
    - Rhythmical transfer of movement upwards to contact
    - Correct sequencing of movement
    - Elbow drives racket up to contact

5. CONTACT
    - Full body extension
    - Lateral trunk flexion
    - Tossing arm tucks into body
    - In front of body into court and to hitting arm side of head
    - Body rotated so that it is facing the target

6. FOLLOW THROUGH
    - Tossing arm remains tucked in
    - Forward movement in the direction of the target
    - Full follow through of hitting arm to opposite side of body

These components were used in an attempt to correct the mechanics of the service action. The same person (the investigator) gave the feedback to every subject, which ensured the consistency of the analysis and feedback process. The investigator determined a kind of template for the "ideal form" of a serve based on his years of experience in tennis. This template gave a reference point for bandwidth of feedack, since corrective KP was not given for serves falling within the parameters of the "ideal form."

Template for Observing Technique	
Variable	Ideal
Knee flexion	90°-110°
Ball toss drop	0 - 25 cm
Ball toss position	70cm in front
Elbow @ cocked position	90°
Torso vs arm	90° - 100°
Elbow extension	170° - 180°

According to Rose (1997), there are three important issues to consider when providing feedback in the learning of skills, namely: the form of feedback given, the precision of the feedback; and the frequency of the feedback.

In the current study, there were two forms of feedback that were provided. These were the verbal feedback as well as verbal feedback with videotape replay. The verbal feedback that was given focused on the kinematics of the stroke with the focus on error-correcting transitional cues. Kernodle and Carlton (1992) demonstrated in videotape replay feedback, using the overarm throw, that higher movement ratings were achieved by the group that received transitional cues prior to viewing the videotape replay.

With regards to the precision of the feedback provided, Magill and Wood (1986) showed that this is related to the skill level of the learner. The authors concluded that beginners should not be given feedback with too much precision until they have practiced the task enough to be able to benefit from the detailed information. For the purposes of this study, the feedback given was not too precise so as to overload the learners with too much information.

Wulf, Shea and Matschiner (1998) concluded that the complexity of the skill determined the optimal level of frequency required when providing feedback. They argued that the less complex the skill, the less important the frequency of feedback is. Thus it is not necessary to provide feedback after every trial for simple tasks. Another factor related to the frequency of feedback is that feedback given too frequently can hinder learning as there is an overload of attention. With these aspects taken into consideration, summary feedback was given after the completion of the 10 recorded serves. This was done so that only the most commonly occurring and relevant errors could be identified and only these were discussed with the learner. This attempts to eliminate the possibility of overloading the attention of the learner.

Analysis of the Serve

The pretest and posttest video data for each serve for every subject, were recorded by the digital video camera, then transferred to the laptop computer where they were directly downloaded onto the DartTrainer® programme using the DV import mode. Once all the video clips of the serve were downloaded onto the DartTrainer® program, the analyzer mode was selected. The author then set about breaking down the serve into its various components. An example of this was provided in Figures 3, 4 and 5, presented earlier in this chapter in the section of selection of the measurement instruments. Five different variables were selected for measurement and subsequent data analysis:

Ball toss drop

To measure distance, the program requires a one metre reference distance in the clip being viewed. This was provided by the marked one metre on the court using the side view. This was necessary for the measurement of the ball toss drop, which was measured form the highest point the ball reached after the toss down to the contact point.

Ball position

The ball position measured the distance the ball was contacted in front of the body. This measurement was taken from the back edge of the baseline (at contact height) to contact point. Any ball that was contacted behind the baseline was recorded as a negative value.

Elbow angle at the power position

The elbow angle at the power position, when there is supposed to be a brief pause in the service action (Schönborn, 1998/1999), was measured using the side view of the serve.

Torso vs. arm position

The torso vs. arm position was taken as the angle produced at the shoulder between the upper body and the upper arm at contact. The front view was used to calculate this angle. The front was also used to calculate the angle at the elbow at contact, recorded as elbow extension.

Knee bend

The final component of the serve that was analysed was the knee bend. The deepest knee angle of the subject was taken. Depending on the server's orientation to the baseline either the front or the side view was used. If the server was more front on to the net, the side view was used and if the server was more side on to the net, the front view was used to calculate this variable

Data Analysis

Descriptive statistics were utilised to determine if there were any pre- to posttest changes in either the kinematic variables or in serving speed and accuracy, for the subjects in Group 1 and in Group 2. Repeated measures Analysis of Variance (ANOVA) was applied to determine if there were any between-group and within-subject changes when comparing the pre- to post-intervention performances on each of the kinematic, speed and accuracy variables. All dependent variables will be tested for homogeneity of variance using Levene test. If variances are hetereogenous, Brown-Forsythe tests will be employed for testing any main effects. A special thanks is extended to Mr. Alex Stahn for his support in processing this data.

Chapter Four

Results and Discussion

This chapter is structured in sections that correspond to the research questions. The raw data for this Chapter appears in Appendix A. Speed and accuracy were measured separately during the study. They will, however, be discussed together because of their intimate relationship in the motor learning literature (Schmidt & Lee, 1999). Also, if the speed of the serve is sacrificed for a more accurate one, the accuracy may be negated by making it easier for the opponent to reach the ball and return it comfortably. Vice versa, if accuracy is neglected in the favour of speed, the ball will be within the opponent's reach to return it.

Research Question One

Will there be any changes in the technique, speed and/or accuracy of the tennis serve, of subjects who experience the verbal KP only intervention?

Technique

For the subjects in Group 1 (verbal KP only), a description of the changes in pre- to post-intervention values of the six kinematic variables measured as indicators of technique are presented in Table 2. Two interesting trends are present:

Table 2. Pre-to post-intervention comparison between the six kinematic variables representing serving technique for the subjects in Group 1 (n = 10)

Technique Variables	**Pre-intervention Mean ± SD**	**Post-intervention Mean ± SD**
Knee Angle(°)	149.54 ± 19.37	147.89 ± 18.42
Elbow angle (°)	106.83 ± 35.56	102.13 ± 30.48
Torso vs Arm (°)	126.78 ± 18.94	119.67 ± 14.53
Elbow extension (°)	158.01 ± 18.70	162.64 ± 9.62
Ball position (cm)	21.09 ± 14.45	20.65 ± 15.48
Ball drop (cm)	66.79 ± 39.58	77.85 ± 41.49

- With regards to what the investigator had identified as the "ideal form" in respect to each of these variables (see description in Chapter Three), the subjects moved closer to the ideal. The mean scores for the knee angle, torso vs. arm, elbow angle and elbow extension also show a small change in the direction of the more "ideal form".

  Ball position and ball drop showed an inclination away from the ideal.

- The smaller SD values on the post-intervention performance, suggest that the subjects in Group 1 become more consistent with regards to knee angle, torso vs. arm, elbow angle and elbow extension. Both the ball position and ball drop showed more variability.

Speed and Accuracy

For the subjects in Group 1 (vKP only), a description of the changes in pre- to post-intervention values of the three variables measured as indicators of speed and the one indicator of accuracy, are presented in Table 3.

Table 3 . Pre- to post-intervention comparison between the three variables for serving speed and the one accuracy variable for the subjects in Group 1 (n = 10)

Speed & Accuracy Variables	Pre-intervention Mean ± SD	Post-intervention Mean ± SD
Slowest Speed (kph)	67.1 ± 30.80	74.30 ± 27.04
Fastest Speed (kph)	92.3 ± 38.81	94.10 ± 30.18
Average Speed (kph)	82.19 ± 31.03	84.95 ± 27.10
Accuracy (pts)	10.70 ± 5.31	9.00 ± 4.32

Speed

A comparison of the average slowest speed on the pre-intervention (67.10 kph) compared to the post-intervention (74.30 kph) indicates that the subjects in Group 1 served faster in general on the post-intervention test. Their average fastest speed also became higher (92.30 kph to 94.10 kph). It can be seen by looking at the average speed of the serve pre-intervention (82.19 kph) compared to the average speed of the serve post-intervention (84.95 kph), that there was a slight increase in the speed of the serve.

It can also be noted that the variability in terms of the speed of the serve also improved slightly (the SD became less on the post-intervention tests for the slowest (30.80 to 27.04), fastest (31.81 to 30.18) and the average speed (31.03 to 27.10)). This means that the subjects became somewhat more consistent with regards to the speed of their serves.

Accuracy

The points earned for serving accuracy decrease slightly from the pre- (10.70 pts) to the post-intervention test (9 pts). This change was not statistically significant. However, the consistency of the group as a whole showed an inclination to be more consistent, with SD values changing from 5.31 on the pre-intervention test to 4.32 on the post-intervention.

Research Question Two

Will there be any changes in the technique, speed and/or accuracy of the tennis serve, of the subjects who experience the verbal with the video-supported KP intervention?

Technique

For the subjects in Group 2 (v/Video KP), a description of the changes in pre- to post-intervention values of the six kinematic variables measured as indicators of technique are presented in Table 4. There were a few interesting results that prevailed in the verbal feedback with video support group.

- When looking at the kinematic variables, the results for Group 2 did not follow the same pattern as for Group 1, the verbal only KP group. Group 2 did show a trend to move closer to the ideal form in terms of torso vs. arm (131.61° to 129.37°), elbow angle (94.46° to 91.32°), elbow extension (156.03° to 158.68°) and ball position (30.69 to 31.21cm).

- However, for the knee angle and the ball drop, both values moved slightly away from the ideal form.

Table 4. Pre- to post-intervention comparison between the six kinematic variables representing serving technique for the subjects in Group 2 (n = 8)

Technique Variables	Pre-intervention Mean ± SD	Post-intervention Mean ± SD
Knee Angle (°)	153.62 ± 14.59	157. 54 ± 12.54
Elbow angle (°)	94.46 ± 23.10	91.32 ± 26.14
Torso vs Arm (°)	131.61 ± 11.01	129.37 ± 6.85
Elbow extension (°)	156.03 ± 12.19	158.68 ± 12.59
Ball position (cm)	30.69 ± 19.19	31.21 ± 16.86
Ball drop (cm)	88.81 ± 49.81	97.41 ± 37.94

- The verbal feedback with video support group did show an improvement in the consistency of movement in some of the kinematic variables, i.e. knee angle, torso vs. arm and ball position. Elbow angle and elbow extension did not show an improvement in terms of this consistency.

Speed and Accuracy

For the subjects in Group 2 (v/Video KP), a description of the changes in pre- to post-intervention values of the three variables measured as indicators of speed and the one indicator of accuracy, are presented in Table 5.

Speed

A comparison of the average slowest speed on the pre-intervention (76.50 kph) compared to the post-intervention (66.50 kph) indicates that the subjects in Group 2 served slower in general on the post-intervention test. Their average fastest speed actually became higher (98.75kph to 100.38 kph). It can be seen by looking at the average speed of the serve pre-intervention (88.65 kph) compared to the average speed of the serve post-intervention (87.46 kph), that there was a slight decrease in the speed of the serve.

Table 5. Pre- to post-intervention comparison between the three variables for serving speed and the one accuracy variable for the subjects in Group 2 (n = 8)

Speed & Accuracy Variables	**Pre-intervention Mean ± SD**	**Post-intervention Mean ± SD**
Slowest Speed (kph)	76.50 ± 22.39	66.50 ± 28.00
Fastest Speed (kph)	98.75 ± 23.40	100.38 ± 24.65
Average Speed (kph)	88.65 ± 22.49	87.46 ± 25.19
Accuracy (pts)	10.63 ± 6.19	7.75 ± 6.65

It can be noted that the variability in terms of the speed of the serve increased (the SD became more on the post-intervention tests for the slowest, fastest and average speed for the serves). This means that the subjects decreased their consistency with regards to the speed of their serves.

Accuracy

The points earned for the accuracy decreased from the pre- (10.63 pts) to the post-intervention (7.75 pts). Also, the consistency of the group as a whole also showed to be less consistent, with the SD values changing from 6.19 on the pre-intervention to 6.65 on the post-intervention tests.

Research Question Three

Will there be any significant differences in technique, speed and/or accuracy of the tennis serve, among subjects who experience the verbal KP only compared to the subjects who experience the video-supported KP intervention?

The results of the ANOVA are presented in the following tables. Main effects were calculated to determine if there is a significant difference found for each main variable (group, treatment or gender). Subsequent analysis was calculated on the one significant main effect found, i.e. the effect of gender. Interaction effects were calculated to determine if there were any significant interactions, where change in one variable is dependant on the effect of another variable.

Main Effects for Technique (the Kinematic Variables)

Table 6. Results of the ANOVA to determine the main effects for kinematic variables

Variable	F-value	Significance
Gender (Men vs. Women)		
Knee Angle (°)	13.75	0.00*
Elbow Angle (°)	10.66	0.01*
Torso vs. Arm (°)	0.00	0.99
Elbow extension (°)	7.74	0.02*
Ball position (cm)	2.68	0.12
Ball drop (cm)	4.55	0.05
Group (Verbal vs. v/Video)		
Knee Angle (°)	0.94	0.35
Elbow Angle (°)	2.07	0.17
Torso vs. Arm (°)	0.20	0.67
Elbow extension (°)	0.07	0.80
Ball position (cm)	2.67	0.13
Ball drop (cm)	0.75	0.40
Treatment (Pre vs. Post)		
Knee Angle (°)	0.73	0.41
Elbow Angle (°)	2.19	0.16
Torso vs. Arm (°)	0.03	0.87
Elbow extension (°)	2.07	0.17
Ball position (cm)	0.06	0.81
Ball drop (cm)	4.09	0.06

*p < .05

As can be seen in Table 6, the only significant main effect for the kinematic variables associated with technique, were found in the gender differences. Knee angle (0.00), elbow angle (0.01) and elbow extension (0.02) were the three variables that showed significant differences. It could be speculated that these differences exist because many cultures encourage boys to be more physically active and participate in more sport than girls. The significant difference with regards to the knee angle and the elbow angle could be explained when boys are taught at an early age how to throw, and then have many more opportunities to practice this than most girls do. Because the knee angle and elbow position play an important part in the overhand throwing motion, this also could be the reason for the significant difference between the men and the women.

Interaction Effects for Technique (the Kinematic Variables)

When looking at the interaction effects as reported in Tables 7, 8 and 9, only one significant effect was found. This was a significant change in the knee angle when comparing the verbal only group to the verbal with video support group. When referring to the descriptive statistics, it is found that the verbal only feedback group bent their knees more in the post-test (149.54 to 147.89), while the verbal with video support group bent their knees less in the post-test (153.62 to 157.54). These changes could help to explain the slight changes in the serving speed of the two groups. The verbal only feedback group increased all the components of their speed, while the verbal with video support group decreased in average speed and slowest speed. The use of more knee bend may have helped the verbal only group to improve their serve speed because they were able to stretch the muscles involved in the action better, thereby increasing the speed of the racket.

Table 7. A comparison of the changes from pre- to post-intervention between the verbal and video group (Treatment * Group) irrespective of the gender with regards to the kinematic variables

Variable	F-value	Significance
Knee Angle (°)	5.01	0.04*
Elbow Angle (°)	0.03	0.87
Torso vs. Arm (°)	1.55	0.23
Elbow extension (°)	0.20	0.66
Ball position (cm)	0.14	0.72
Ball drop (cm)	0.23	0.64

*p < .05

Table 8. A comparison of the changes from pre- to post-intervention between the verbal and video group (Treatment * Group) for the men and the women (Treatment * Group * Gender) with regards to the kinematic variables

Variable	F-value	Significance
Knee Angle (°)	0.79	0.39
Elbow Angle (°)	0.69	0.42
Torso vs. Arm (°)	1.29	0.27
Elbow extension (°)	0.74	0.40
Ball position (cm)	1.38	0.26
Ball drop (cm)	0.22	0.65

*p < .05

Table 9. A comparison of the changes from pre- to post-intervention between men and women irrespective of the (treatment) group they were in (Treatment * Gender) for kinematic variables

Variable	F-value	Significance
Knee Angle (°)	0.00	0.99
Elbow Angle (°)	0.00	0.99
Torso vs. Arm (°)	1.14	0.30
Elbow extension (°)	1.52	0.24
Ball position (cm)	0.56	0.47
Ball drop (cm)	1.21	0.29

*p < .05

Main Effects for Overall Speed and Accuracy

The only significant main effect for the variable of speed and accuracy of the serve was found in the gender differences (see Table 10). When looking specifically at the variables measured with regards to the difference reported in the overall speed, the results showed significant differences in all three speed variables. It can be speculated that the men in this study were physically stronger than the women therefore they could generate more force, which translated to greater speed. Another possible reason could be that the men were more skilful in the overhand throwing motion than the women. The reason that this is suggested as a possibility for the difference in serving speed is that the serve is considered to be predominantly an overhand throwing motion.

Table 10. Results of the ANOVA to determine the main effects for speed and accuracy

Variable	F-value	Significance
Gender (Men vs. Women)		
Slowest Speed (kph)	6.81	0.02*
Fastest Speed (kph)	12.47	0.00*
Average Speed (kph)	11.67	0.00*
Accuracy (pts)	1.36	0.26
Group (Verbal vs. Video)		
Slowest Speed (kph)	0.04	0.85
Fastest Speed (kph)	0.78	0.39
Average Speed (kph)	0.49	0.50
Accuracy (pts)	0.01	0.95
Treatment (Pre vs. Post)		
Slowest Speed (kph)	0.22	0.65
Fastest Speed (kph)	0.54	0.48
Average Speed (kph)	0.04	0.85
Accuracy (pts)	1.13	0.31

*$p < .05$

Interaction Effects for Speed and Accuracy

With regards to the interaction effects for overall speed, no significant effects were found. This means that there were no significant differences between the two groups in terms of the impact of their respective intervention programmes on serving speed or accuracy, even if the data were analysed by gender.

Table 11. A comparison of changes from pre to post-intervention between the verbal and video group (Treatment * Group) irrespective of the gender for speed and accuracy

Variable	F-value	Significance
Slowest Speed (kph)	4.62	0.05
Fastest Speed (kph)	0.04	0.85
Average Speed (kph)	1.01	0.33
Accuracy (pts)	0.04	0.84

*p < .05

Table 12. A comparison of the changes from pre- to post-intervention between the verbal and video group (Treatment * Group) for the men and the women (Treatment * Group * Gender) for speed and accuracy

Variable	F-value	Significance
Slowest Speed (kph)	0.20	0.66
Fastest Speed (kph)	0.59	0.46
Average Speed (kph)	0.01	0.91
Accuracy (pts)	0.06	0.80

*p < .05

Table 13. A comparison of the changes from pre- to post-intervention between men and women irrespective of the (treatment) group they were in (Treatment * Gender) for speed and accuracy

Variable	F-value	Significance
Slowest Speed (kph)	0.46	0.51
Fastest Speed (kph)	0.21	0.66
Average Speed (kph)	1.17	0.30
Accuracy (pts)	0.26	0.62

*p < .05

Summary

Although no significant differences were found in any of the pre- to post-test comparisons, the results followed a similar pattern in the two groups. Group 2 showed an improvement in all the kinematic variables except for elbow angle, while Group 1 showed an improvement in all the kinematic variables except for two (ball drop and ball position).

One difference between the groups that needs some attention deals with the results of the test of serving speed and accuracy (pts). Group 1 recorded a slight improvement in the speed of their serves, but not in terms of their accuracy. For Group 2, however, the speed decreased slightly and the performers were less accurate after the intervention period. A possible explanation for this may be that the video support group received more information as feedback to process than the verbal-only group did. They received the same amount of verbal KP, but also viewed the video replay to support that KP. This could mean that viewing the replay of their serves involved more critical thinking about their performance. They may have generated a mental image of their serve as a means to attempt to make the suggested corrections. They may have focused their attention more on the kinematics of their movement than the result of the serve. In other words, the video-supported KP may have given them more to think about, and that volume and focus could have affected their speed and accuracy in a negative way.

Another point of interest that arises when viewing the results of both groups is that there was an increase in the distance that the ball dropped after being tossed. Due to the elbow extension either remaining the same or moving closer to the ideal when compared to the pre-intervention values, it can be deduced that the ball was tossed higher during the post-intervention testing. A possible explanation for this is that the learners felt they needed more time to make the corrections to their serve and thus felt that tossing the ball higher would allow them to make the necessary changes to their movement pattern.

Chapter Five

Conclusions and Recommendations

Chapter Four presented the data to illustrate the changes that occurred as a result of the two different intervention programmes. This chapter will discuss the relevance of the results of the study.

Conclusions

There has been previous research dealing with the use of videotape replay as a means for the delivery of augmented feedback (Rikli & Smith, 1980; Guadagnoli et al. 2002). These studies and others have looked at different aspects with regard to the use of visual feedback and videotape replay. For example:

- Messier and Cirillo (1989) showed that an experimental group receiving verbal and visual feedback (KP) improved with regard to their technique. Their study focused on how female beginning level runners reacted to this form of feedback. They found some significant improvements in the running technique of members of the experimental group, when compared to that of the control group.

- Rikli and Smith (1980) studied the effects of videotape feedback on tennis serving technique with advanced beginner and intermediate tennis players. The study was scheduled over a number of days, and videotape feedback was given at various stages of the instructional cycle. The results of the posttests revealed that there were no significant differences between any of the groups, which led the researchers to the conclusion that the temporal location (timing or scheduling) of this form of feedback did not influence the effectiveness of the videotape feedback. The study showed that videotape feedback may be used in addition to the more common verbal feedback, but under certain circumstances. The conclusion of the authors, however, was that it was not as effective as has generally been believed.

- Emmen et al. (1985) showed that the use of videotape replay was no more effective than traditional augmented feedback in the learning of the tennis serve by beginners.

The delivery schedule for augmented feedback in the current study intended to define the lower limit of effectiveness with regard to the use of a newly available, digital-based means (Dartfish®) for providing video-supported KP. This study attempted to discover whether the provision of Dartfish®-supported KP could produce an immediate effect on selected kinematic variables such as speed and accuracy of the tennis serve using beginning level (but not novice) tennis players. The results of the study showed that there were no significant differences between the group who received verbal with the support of videotape replay, when compared to the group who only received verbal KP. This means that Dartfish® supported KP is no more effective in producing <u>immediate</u> changes in serving speed, accuracy or technique, than verbal KP. This is in line with the findings of Emmen et al. (1985) and van Wieringen et al. (1989).

The fact that no significant differences were achieved between the pre- and posttest of subjects receiving the Dartfish®-supported KP means that this technology was not able to produce significant changes in the subjects' tennis serve over such a short period of time. This could mean that the number of practice sessions with Dartfish®-supported KP needs to be increased to a point where significant improvements are achieved. The intervention period in the current study took place on the same day as the pre- and posttesting, and lasted no longer than 30 minutes. This is not, then, the lower limit for effectiveness of Dartfish®-supported KP. The results of the study conclude that this intervention period is too short to produce any meaningful changes in the technique, accuracy and speed of the tennis serve in novice tennis players. This has been shown previously by Guadagnoli et al. (2002) who not only demonstrated that videotape feedback was a useful method of practice, but also concluded that it may take some time before the benefits take place.

With regard to the stages for learning and how to use videotape feedback as identified by Darden (1999), the subjects in the current study may have still been in what he called the "shock stage" (Stage One). After questioning subjects after the conclusion of this study, it was clear that the subjects had limited experience in viewing themselves on videotape. Darden described this "shock stage" as the initial phase of experience when learners are not able to attend to all the task-related cues (they are still busy looking at themselves as a whole). This inability to attend to important cues severely limits their ability to learn through the use of videotape feedback. In other words, the subjects in the Dartfish®-supported KP group may not have had enough experience in the use of videotape replays as a form of feedback, to be able to use the information presented to them in order to improve their skill level in the tennis serve.

The fact that no significant differences were achieved between the pre- and posttests of subjects receiving verbal KP only, also reinforces the conclusion that immediate significant improvements cannot be expected, even when subjects are presented with KR, KP and the opportunity to rehearse changes in techniques prior to posttesting. This may have implications for tennis coaches who offer short clinics and workshops for beginners. Even though one might expect improvements in beginners who receive professional coaching, those improvements will not necessarily be immediate. This conclusion may be limited to improvements in the serve, one of the most difficult techniques in terms of timing and consistency in tennis.

Recommendations Regarding the Technology

The computer software analysis program used in the study (Dartfish®) is a commercially available product that could be used to assist coaches in a more precise analysis of performance than is possible with normal visual observation. The Dartfish® ***Analyser*** feature was used to break the serving technique down into its various components. This mode is useful for the measurement of angles and distances. However, this mode does present some practical problems:

Due to the number of serves (10 for the pretest and 10 for the posttest) and the number of kinematic variables identified as important for of this study (six), the analysis of the serve for one subject took a minimum of three hours in front of the laptop, marking and then calculating angles and distances for 20 serves. This can be translated into the generation of 20 x 6 kinematic variables = 120 measurements per person. Working to complete these measurements is very precise work and it is impossible to do more than two subjects in a single session. This means that coaches cannot complete biomechanical analyses of large numbers of performers in a short period of time. The Dartfish® ***Analyser*** feature is only recommended when the coach/sport scientist has sufficient time in between coaching session. Perhaps take learners in small groups or individually could also facilitate the timely delivery of the KP derived from the biomechanical analysis. Identifying a few typical performances suitable for analysis would also reduce the amount of time needed to quantify the kinematic variables in performances.

There are other Dartfish® features that could be mobilised to support performance improvement. It is not known at this time how the use of these features impacts on the learning of skills:

- The ***StroMotion*** feature on the DartTrainer® software can break a movement down into various components by taking still pictures at certain points in the movement performance. The coach/sport scientist is able to determine which components of the movement need to be highlighted. This feature is suited to a skill that requires the learner to move between two points. If it is used for a skill where the subject remains stationary, the still pictures of the selected parts of the movement will overlap each other, making viewing and subsequent analysis very difficult. However, when using a skill requiring movement from the original position, the critical features can be highlighted for the learners. This could possibly alleviate the problems encountered with the learners being in Stage One (Darden, 1999). Here, the critical components of the skill are already highlighted for the learners and the picture does not move. The learner can take as long as needed viewing one component before moving on to view the next component.
- The DartTrainer® software also has a ***Simulcam Mode*** that aids in putting two different trials of a skill next to each other for comparison. Using this feature, two trials from the same person can be synchronised side-by-side (or four trials can be viewed in a 2 x 2 window) in order to identify where there may be variability between performances. It is also possible to place the subject's trial next to that of a model performing the same skill. This will assist in highlighting the areas that a

learner may deviate from the optimal technique. This takes the notion of video-modelling a step further by presenting the model alongside the learner's own performance for the purpose of comparison. The research of Emmen et al. (1985) involved the use of videotape feedback with one of the experimental groups receiving both video modelling feedback as well as videotape feedback. This study used the videotape replay of the one followed by presentation of the other. With the ***Simulcam Mode***, it is possible to view attempts simultaneously on the same screen. The coach/sport scientist will then be able to note any deviations from the model in terms of temporal or biomechanical differences, and play them back for the performer to observe for him/herself.

Future Research

The results of the current study support previous research that found that there are no immediate significant improvements in performance when video-supported feedback is used, despite recent innovations in digital technology and the use of computer software packages. Future research is needed to establish the lower limit of the time of intervention needed in order for videotape feedback to produce significant improvements in kinematic, speed and/or accuracy variables of performance.

In addition to exploring the length of intervention period needed, research is also needed into the relative impact of this form of technology on learning at the different stages of skill development. For example, the effects are anticipated to be different for beginners when compared to experts, but the exact boundaries of those differences are not known.

It may be of importance in the future to investigate possible gender differences in the study of video-based feedback. There were significant differences between genders found in this research regarding effects on speed and selected kinematic variables. This discovery also opens the possibility that cultural differences may also be a source for future research topics.

The product that was used in the current study (DartTrainer, Dartfish®), has several features intended to support the analysis of skills. Only one of these features was used for the purposes of this study. It may be fruitful to investigate how the other features will affect the learning of skills. The product is useful in the analysis and presentation of skills, therefore making it useful to the coach and sport scientist. This will help them to make more accurate analysis and provide better, more effective support to the learner. It does, however, need to be established whether this product will benefit the learning of skills with the learner using the product.

Research also needs to be completed with other commercially available software packages that are available on the market. The use of technology is a welcome addition to sport science, but technology must be used thoughtfully. Until the boundaries and limitations of product usefulness are defined, the impact of technological advances of skill learning and the improvement of technique, speed and accuracy, will not be optimised.

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Appendix A

Results for biomechanical assessment Groups 1 and 2

Results for biomechanical assessment of Group 1 (verbal KP only)

Woman

PRE-INTERVENTION

Average Speed	61	Fastest Speed	66
Slowest Speed	55	Accuracy Points	4

	1	2	3	4	5	6	7	8	9	10
Knee flexion	177.5	178.3	178.8	178.9	179.3	173.2	171.9	175.6	174.9	178.1
Torso vs arm	93.7	99	129.5	88.9	125.2	79.3	102.1	91.3	97.5	101.6
Elbow at cocked	91.5	95.9	92.4	94	87.2	90	90	94.8	90.6	90.5
Elbow extension	107.1	124.7	151.1	107	133.7	96.8	112.8	85.5	124.4	118
Ball toss drop	64	63	53	49	68	48	67	55	78	69
Ball toss position	24	39	16	44	23	31	18	15	25	5

INTERVENTION - FEEDBACK GIVEN

Close stance
Use legs to extend up to contact
Keep wrist straight at cocked position
Bring racket in behind body on the way up to contact

POST INTERVENTION

Average Speed	54,2	Fastest Speed	59
Slowest Speed	50	Accuracy Points	6

	1	2	3	4	5	6	7	8	9	10
Knee flexion	170.6	174.7	178.9	174.2	176.7	178.6	177.1	179.5	174.6	177.4
Torso vs arm	137.1	111.1	131.9	128.3	148.4	143.1	131.6	118	126.2	122.7
Elbow at cocked	99	84.6	96.9	87.6	103.2	89	80.8	78.1	83.8	82.7
Elbow extension	164.3	138.1	163.5	153.6	164.2	167.8	149.4	152	146.8	146
Ball toss drop	51	69	74	48	63	84	96	87	82	62
Ball toss position	23	17	36	25	37	44	45	25	42	19

Results for biomechanical assessment of Group 1 (verbal KP only)

Man

PRE-INTERVENTION

Average Speed	135.4	Fastest Speed	149
Slowest Speed	121	Accuracy Points	8

	1	2	3	4	5	6	7	8	9	10
Knee flexion	123.8	127.8	122.6	125.8	122.6	125.8	121.3	120.7	126.1	124.4
Torso vs arm	114.3	126.9	123.6	123.3	127.5	118.3	124.9	116.6	112.1	114.4
Elbow at cocked	58.5	61.2	63.8	66.2	51.8	67.8	63.7	60.5	55.8	58.8
Elbow extension	170.2	166.6	162.6	166.5	165.1	158.1	169.1	171	168.3	160.5
Ball toss drop	67	28	34	29	35	26	33	44	34	35
Ball toss position	22	24	18	22	21	18	15	36	9	14

INTERVENTION - FEEDBACK GIVEN

Toss ball 10cm further right
Rotate shoulders more
Get hitting elbow higher in power position
Get elbow to lead racket up to contact for more racket speed

POST INTERVENTION

Average Speed	127.2	Fastest Speed	144
Slowest Speed	119	Accuracy Points	12

	1	2	3	4	5	6	7	8	9	10
Knee flexion	120.6	126.2	122.1	122.2	120.2	120.4	131.6	122.3	125.7	120.7
Torso vs arm	115.9	127.6	128.4	121.5	125.6	129.1	116.7	115.1	118.4	113
Elbow at cocked	77.5	63.2	71.6	51.8	65.6	60.7	62.3	73.6	62.2	56.5
Elbow extension	166.3	173.6	167.1	165.5	168.9	165	159.8	167	164.8	163.9
Ball toss drop	91	56	42	64	59	57	67	75	52	64
Ball toss position	-9	22	15	41	7	28	21	22	10	26

Results for biomechanical assessment of Group 1 (verbal KP only)

Woman

PRE-INTERVENTION

Average Speed	60.2	Fastest Speed	74
Slowest Speed	55	Accuracy Points	14

	1	2	3	4	5	6	7	8	9	10
Knee flexion	155.3	160.1	163.8	162.3	164.7	163.2	159.1	166	165.7	160.9
Torso vs arm	88.5	100.8	113.9	106.3	117.1	120.7	102.5	114.5	107.5	112
Elbow at cocked	129.9	142.4	118.4	137.9	124	126.5	129.9	126.3	126.9	131
Elbow extension	132.6	148	142.4	137.4	133.2	143.1	132.6	142.1	150.7	133.8
Ball toss drop	109	90	126	109	87	117	144	141	104	118
Ball toss position	9	17	1	9	12	11	40	-13	4	3

INTERVENTION - FEEDBACK GIVEN

Keep racket up in cocked position
Don't let ball drop too far - use legs to extend up to contact point
Get body moving in direction of target

POST INTERVENTION

Average Speed	60.4	Fastest Speed	67
Slowest Speed	55	Accuracy Points	11

	1	2	3	4	5	6	7	8	9	10
Knee flexion	159	173.5	161.7	156.7	176.1	167.8	162.8	156.9	159.4	166.7
Torso vs arm	94.4	100.8	110.3	102.5	155.6	109.1	138.2	121.6	111.9	114.4
Elbow at cocked	116.9	122	139.7	134.1	126.1	130.4	133	129.5	138.6	126
Elbow extension	152.3	139.1	141.1	148.6	145.3	140.6	162.3	139.1	145.5	142.8
Ball toss drop	162	158	115	145	195	129	171	149	102	142
Ball toss position	7	1	1	25	-11	-44	20	-7	5	11

Results for biomechanical assessment of Group 1 (verbal KP only)

Woman

PRE-INTERVENTION

Average Speed	65.1	Fastest Speed	82
Slowest Speed	30	Accuracy Points	11

	1	2	3	4	5	6	7	8	9	10
Knee flexion	161.4	148	143.3	143.3	152.3	162	151.6	146.9	157.8	151.1
Torso vs arm	106.2	99.7	128	120.1	114.2	117.6	131.1	119.6	96.6	126.1
Elbow at cocked	99	112.8	109.7	120	111.9	101.4	99.9	106.1	113.6	113.1
Elbow extension	145.2	129.3	149.2	158.5	147	142.7	159.7	147	123.9	143.5
Ball toss drop	161	131	169	117	148	146	130	130	164	162
Ball toss position	-39	46	-19	48	54	-5	-39	-7	18	25

INTERVENTION - FEEDBACK GIVEN

Close stance
Toss ball further forward and lower
Keep wrist straight in power position

POST INTERVENTION

Average Speed	79.5	Fastest Speed	83
Slowest Speed	69	Accuracy Points	11

	1	2	3	4	5	6	7	8	9	10
Knee flexion	151.2	155.2	151.6	164.4	159.1	147.7	153.6	143.9	143.8	150.5
Torso vs arm	125.5	122.4	130.2	114.3	113.7	125.7	125.2	118.4	126.8	124.5
Elbow at cocked	102.4	101.7	106.2	105.3	103	105.5	111.2	116.3	88.5	97.3
Elbow extension	146.7	146.3	158.1	141.8	151	148.9	158.8	140.8	148.9	151.3
Ball toss drop	136	165	155	142	142	155	145	144	160	178
Ball toss position	-42	-9	49	-45	-11	13	9	-7	51	11

Results for biomechanical assessment of Group 1 (verbal KP only)

Man

PRE-INTERVENTION

Average Speed	79,7	Fastest Speed	94
Slowest Speed	54	Accuracy Points	12

	1	2	3	4	5	6	7	8	9	10
Knee flexion	153.8	143.5	155.5	145.1	157.4	153.2	162.3	149	150.6	161.5
Torso vs arm	125.5	142.4	149.3	124.6	142.1	149.5	145.2	146.6	142.4	143.2
Elbow at cocked	91.8	67.3	71.5	77.2	66	67.1	63.8	73.9	65.7	52.9
Elbow extension	162.8	171.2	177.8	171.3	174.3	176.1	172.3	173.3	170	179.5
Ball toss drop	22	28	24	36	20	37	33	53	45	32
Ball toss position	17	23	3	15	17	15	29	13	23	9

INTERVENTION - FEEDBACK GIVEN

Toss ball 10cm higher
Use deeper knee bend to explode into contact
Pronate into contact

POST INTERVENTION

Average Speed	103	Fastest Speed	114
Slowest Speed	72	Accuracy Points	17

	1	2	3	4	5	6	7	8	9	10
Knee flexion	145.2	138.5	151.4	147.3	156.7	153.7	145.6	153.6	148.2	143.4
Torso vs arm	133.3	136	136.5	135.1	141	150	140.5	139.8	138.2	138.6
Elbow at cocked	88.5	75.7	68.5	70.7	71.5	73.7	70.8	62.7	60.2	70.7
Elbow extension	177.5	172.4	176.9	168.8	173.3	179.6	176.2	176.1	168.8	169.2
Ball toss drop	38	56	42	32	33	42	53	35	44	48
Ball toss position	31	40	44	10	36	-2	36	34	26	36

Results for biomechanical assessment of Group 1 (verbal KP only)

Man

PRE-INTERVENTION

Average Speed	95.8	Fastest Speed	102
Slowest Speed	87	Accuracy Points	8

	1	2	3	4	5	6	7	8	9	10
Knee flexion	140.1	130.3	133.9	138.7	139.4	132.9	142.6	132.5	142.2	132.5
Torso vs arm	126.3	115.1	121.3	130.4	123.4	123.7	117.8	116.4	125.5	113.1
Elbow at cocked	93.7	95.4	98.7	107	114.4	87	97.8	97.3	91.1	80.5
Elbow extension	175.6	168.3	173.5	174.5	173.8	170.4	164.1	173.6	173.6	161.1
Ball toss drop	41	37	34	44	32	42	43	39	30	61
Ball toss position	59	29	29	25	11	22	50	-7	22	54

INTERVENTION - FEEDBACK GIVEN

Toss ball 20cm further forward and 15cm more to right
Rotate shoulders more
Extend up into contact, keeping tossing arm closer to body

POST INTERVENTION

Average Speed	91.1	Fastest Speed	107
Slowest Speed	83	Accuracy Points	8

	1	2	3	4	5	6	7	8	9	10
Knee flexion	132.8	142.4	141.2	143	131.8	125.5	135.4	132.8	140.4	142.3
Torso vs arm	120	112.6	121.1	126.4	107.6	124.4	129.1	122.3	109.4	118
Elbow at cocked	89.5	80.4	88.2	99.5	82.7	84.2	89	76.4	88.4	90.7
Elbow extension	167.8	173.7	170.7	175	169.2	171.4	178.6	174.6	158.6	173.2
Ball toss drop	51	43	26	39	53	64	53	57	41	51
Ball toss position	28	-18	22	26	15	35	43	11	38	50

Results for biomechanical assessment of Group 1 (verbal KP only)

Woman

PRE-INTERVENTION

Average Speed	63.2	Fastest Speed	71
Slowest Speed	53	Accuracy Points	6

	1	2	3	4	5	6	7	8	9	10
Knee flexion	166	175	177.3	170.8	171	165.3	170.1	166.6	171.7	173.3
Torso vs arm	158.6	157	164.7	166.9	148.4	169.2	155.6	174.4	165.5	152
Elbow at cocked	160.8	136.1	133.5	132.5	142.3	136.8	135.6	126.8	133.8	122
Elbow extension	153.7	166.1	167.9	165.4	151.3	170.4	163.9	178.1	176.6	150
Ball toss drop	24	45	41	26	37	53	41	35	41	24
Ball toss position	1	43	40	16	14	47	20	21	32	3

INTERVENTION - FEEDBACK GIVEN

Close stance
Toss ball higher and 10cm further back
Don't hyperextend the wrist in the cocked position

POST INTERVENTION

Average Speed	64.8	Fastest Speed	75
Slowest Speed	48	Accuracy Points	12

	1	2	3	4	5	6	7	8	9	10
Knee flexion	174.8	174.8	175.8	170.9	177.4	171.9	171.8	136.6	132.1	123.8
Torso vs arm	159.4	167.3	157	154.9	166.5	159	159.2	163.6	168.8	166
Elbow at cocked	137.2	126	128.6	150.8	134.8	136.3	132.9	177.4	170.3	168.7
Elbow extension	170.5	177.6	176.3	163.7	172.2	165.1	171.3	158.5	171	179.6
Ball toss drop	36	19	31	21	41	45	40	38	46	34
Ball toss position	40	10	38	22	22	36	24	20	23	37

Results for biomechanical assessment of Group 1 (verbal KP only)

Man

PRE-INTERVENTION

Average Speed	101.6	Fastest Speed	113
Slowest Speed	73	Accuracy Points	6

	1	2	3	4	5	6	7	8	9	10
Knee flexion	125.1	136.5	124.4	137.8	130.1	129.7	136.1	127.4	129.8	132
Torso vs arm	127.7	126.7	126.5	128.5	118.3	144.3	135.8	126.6	124.2	124.5
Elbow at cocked	135	137.1	133.2	142.4	144.1	143.4	141.3	144.9	157.9	145.3
Elbow extension	163.5	169.3	173.3	174.8	162.0	164.7	173.9	170	170.5	171.6
Ball toss drop	42	32	44	27	29	30	27	45	35	39
Ball toss position	45	42	21	18	29	8	30	22	6	47

INTERVENTION - FEEDBACK GIVEN

Rotate shoulder more
Start to bend knees after toss, to get better extension to contact
Toss ball 15cm higher

POST INTERVENTION

Average Speed	95.4	Fastest Speed	104
Slowest Speed	87	Accuracy Points	5

	1	2	3	4	5	6	7	8	9	10
Knee flexion	140.9	127.7	147.8	135.6	141.6	145.4	142.9	142.2	134.2	140.4
Torso vs arm	119.3	125.4	127.8	123.9	124.1	120.6	122.9	117.3	132.3	129.2
Elbow at cocked	135	127.4	121	124.9	136.8	148.2	138.3	133.7	136	146.7
Elbow extension	161.8	154.5	156.5	160.6	164.1	164.7	168.9	159.6	162.6	174.2
Ball toss drop	48	60	56	60	40	45	53	42	42	52
Ball toss position	8	32	31	5	8	6	9	-5	10	8

Results for biomechanical assessment of Group 1 (verbal KP only)

Woman

PRE-INTERVENTION

Average Speed	37,1	Fastest Speed	43
Slowest Speed	32	Accuracy Points	19

	1	2	3	4	5	6	7	8	9	10
Knee flexion	151	168.7	165.6	161.7	160.9	169.3	172.1	165.9	162.3	170.5
Torso vs arm	157.7	137.7	148.2	155	150.6	153.7	146.3	145.8	154.1	159.4
Elbow at cocked	170.4	166.6	172.2	162.2	169.5	163.8	160.2	156.8	168.9	161.6
Elbow extension	173	168.5	178.4	172	176.9	169.3	176.8	162.8	177.6	175.5
Ball toss drop	75	61	56	81	67	80	64	86	57	57
Ball toss position	-13	23	19	-11	-4	-30	18	-29	36	-13

INTERVENTION - FEEDBACK GIVEN

Close stance
Toss ball 20cm higher
Rotate shoulders more
Swing racket in behind body to generate racket speed

POST INTERVENTION

Average Speed	52,6	Fastest Speed	58
Slowest Speed	44	Accuracy Points	3

	1	2	3	4	5	6	7	8	9	10
Knee flexion	154.3	150.9	161.2	168.4	153.8	161.2	161	154.8	161.1	164.3
Torso vs arm	156.7	147.3	132.8	149	155.5	134.5	125.6	144.1	146.3	144.4
Elbow at cocked	134.2	136.5	107.7	98.7	138.4	120.7	128	148.5	148.9	113.1
Elbow extension	178.5	168.5	155.8	177.4	179	159.8	135.5	175.5	170	164.2
Ball toss drop	83	80	105	95	104	107	102	37	96	94
Ball toss position	54	-7	-6	-4	57	14	-15	-5	19	-6

Results for biomechanical assessment of Group 1 (verbal KP only)

Man

PRE-INTERVENTION

Average Speed	122.8	Fastest Speed	129
Slowest Speed	111	Accuracy Points	19

	1	2	3	4	5	6	7	8	9	10
Knee flexion	126.3	128.3	120.5	126.2	116.7	137.6	119.6	126	124.5	120.9
Torso vs arm	121.6	110.8	117.5	120.8	116.1	119.5	122.7	125.5	118.9	123.4
Elbow at cocked	68.8	69.4	69	63.8	66.3	67.5	68.8	70.7	62.9	72.9
Elbow extension	167.5	156.8	165.2	170.6	164.5	160.6	164.2	161.3	158	166.4
Ball toss drop	95	82	77	81	102	108	112	101	99	106
Ball toss position	41	50	53	40	52	51	58	59	75	49

INTERVENTION - FEEDBACK GIVEN

Use deeper knee bend to explode into ball
Rotate shoulders and hips a bit more during the toss phase

POST INTERVENTION

Average Speed	121.3	Fastest Speed	130
Slowest Speed	116	Accuracy Points	5

	1	2	3	4	5	6	7	8	9	10
Knee flexion	116	116.3	111	117.7	128	119.2	117.4	120.9	117.9	118.3
Torso vs arm	121.6	118.7	116.6	117.2	115.9	120.7	118.4	112.2	123.2	126.5
Elbow at cocked	68.5	74.4	65.2	63	66.8	69.9	66.5	66.7	68.5	71.1
Elbow extension	168.5	168.9	145.5	168.6	172.5	171.3	166.5	164.8	170.2	160.7
Ball toss drop	78	83	83	80	90	73	77	77	86	72
Ball toss position	56	49	50	42	54	42	65	59	55	44

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Woman

PRE-INTERVENTION

Average Speed	84,6	Fastest Speed	90
Slowest Speed	77	Accuracy Points	13

	1	2	3	4	5	6	7	8	9	10
Knee flexion	136.6	138.2	154.4	150.3	152.7	153.3	144.2	154.8	145.3	149.6
Torso vs arm	125.7	106.8	112.9	122.5	123.1	124.4	116.2	128.2	104	119.7
Elbow at cocked	97.1	96.6	97.6	97	93.4	111.8	110.3	104.1	108.8	100
Elbow extension	159.8	139.6	142.6	142.1	135.4	140.5	150.1	134	156.5	145.6
Ball toss drop	85	88	101	84	123	76	73	83	71	95
Ball toss position	-11	-31	-21	-40	-23	32	45	-23	16	13

INTERVENTION - FEEDBACK GIVEN

Close stance
Toss ball 15cm further forward and 20cm to the left
Don't hyperextend wrist in cocked position

POST INTERVENTION

Average Speed	82,8	Fastest Speed	94
Slowest Speed	66	Accuracy Points	18

	1	2	3	4	5	6	7	8	9	10
Knee flexion	142	155	160.1	149.4	147.2	164.1	142.3	150.7	154	153.7
Torso vs arm	126.8	117.4	113.2	117.9	120.5	121.3	114.3	125.8	124.7	122.5
Elbow at cocked	77.5	75.4	94.9	88.8	82.4	75.8	87.4	81.4	86.6	85.3
Elbow extension	158.9	131.2	140	150.2	137.5	134.8	150.6	147.7	147.3	146.3
Ball toss drop	106	115	94	95	119	140	101	98	91	114
Ball toss position	27	-4	22	9	4	11	59	5	51	28

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Man

PRE-INTERVENTION

Average Speed	129.7	Fastest Speed	138
Slowest Speed	118	Accuracy Points	17

	1	2	3	4	5	6	7	8	9	10
Knee flexion	134.5°	136°	136.8°	133.1°	130.5°	137.7°	135°	144°	133.8°	157.6°
Torso vs arm	128.1°	149.6°	131.6°	132.9°	133°	152.3°	143°	142.8°	148.8°	132.4°
Elbow at cocked	78.4°	62.1°	81.8°	82.3°	85.9°	76.3°	76°	75.4°	81.7°	74.9°
Elbow extension	166.2°	172.7°	167.7°	167.7°	167.2°	167.5°	167.4°	174.4°	170.8°	171.4°
Ball toss drop	44cm	37cm	63cm	59cm	51cm	39cm	39cm	70cm	50cm	42cm
Ball toss position	38cm	30cm	32cm	24cm	29cm	32cm	32cm	25cm	18cm	21cm

INTERVENTION - FEEDBACK GIVEN

Get body moving in direction of target
Toss ball 10cm further to right of head
Rotate shoulders more

POST INTERVENTION

Average Speed	124.8	Fastest Speed	139
Slowest Speed	77	Accuracy Points	12

	1	2	3	4	5	6	7	8	9	10
Knee flexion	143.7°	149°	162.3°	142.8°	136.8°	139.4°	141.1°	146.5°	134.7°	131.8°
Torso vs arm	132.3°	142.5°	133°	129.4°	140.7°	138.9°	135°	135°	143.7°	143.1°
Elbow at cocked	75.5°	89.1°	83.5°	70.2°	82.3°	80.6°	81°	77.9°	82.8°	68.4°
Elbow extension	173.9°	176.8°	176°	167.6°	171.9°	178.2°	174.1°	167.6°	173.8°	178.1°
Ball toss drop	65cm	65cm	49cm	82cm	51cm	56cm	56cm	53cm	71cm	60cm
Ball toss position	30cm	13cm	20cm	18cm	18cm	24cm	24cm	15cm	25cm	24cm

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Woman

PRE-INTERVENTION

Average Speed	68.9	Fastest Speed	83
Slowest Speed	52	Accuracy Points	2

	1	2	3	4	5	6	7	8	9	10
Knee angle	178.6°	178.8°	171.4°	173.2°	175.5°	178.6°	175.2°	169.8°	173°	172.4°
Torso vs arm	132.2°	131.7°	130.2°	133.8°	110.9°	118.2°	144.9°	117°	118.5°	122.5°
Elbow at cocked	87.6°	95.7°	114.1°	85.3°	79.1°	84.3°	98.4°	95.1°	116.6°	102.3°
Elbow extension	157°	136°	155.5°	161.6°	131.3°	146°	163.2°	128.9°	124.7°	120.1°
Ball toss drop	121cm	196cm	175cm	196cm	126cm	211cm	167cm	200cm	156cm	220cm
Ball toss position	64cm	93cm	-54cm	146cm	63cm	104cm	-52cm	152cm	60cm	112cm

INTERVENTION - FEEDBACK GIVEN

Stance too open
Keep racket up at power position (wrist hyperextended)
Bend knees and extend into contact area

POST INTERVENTION

Average Speed	61.3	Fastest Speed	83
Slowest Speed	12	Accuracy Points	1

	1	2	3	4	5	6	7	8	9	10
Knee angle	175.8°	177.5°	178°	179.3°	178.1°	176.2°	174.6°	175.7°	175.1°	177.1°
Torso vs arm	121.2°	126.2°	125.4°	119.1°	121°	122.7°	124.3°	125.3°	125.1°	127.3°
Elbow at cocked	99.5°	111.4°	121°	108.4°	105.4°	106.7°	65.8°	108.2°	88.2°	113.2°
Elbow extension	150.9°	123.5°	153.4°	133.9°	147.2°	130.1°	131.2°	137.3°	125.3°	143.9°
Ball toss drop	167cm	226cm	115cm	174cm	143cm	204cm	132cm	143cm	185cm	159cm
Ball toss position	11cm	11cm	0cm	11cm	50cm	75cm	18cm	68cm	52cm	22cm

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Man

PRE-INTERVENTION

Average Speed	71.1	Fastest Speed	77
Slowest Speed	61	Accuracy Points	6

	1	2	3	4	5	6	7	8	9	10
Knee flexion	162.4°	144.2°	169.7°	166.6°	157.2°	155.9°	155.8°	166.6°	170.1°	156°
Torso vs arm	88.3°	154.3°	144.1°	145.4°	154.1°	148.8°	140.5°	139.7°	135.1°	141.3°
Elbow at cocked	56.3°	46.6°	55.7°	51.4°	48.6°	56.5°	49°	43.9°	47.7°	52.1°
Elbow extension	160°	174.7°	166.4°	168°	174.5°	176°	163.5°	176.2°	167.6°	174.1°
Ball toss drop	157cm	138cm	122cm	116cm	132cm	133cm	132cm	170cm	139cm	118cm
Ball toss position	41cm	28cm	22cm	45cm	46cm	47cm	40cm	42cm	14cm	45cm

INTERVENTION - FEEDBACK GIVEN

Toss ball lower
Increase angle of elbow at cocked position
Bend knees more

POST INTERVENTION

Average Speed	63.4	Fastest Speed	75
Slowest Speed	54	Accuracy Points	16

	1	2	3	4	5	6	7	8	9	10
Knee flexion	174.4°	157.2°	157.8°	148.8°	168.7°	163.8°	150°	159.9°	171.5°	159.4°
Torso vs arm	136°	112°	140.3°	145.1°	131.5°	129.4°	134.5°	149.9°	143.1°	136.6°
Elbow at cocked	56.2°	41.2°	44.4°	49.8°	35.8°	39.1°	49.1°	49.6°	36.4°	47.1°
Elbow extension	167.5°	142.3°	159.3°	171.7°	172.4°	159.6°	173.4°	171°	169°	170.8°
Ball toss drop	110cm	96cm	130cm	107cm	123cm	107cm	114cm	85cm	128cm	86cm
Ball toss position	55cm	25cm	51cm	40cm	45cm	64cm	63cm	33cm	39cm	56cm

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Man

PRE-INTERVENTION

Average Speed	100.1	Fastest Speed	117
Slowest Speed	77	Accuracy Points	14

	1	2	3	4	5	6	7	8	9	10
Knee flexion	136.9°	148.8°	148°	158.9°	145°	153.2°	92.7°	150.4°	144.1°	153.8°
Torso vs arm	124.6°	132.6°	123.9°	133.8°	120.1°	125.5°	130.7°	129.1°	119.2°	124.5°
Elbow at cocked	83.2°	73°	83.1°	89.2°	84.2°	72.9°	157.2°	82.5°	83.9°	84.2°
Elbow extension	149.5°	161°	146.7°	164.1°	151.8°	153.4°	152.7°	159.7°	140.9°	159.8°
Ball toss drop	20cm	20cm	21cm	24cm	29cm	28cm	20cm	18cm	25cm	11cm
Ball toss position	25cm	24cm	34cm	20cm	33cm	25cm	23cm	32cm	43cm	24cm

INTERVENTION - FEEDBACK GIVEN

Toss 10-15cm further forward.
Rotate shoulders more.
Drop racket head further behind back.

POST INTERVENTION

Average Speed	98.8	Fastest Speed	114
Slowest Speed	77	Accuracy Points	6

	1	2	3	4	5	6	7	8	9	10
Knee flexion	148.5°	144.3°	145.4°	159.1°	147.5°	141.1°	146.5°	139.1°	135.7°	147.2°
Torso vs arm	131.3°	132.9°	135.8°	126.5°	120.2°	123.4°	133.5°	113.3°	117.6°	121.9°
Elbow at cocked	66.8°	72.1°	74.4°	75.8°	79.6°	80.7°	75.2°	81°	71.8°	74.6°
Elbow extension	162.9°	159.3°	164.7°	152.4°	153.7°	159.9°	166.4°	156.5°	148.1°	160.3°
Ball toss drop	48cm	51cm	29cm	35cm	26cm	41cm	37cm	28cm	39cm	36cm
Ball toss position	63cm	73cm	47cm	44cm	42cm	46cm	49cm	46cm	64cm	60cm

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Woman

PRE-INTERVENTION

Average Speed	108,3	Fastest Speed	120
Slowest Speed	99	Accuracy Points	4

	1	2	3	4	5	6	7	8	9	10
Knee flexion	155.2°	154.7°	152.4°	143.7°	151.8°	152.5°	153°	163.4°	151.7°	150.8°
Torso vs arm	126.7°	138.8°	130.5°	125.7°	130.7°	131.3°	138.6°	137.9°	134.8°	134.8°
Elbow at cocked	96.8	92.3°	104°	89.2°	104.5°	101.9°	97.5°	97.3°	102.6°	93.7°
Elbow extension	167.4°	171°	171.5°	161.2°	164.8°	173.2°	176°	174.7°	172.4°	168.5°
Ball toss drop	121cm	77cm	79cm	76cm	51cm	88cm	63cm	84cm	74cm	68cm
Ball toss position	67cm	32cm	71cm	45cm	14cm	67cm	17cm	38cm	24cm	34cm

INTERVENTION - FEEDBACK GIVEN

Use knees more to explode up to ball
Use full follow through across body to non-hitting arm side

POST INTERVENTION

Average Speed	119,1	Fastest Speed	129
Slowest Speed	110	Accuracy Points	2

	1	2	3	4	5	6	7	8	9	10
Knee flexion	152.6°	151.2°	156°	156.4°	164.3°	160.5°	152.7°	158.8°	158°	152.4°
Torso vs arm	130.4°	146.6°	145.4°	132.1°	129.4°	135.2°	136.2°	133.3°	129.5°	131.5°
Elbow at cocked	110.3°	106°	108.4°	98.1°	90.3°	98.7°	89.2°	100.1°	104.8°	96°
Elbow extension	175.4°	175.3°	174.1°	164.3°	168.7°	170.4°	172.3°	176.1°	177.3°	169.3°
Ball toss drop	101cm	77cm	99cm	91cm	79cm	84cm	92cm	88cm	73cm	81cm
Ball toss position	60cm	60cm	20cm	37cm	41cm	49cm	12cm	44cm	53cm	21cm

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Woman

PRE-INTERVENTION

Average Speed	64,6	Fastest Speed	73
Slowest Speed	56	Accuracy Points	10

	1	2	3	4	5	6	7	8	9	10
Knee flexion	172.1	175.2	171.6	175.9	172.1	172.6	169.1	171.6	179.7	173
Torso vs arm	107.2	115.5	113.4	135.8	113.4	129	116.9	129.1	103.9	135.7
Elbow at cocked	121	126.7	130.6	130.2	122.1	126.7	130.3	115.7	116.7	111.8
Elbow extension	134.6	149	141.2	170.1	111.7	153.7	133.6	145.3	141.4	159.7
Ball toss drop	56	59	51	52	57	47	65	57	72	54
Ball toss position	27	3	37	33	20	5	7	25	7	18

INTERVENTION - FEEDBACK GIVEN

Close stance
Don't hyperextend wrist in power position
Use knees to reach up to ball

POST INTERVENTION

Average Speed	62,3	Fastest Speed	73
Slowest Speed	57	Accuracy Points	4

	1	2	3	4	5	6	7	8	9	10
Knee flexion	171.5	177.4	174.3	172.5	173.4	170.8	176.6	176.2	173.1	178.9
Torso vs arm	125.4	134.6	123.3	119.5	127.4	115.4	111.8	120.4	122.4	127.5
Elbow at cocked	134.7	126.9	114.4	122.9	124.7	120.4	127.3	129.5	130.1	121.1
Elbow extension	137.8	168.8	173.2	158.4	163.7	174.3	147.8	152.4	154.3	148.3
Ball toss drop	115	124	116	111	98	106	107	90	72	106
Ball toss position	-22	-64	22	53	3	33	-30	3	-10	15

Results for biomechanical assessment of Group 2 (verbal with video supported KP)

Woman

PRE-INTERVENTION

Average Speed	81.9	Fastest Speed	92
Slowest Speed	72	Accuracy Points	19

	1	2	3	4	5	6	7	8	9	10
Knee flexion	142	140.1	141.2	146.5	140	139.7	130	134.7	137.9	134.2
Torso vs arm	168.7	150.4	163.1	154	155.4	134.4	135.9	113.2	171.5	158.7
Elbow at cocked	115.5	119.6	125.4	114	110.8	108.2	114.3	124.9	131.2	130.1
Elbow extension	172.8	140.3	160.4	155.6	155.4	153.2	151.6	145.6	151.5	150.8
Ball toss drop	112	115	99	99	85	101	125	102	74	128
Ball toss position	18	43	-7	11	3	13	31	2	26	59

INTERVENTION - FEEDBACK GIVEN

Stance too open to court – will not get horizontal rotation of shoulders and hips
Toss ball approximately 10cm further forward
Wrist hyperextending in power position
Tuck tossing arm into body earlier

POST INTERVENTION

Average Speed	87.2	Fastest Speed	96
Slowest Speed	79	Accuracy Points	3

	1	2	3	4	5	6	7	8	9	10
Knee flexion	165.7	152.2	148.2	152.2	154.2	156.3	155.5	144.5	145.7	141.3
Torso vs arm	124.7	133.2	131.5	144.5	135.6	134.6	125.2	135.8	137	139.8
Elbow at cocked	120.2	107.2	118.2	126	128.9	120.1	137.9	114.1	116	107.5
Elbow extension	160.7	158.5	154.9	170.4	156.3	161.1	163.8	155.8	154.2	156
Ball toss drop	124	130	120	112	106	116	106	88	91	105
Ball toss position	43	44	29	21	28	14	5	48	51	68