EFFECTS OF AUGMENTED REAL-TIME AUDITORY FEEDBACK ON TOP-LEVEL PRECISION SHOOTING PERFORMANCE

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This study examined the effects of training with real-time auditory feedback in precision shooting. Top-level shooters (N=9) were randomly assigned to the feedback or non-feedback group. Each group performed a pre-test, a 4-week training intervention and a post-test. The feedback group was provided with augmented real-time auditory feedback based on postural and rifle barrel stability during training sessions. Increases in performance were measured through changes in postural stability, rifle barrel stability, shot outcome and shot group diameter. Real-time auditory feedback did not increase postural or rifle barrel stability in the feedback group. No meaningful differences were found related to shot outcome or shot group diameter in air rifle testing. The feedback group was able to reduce shot group diameter during smallbore testing. In summary, the augmented real-time auditory feedback did not improve postural or rifle barrel stability. Future research should focus on examining the effects of auditory feedback on smallbore performance.

KEYWORDS: precision shooting, auditory feedback, postural stability, rifle barrel stability, knowledge of performance

Stacy Marie Underwood

April 20, 2009
EFFECTS OF AUGMENTED REAL-TIME AUDITORY FEEDBACK ON TOP-LEVEL PRECISION SHOOTING PERFORMANCE

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EFFECTS OF AUGMENTED REAL-TIME AUDITORY FEEDBACK ON TOP-LEVEL PRECISION SHOOTING PERFORMANCE

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science in the College of Education at the University of Kentucky

By

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Lexington, Kentucky

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Lexington, Kentucky

2009

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Chapter One: Introduction

Introduction

Precision shooting is a competitive sport that integrates body control, skill and focus at the highest level. Success in the sport is based on the ability to repeatedly synchronize all components to hit a small target (i.e. one millimeter in the air rifle event). Four of the five rifle events (i.e. Men and Women’s Air Rifle and Three Position Rifle) include the standing position, the least stable position for shooting. The large component of standing in a given event requires an athlete to become not only proficient, but exceptional in standing position shooting to be victorious.

Unlike other athletic events, a systemic method of training based on scientific evidence has yet to be created. The absence of standardized training is mostly due to the lack of research for precision shooting. Therefore most shooting athletes base their training methods on anecdotal evidence from other athletes or coaches. Training times, frequencies, positions and shot plans are created based on what worked for others or trial and error by the shooter. This can be frustrating for both athlete and coach if improvement in performance is slow or inconsistent. Further investigation of the progression of skill from novice to top-level shooter would create a better understanding of how to train.

From the research that has previously been conducted, some understanding of what makes an elite shooter has been compiled. One major distinction in skill level is the ability to minimize postural sway during the seconds preceding a shot (Era et al., 1996). Furthermore, a top-level shooter focuses on creating rifle stability and only fires when this condition is achieved (Konttinen et al., 2000).
This information has led to more recent studies conducted to determine training methods to further develop novice and top-level shooters using augmented feedback. Many areas still require further investigation to provide conclusive results such as the use of live fire to allow for barrel recoil effect and follow through that previously have not been included. Also, the use of top-level shooters in training studies will offer a more complete understanding of how to develop these athletes.

It is my hypothesis that training focusing specifically on the fundamental elements of shooting will develop a high skill leveled shooter. Specifically, if a shooter trains with a system that provides real-time auditory feedback on postural and barrel stability the shooter will increase performance through improving overall score. Currently no such training system is commercially available or has been investigated.

**Statement of Problem**

To investigate the effects of augmented real-time auditory feedback on shooting performance in top-level shooters.

**Purpose**

The purpose of this study was to investigate innovative training methods. Two questions are to be answered.

1. What effect does auditory feedback have on postural and barrel stability?
2. What effect does auditory feedback have on shot outcome and shot group diameter?
Hypotheses

1. After feedback training, subjects will decrease postural and barrel sway and the control group will remain unchanged.

2. After feedback training, subjects will increase performance based on shot outcome and the control group will remain unchanged.

3. After feedback training, subjects will decrease shot group diameter and the control group will remain unchanged.

Significance of the Study

While it is known that decreasing postural and barrel sway aids in improving performance, no training methods or systems are currently available to provide information on how to change to achieve these goals. Auditory feedback has been shown to increase performance in novice shooters (Konttinen et al., 2004). No study has used real-time auditory feedback for postural and rifle stability during live fire in top-level shooters.

Delimitations

There are a number of criteria that were controlled as delimiting factors for this study. They are as follows:

1. Small sample size of 5 subjects in the intervention and 4 subjects in the control groups.
2. Highest match score greater than 580/600 and 570/600 in air rifle and 50 foot smallbore, respectively, equating to a U.S. ranking of about 30th to 45th and 20th to 30th in collegiate shooting, respectively.

3. Four weeks of training with air rifle for 20 shots, twice a week

Limitations

1. Training for other shooting events was not controlled.

2. Performance anxiety due to testing environment.

3. Data was lost for some of the pre-test due to a software error during collection.

4. Sensitivity/ type of force plates used.

5. Sampling rate of cameras.


7. Identification of shot time.

Assumptions

1. Calibration of electronic targets is correct.

2. Subjects are proficient in the skills required to obtain a high level of performance and execute these skills successfully throughout the study.

3. Ammunition and equipment was of the appropriate quality.

Definitions

Definitions of terms and phrases used in this research are provided to avoid confusion.

Air rifle: Firearm that uses compressed air to propel a .177 caliber pellet.

Air rifle event: All shots are fired in the standing position. Women shoot 40 shots and
men shoot 60 shots for a total of 400 or 600 points, respectively. In collegiate
shooting all athletes shoot 60 shots regardless of gender.

Barrel: End of rifle at which the projectile exits. The sight sits on top of the barrel.

Finals: Individual winners are determined through event finals. Air rifle and three
position finals are fired in the standing position. Competitors fire 10 shots on timed
commands. Each scoring ring is divided into 10 sections. The highest possible score for
a shot is 10.9 points and an aggregate of 109.0 points.

Live fire: The use of live ammunition or air rifle pellets.

Record shots: Shots fired during competition that count towards the competitor’s score
aggregate.

Three position smallbore: Competitor’s fire from the prone, standing and kneeling
positions. Men and women fire 20 (i.e. 3 x 20=600 point aggregate) and 40 (i.e. 3
x 40=1200 point aggregate) shots, respectively, in each position.

Shot group diameter: The diameter (mm) that encompasses all shots in a 20 shot series

Shot outcome: The value given to an individual shot based on the distance to the center of
the target. The highest score possible is 10 points, or 10.9 points during finals
events.

Sighting Shots: Shots fired before record shots to make sight corrections. Shots fired
during this time are not recorded towards competitor’s score aggregate. Also
referred to as “sighting in”.

Smallbore: A .22 caliber rifle used in the prone and three position events.
Chapter Two: Review of Literature

This chapter is divided into three sections. The first will discuss the performance requirements for successful shooting. The role of postural stability and rifle stability in novice and top-level shooters will be described in detail. Secondly, the theory regarding feedback, including type and frequency, will be examined. Finally, an assessment of current technology available to evaluate outcome and performance will be provided.

Articles will be discussed thematically throughout the review.

Performance Requirements

The transition from novice to elite in athletics is directly related to the development of skills critical to successful performance. To develop novice athletes, an extensive understanding of the elements that compose an elite performance is required. The current skill level of a novice athlete must be assessed to create a training plan. Current literature and empirical evidence has identified two main components for improved performance: postural stability and rifle barrel stability.

Postural Stability

Coaches in the sport of rifle will describe creating a balanced and stable position as crucial. As body sway increases, the magnitude of error created at the line of fire is amplified by the time the bullet hits the target. Era et al.’s (1996) study provides support for the importance of postural stability during shooting. Subjects were required to fire 100-200 shots in the standing position. Postural stability during the best and worst shots
of various skill-level shooters from international, national and novice shooters were examined, Figure 2.1.

![Center of force graphs for various shooter levels](image)

**Figure 2.1**: Center of force for top-level male (A), top-level female (B), national level shooters (C) and control group (D) from Era et al.’s (1996) study. Note vertical axes are of different scales.

Distinct differences between the skill groups are evident. The top-level male shooters had initially smaller sway values at less than 2.5 mm²/s. Sway velocities steadily decreased leading up to the shot to velocities of less than 2 mm²/s. In this group,
there was no correlation between sway velocity and score. In other words, a bad shot was not the result of an increase in postural sway. The inexperienced group’s magnitude of movement was far greater 6.0 s before the shot, between 10-14 mm²/s. The group only reached sway velocities between 8-10 mm²/s before the shot; these values are significantly larger than initial sway velocities of top-level shooters. In other words, inexperienced shooters are unable to achieve a state of steadiness conducive to executing a good shot. Larger variation in postural stability was highly correlated with the bad shots. Postural stability alone could distinguish skill level of participants.

A closer examination of postural stability in novices was the focus of Mononen et al.’s (2007) research. Participants had previously undergone basic military marksmanship training including 250 shots. The shooting test required participants to fire 30 shots in sets of 10 with a 3 minute rest between sets. Postural sway was measured using force platforms and the Noptel ST 2000 Sport laser training system was used to determine shooting score and rifle barrel movement. Mononen et al. hypothesized that postural stability variables would be correlated with shot score in novice shooters.

Postural sway velocities were reported as 7.1±2.0 mm/s for anteroposterior (AP) and 7.9±1.9mm/s for mediolateral (ML) in novice shooters. When participants were pooled according to low or high variability in postural sway, the low variability group displayed stronger correlations between behavioral variables and performance. This trend lends support to the hypothesis that at a certain skill level, shot outcome is not affected by postural stability.

An investigation of similar behavioral variables for elite shooters was completed by Ball et al. (2003). Six members of the Australian Olympic Committee shooting team
fired 20 shots in the standing position. When performing an inter-individual analysis between body sway and performance no correlation was detected. Intra-individual analysis, however, presented a significant correlation for all subjects but the specific variable and time period that was significant was highly individualized (see Table 2.1).

**Table 2.1.** Regression equations predicting performance from body sway parameters for each subject in Ball et al.’s (2003) study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Shooter</th>
<th>$R^2$</th>
<th>$P$</th>
<th>Regression equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 s to shot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>R2</td>
<td>36.1</td>
<td>0.02</td>
<td>$11.7 - 0.34 \text{COP}<em>{x}\text{Range s5} - 0.84 \text{COP}</em>{y}\text{Range s5}$</td>
</tr>
<tr>
<td>PosX</td>
<td>R3</td>
<td>36.9</td>
<td>0.03</td>
<td>$5.83 + 0.26 \text{COP}<em>{x}\text{Range s5} - 2.93 \text{COP}</em>{y}\text{Range s5}$</td>
</tr>
<tr>
<td>PosZ</td>
<td>R6</td>
<td>23.0</td>
<td>0.03</td>
<td>$3.33 - 0.62 \text{COP}_{x}\text{Range s5}$</td>
</tr>
<tr>
<td>3 s to shot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score</td>
<td>R3</td>
<td>36.5</td>
<td>0.03</td>
<td>$11.1 + 0.28 \text{COP}<em>{x}\text{Range s3} - 1.64 \text{COP}</em>{y}\text{Range s3}$</td>
</tr>
<tr>
<td>Score</td>
<td>R5</td>
<td>37.2</td>
<td>0.02</td>
<td>$10.3 - 0.33 \text{COP}<em>{x}\text{Range s3} + 0.12 \text{COP}</em>{y}\text{Length s3}$</td>
</tr>
<tr>
<td>PosX</td>
<td>R3</td>
<td>40.9</td>
<td>0.02</td>
<td>$-1.42 - 0.73 \text{COP}<em>{x}\text{Range s3} + 4.7 \text{COP}</em>{y}\text{Range s3}$</td>
</tr>
<tr>
<td>PosZ</td>
<td>R5</td>
<td>33.2</td>
<td>0.03</td>
<td>$0.24 + 0.35 \text{COP}<em>{x}\text{Length s3} - 0.2 \text{COP}</em>{y}\text{Length s3}$</td>
</tr>
<tr>
<td>PosZ</td>
<td>R6</td>
<td>22.3</td>
<td>0.04</td>
<td>$2.45 - 0.47 \text{COP}_{x}\text{Range s3}$</td>
</tr>
<tr>
<td>1 s to shot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PosX</td>
<td>R2</td>
<td>28.2</td>
<td>0.02</td>
<td>$2.39 - 3.25 \text{COP}_{y}\text{Range s1}$</td>
</tr>
<tr>
<td>PosZ</td>
<td>R5</td>
<td>26.7</td>
<td>0.02</td>
<td>$0.42 + 0.67 \text{COP}_{x}\text{Range s1}$</td>
</tr>
</tbody>
</table>

The top-level shooters were able to increase stability in the seconds before trigger pull. This trend in top-level shooters was confirmed in the study by Ball et al. (2003). Inter-individual assessment of six elite shooters presented no correlation between body sway and performance. Furthermore, the magnitude of movement decreased as the shooter came closer to trigger pull. Elite shooters were able to stabilize their posture from a center of pressure of $3.3\pm0.8$ mm (ML), $1.2\pm0.4$ mm (AP) five seconds before the shot to $1.1\pm0.3$ mm (ML), $0.7\pm0.2$ mm (AP) one second before the shot. This finding validates the notion that result found in novice athletes cannot be extrapolated to elite athletes.
Rifle Barrel Stability

Due to the differences in postural stability the role of rifle stability during shooting for novice and top-level shooters is distinctive. The unstable nature of a novice’s position magnifies gun barrel movement and the movement pattern is more unpredictable. An elite shooter’s position allows for a stable foundation to create rifle stability. The pattern of movement tends to be more predictable creating an opportunity for more successful shots. Elite shooters can therefore be more critical of the shots they execute. Konttinen et al.’s (1998) evaluated the aiming strategy used to create rifle stability between novice and elite shooters. Differences in barrel amplitude between groups are presented in Figure 2.2.
Figure 2.2 Rifle barrel movement amplitude of elite and pre-elite shooters for high and low scoring shots in Konttinen et al.’s (1998) study, where W1 to W4 equates to windows encompassing the 7.5 s preceding triggering.

Two observations can be noted on the differences between the two groups. First the elite group starts at a steadier state with barrel movement amplitude of less than 14 mm. Secondly, the elite group is able to lower the amplitude to less than 10 mm by the time the shot is fired. Despite improving stability while aiming, the pre-elite group is never able to achieve an amplitude below 14 mm. Due to the differences in groups, analysis of rifle stability can be used to distinguish the skill level of subjects. Konttinen et al. determined that rifle stability was significantly related to shot outcome in both groups.
An analysis of brain function, based on preparatory slow brain potentials (SP) from electroencephalographic activity, during aiming reflected strategies unique to each group. The SP’s that were monitored were chosen based on empirical evidence that suggested the sites would best display psychomotor regulation during precision shooting. Konttinen et al. demonstrated that elite shooters achieved an “alert state of immobility” during aiming. This “state of being” allows the athlete to control posture and rifle movement as one unit. Therefore, when the rifle barrel is unstable, elite shooters exert more effort to control rifle movement and increase stability.

Pre-elite shooters were able to create a more stable rifle position when they exerted effort on motor regulation. The pre-elite shooter was more focused on firing at the first appropriate time rather than focusing on creating stability and waiting to fire. Konttinen et al. suggested that pre-elite shooters must focus on postural and rifle stability as two separate entities. Elite shooters are able to control the postural and rifle stability as one unit. This advantage allows for the elite shooter to perform in a “state of alert immobility” that allows for more specific selection of shots.

The aiming strategy of shooters was investigated in further detail in Konttinen et al.’s (2000) study. The subject pool was the same as the previously discussed study (i.e. Konttinen et al., 1998). Subjects fired 200 record shots in the standing position. Shots were categorized into high outcome (10.0-11.0), moderate outcome (9.0-9.9), low outcome (0.0-8.9) using a decimal scoring system. Score alone could differentiate groups with elite shooters producing higher scores (M=9.67, SD=0.77) than pre-elite shooters (M=9.21, SD=1.03).
A crucial time period was discovered for both groups between 300-400 ms before triggering. This time period was a determinant of the successfulness of the shot. The development of the shot outcome during this critical period could differentiate between the two groups. This was measured as the location of the barrel in the preceding 1 second divided into 100 ms time windows. Pre-elite shooters had a larger change in shooting results as the time of triggering approached. This group also started at a lower score allowing for a more pronounced increase (see Figure 2.3). The figure represents the theoretical value of the shot if fired at that moment.

**Figure 2.3.** Shot development for low, moderate and high outcome shots for two skill groups from Konttinen et al.'s (2000) study. Triggering windows are 100 ms periods with triggering window 1 referencing 100 ms before trigger pull.

Horizontal and vertical velocities of rifle stability were higher in pre-elite shooters in all shot categories. Elite shooters were able to maintain a more stable rifle hold during
aiming even in their low outcome shots. The elite shooter employed an aiming strategy that focused on not triggering until rifle stability was achieved. The pre-elite shooter did not focus on maintaining stability, instead the focus was on taking the first accurate shot that he/she saw.

Although elite shooters scored higher, both groups experience the same amount of triggering error. Triggering index of error was calculated taking the average result during the 300-400 ms before triggering and subtracting it from the actual shooting score. A negative score indicated inefficient triggering performance. Figure 2.4 shows that the elite shooters had lower triggering indexes in the moderate and high outcome shots, however, it was not as detrimental to score. Again, this is due to the elite shooters superior ability to maintain rifle stability.

![Figure 2.4.](image)

**Figure 2.4.** Triggering index of each skill group for three shot outcomes from Konttinen et al.’s (2000) study. A positive score indicates that the shot outcome was higher than in the preceding 300-400 ms indicating good triggering.
Summary of Performance Requirements

Differences in skill level in precision shooting can be assessed through analysis of postural and rifle barrel stability. In novice shooters, postural stability is correlated with shot outcome. Postural stability is correlated with shot outcome in elite shooters only through intra-individual analysis, with stability variables and times highly individualized for each shooter.

Rifle stability is correlated with shot outcome for all skill levels. Top-level shooters display more rifle stability initially during aiming and are able to further increase stability as the shot progresses. Rifle stability in the 300-400 ms before triggering is the best determinant of shot outcome in all skill levels. As skill level develops a shooter is better able to control postural and rifle barrel stability as one component and perform in a “state of alert immobility”.

Feedback Theory

Feedback training provides subjects with another source of information about performance. There are two main factors that constitute augmented feedback, type and frequency.

Type

Type refers to how feedback is provided to subjects, known as knowledge of results (KR) and knowledge of performance (KR) (Salmoni et al., 1984). KR is response produced feedback. It is limited because it only describes the outcome, not the process of how it
was achieved. Knowledge of performance (KP) refers to the movement pattern of the action. It provides information that would otherwise not be visible to the athlete or coach (e.g. aiming hold or weight distribution).

During training and competitions shooters use KR (i.e. shot outcome) as their primary source of feedback beside intrinsic feedback. However, KR for a shot does not instruct the shooter as to how that outcome was achieved. In shooting sports, KP is facilitated through the use of laser training systems (e.g. SCATT, NOPTEL).

The effective use of KR and KP was demonstrated in a training study using novice running target shooters (Viitasalo et al., 2001). Novice shooters were placed in one of four groups. The control group did not participate in any training between testing. One group received only KR in the form of shot outcome. Two groups, FB-I and FB-II, were provided with KR +KP. The KP was presented as photographs of elite shooters and personal coaching. FB-II was also provided with video of elite shooters and additional written information. It was concluded that KR and KR+KP improved performance based on shot outcome during the 12 weeks of training compared to the control group.

Along with the information provided from augmented feedback, the ability to alter the focus of attention from internal (i.e. the movement) to external (i.e. the effects of the movement) is of great importance. Shea et al.’s (1999) study requiring subjects to maintain their balance on a stabilometer demonstrated the importance of feedback, but also the focus of attention it created during learning. Subjects were stratified into four groups based on feedback (i.e. feedback or no feedback) and focus of attention (i.e. internal or external). The feedback group was provided with the same feedback display for the study, however the subjects were told that the feedback represented either their
feet (i.e. internal focus) or the marks on the board (i.e. external focus). Although the same feedback was provided, subjects in the feedback group with external focus performed the best in the post-test and retention test (see Figure 2.6).

**Figure 2.5.** Results of stabilometer training based on degrees out of balance from 0° reported as root mean square errors (RMSE) for 7 trials for practice (days 1 and 2) and retention (day 3) from Shea et al.’s (1999) study.

**Frequency**

The frequency of feedback provided to subjects is difficult to prescribe. In simple tasks (e.g. tasks that can be learned within one practice session or involve one degree of freedom) frequent feedback can be detrimental to performance. Subjects begin to rely on
the feedback instead of using intrinsic feedback to regulate performance. By reducing the proportion of feedback trials performance improves (Wulf et al., 2002). This improvement is due to the increased difficulty in practice as well as subjects learning to use intrinsic feedback.

However, learning of complex tasks (e.g. tasks that involve multiple degrees of freedom or multiple segments) is challenging in itself and the level of difficulty does not need to be increased during practice. In studies where subjects learned a task aided with feedback, reducing the frequency of feedback did not enhance the outcome (Wulf et al., 1998). The difficulty of synchronized multiple components to produce a skilled performance does not allow the individual to become dependent on the feedback (Wulf et al., 2002). In such cases, providing 100% concurrent feedback was the most effective for enhancing performance.

Mononen et al. (2003) reported results consistent with Wulf et al.’s (2002) study using novice shooters. In their study subjects were provided with 4 weeks of augmented kinematic feedback of post-KP. Feedback was provided in the form of aiming point trajectory on a screen. Subjects in the 100% KP group had a significantly higher mean shooting score (7.12) and had lower score variability (4.36) for the two day retention test compared to the other groups with no-KP (6.34, 5.27), 50%-KP (6.16, 5.30) and control (5.10, 6.45). No significant differences were evident in the 10 day retention test between groups suggesting that the effects may be temporary. Results of the training study are presented in Figure 2.7.
Figure 2.6. Mean shooting scores for the four knowledge of performance groups during the pre-test, acquisition and retention from Mononen et al.'s (2003) study.

Similar results were also achieved using real-time augmented auditory feedback to improve novice shooters scores (Konttinen et al., 2004). Real-time auditory feedback was provided as a measure of the distance between the aiming point and center of target and KR was given as the shot score. Subjects in the auditory feedback received 50%-auditory feedback during the shot and 100% KR after shot. The KR group received 100% KR and the control group performed no training. A strong learning effect (effects size, ES=1.71) was seen in the auditory feedback group versus control group for the pretest/posttest. The KR group measured a moderate learning effect (ES=0.64) for the same tests compared with the control. The 10 and 40 day retention also had a strong learning effect (ES= 1.06 and 1.20, respectively) for the auditory feedback group versus the control group. This suggests that the subjects did not become dependent on the feedback and the feedback was effective for training in novice shooters.
The success from Konttinen et al.’s study lends support for the use of auditory feedback with other skill levels. There are no current studies available on the effects of auditory feedback training using top-level athletes.

**Technology**

Training tools available for precision shooting are based on the primary components for successful shooting. Commonly shooters use photographs, laser training systems, and force plates to aid in training.

The use of photographs of a shooter’s position allows for critique by both shooter and coach. The ability to see the position can help the athlete create a vision of the position mentally. This is useful when trying to replicate the position throughout training and competitions. This strategy is useful because it is easy and inexpensive. It can also keep a visual record of each position as the shooter’s skill level progresses. The limitation of photographs is that the bulky shooting equipment often masks small details about the shooter’s actual position.

Shooters can also monitor progression in postural stability through the use of force platforms. Postural stability levels demonstrated by various skill levels can be used as a standard to compare the current level of the shooter. If postural stability is lower than desired balance training can be implemented. While force plates are a useful tool, few shooters have access to use them.

The most popular training aid for shooting athletes is a laser training system (e.g. SCATT, NOPTEL). These systems include an instrumented target holder and a laser transponder attached to the rifle barrel. A trace of the barrel’s movement around the
target in the seconds preceding a shot can provide the shooter with information regarding approach to the target, aiming hold and follow through.

The software provides post-analysis of a training session based on time of triggering. One of the more useful software tools is the theoretical results if triggering occurred at different times. Changing timing can increase performance without the need to make major changes to position or shot plan. Triggering earlier or later can increase the strength of shots from high 9’s (i.e. 9.8 or 9.9) to low 10’s (i.e. 10.0 or 10.1) which can significantly increase aggregate score.

Another useful feature of the software is the information regarding the amount of time the aiming hold was within the ten ring. This information can be useful in two ways. First, if a larger percentage (i.e. 90% of hold) of aiming is in the ten ring but frequent 9’s are still fired the problem may be due to errors in trigger pull or follow through. Second, if a smaller percentage (i.e. less than 80% of hold) of aiming is in the ten ring than the size of the aiming hold needs to be decreased. This can be achieved by increasing postural and barrel stability and correcting natural point of aim.

While useful information can be gained by training with laser systems, there are limitations. First, the accuracy of results reported by the system is questionable especially during live firing. Shooters will frequently report that shooting a “10” on the laser system is easier than on a real-target. Second, if used on a range when others are shooting, specifically smallbore, the system will detect their shots and provide false information. This can be reduced through proper calibration, but not always eliminated.
Summary

The integration of augmented feedback training, both KR and KP, has proven to be successful in improving performance in novice shooters. Development of a training system that provides augmented feedback on performance variables essential to successful shooting (i.e., postural and barrel stability) has the potential to progress the skill of both novice and top-level shooters. Furthermore, a system that can easily be modified to accommodate varying skill levels would be an invaluable tool for the development of shooters in college or national training facilities.
Chapter Three: Methods

Design and Subjects

A randomized-control quasi experimental design was employed to investigate the effects of augmented real-time auditory feedback on shooting outcome in top-level shooters. All procedures were approved by the University of Kentucky’s Institutional Review Board. Nine subjects were recruited from the University of Kentucky Rifle team. After signing informed consent (Appendix 1) they were randomly assigned to control (Mass (kg) = 73.9 ± 43.7; Height (cm) = 173.4± 10.2; High Air Rifle = 587.3 ± 4.9; High Smallbore = 584.0 ± 4.5) and experimental (Mass (kg) = 60.4 ± 8.2; Height (cm) = 164.6 ± 8.3; High Air Rifle = 591.4 ±3.4; High Smallbore = 580.8 ± 6.2) groups.

The inclusion criteria were: 1) male and female; 2) collegiate level or higher shooters (e.g. NCAA Rifle team member, USA Shooting National Team member); 3) all races and ethnicities; 4) aged between 18-30 years; 5) experience of more than 2 months; 6) highest match score greater than 580 and 570 in air rifle and 50 ft smallbore indoor, respectively; 7) average match score for the past year greater than 575 and 560 in air rifle and 50 ft smallbore indoor, respectively. The exclusion criteria were: 1) currently injured which required suspension of shooting training or considered to adversely affect shooting performance; 2) not available to complete 6 week study. Subjects who met the inclusion category were randomly assigned to the feedback group or non-feedback group. (See screening questionnaire Appendix 2)
Procedures

Each subject visited the rifle range a total of 10 times over six weeks. Each training session lasted approximately 45 minutes and each testing session lasted 90 minutes. Subjects wore their customized shooting equipment (i.e. shooting boots, shooting pants and shooting jackets, glove and any other equipment they typically wear) which is compliant with NCAA rules.

The tests and training were performed using International Shooting Sports Federation (ISSF) approved MEGAlink 4K187 electronic targets (Drobak, Norway) which registers shots using four microphones located at the corners of the target. A graphic display of the shot’s location to the nearest tenth of a point was provided to the subject on MEGAlink ML2000 monitor (Drobak, Norway). The subjects stood with feet on separate force plates (Kistler model 9286AA combined with 5233A control unit; Kistler, Winterthur, Switzerland). The front force plate was placed perpendicular to the firing line and the rear force plate was placed parallel to the firing line to accommodate foot position. The control unit was set to thresholds for the vertical force (Fz) of 500 N and for the mediolateral and anteroposterior forces (Fx, Fy) of 250 N. The force plates were connected to the computer via a 16 bit NI-USB-6229 A-D board (National Instruments, Austin, TX) and the data was sampled at 240 Hz. Three markers, placed on the right side at the barrel’s end, were captured at 60 Hz via three Eagle cameras (Motion Analysis Corporation, Santa Rosa, CA) and three-dimensional coordinates of each marker were synchronized using EVaRTv5.0 software with BiofeedTrakv1.0 for feedback training and Cortex v1.0 software for data capture (Motion Analysis Corporation). The target height was raised 3.5 cm to 143.2 cm to cater for the height of the force plates. An
example of the force plate, marker setup and a software view can be seen in Figure 3.1-3.4.

**Figure 3.1** Side view of data collection setup and coordinate system, with the coordinate system and data collection station indicated.
Figure 3.2. View of data collection from behind subject, with the coordinate system, two force plates, target and target monitor indicated. Auditory feedback was provided through headphones.
Figure 3.3 Rifle barrel setup, showing the placement of the three retro-reflective markers.
A pre-test was performed to establish a performance baseline for each subject in both air rifle and smallbore events. Subjects were required to shoot 20 record shots, with unlimited sighting shots in 40 minutes in air rifle and smallbore with no feedback (i.e. same as competition). Before beginning record shots, the subject stepped off the force plates and the plates were zeroed. A conventional ISSF 10 m air rifle target was used for air rifle and a USA Shooting 50 ft target was used for smallbore. The order of the air rifle and smallbore was randomly assigned to each subject. The subject’s integer score and
shot group diameter were recorded from the MegaLink system (Drobak, Norway). To determine each subject’s preferred shooting stance, postural control was measured using both the weight under the front leg (FZ) and rifle barrel speed (SB), recorded on a data sheet (Appendix 3).

Subjects trained 45 min/day, 2 days/week for 4 weeks. Each subject, in both groups, performed 20 record shots using air rifle. Subjects continued to train normally during their 20 hr/wk, but substituted their normal air rifle training for the feedback training on that day. Auditory feedback was provided to the feedback group only through headphones. The feedback limits for subjects in the feedback group were set based on the results of the pre-test. Initial limits for FZ (N) were set from the range of force in the 1 second preceding triggering recorded during the pre-test (e.g. ± 5 N). Barrel speed limits (SB) were set from the maximum speed (mm/s) in the 1 second preceding triggering (e.g. ± 4 mm/s). Subjects were informed of the ranges for each feedback variable with the objective to reduce sway within the limits so that the sounds are silenced. FZ was represented by two tones, a low pitch tone if under the limit and a high pitch tone if over the limit. SB was represented by a different signal. Limits were adjusted during training if too difficult (e.g. no period of silence) or too easy (e.g. 100% silence). All subjects were shown their shot integer score throughout the 20 shots.

The same shooting test completed during the pre-test was repeated 6-8 days following the completion of the final training session. No feedback was given during post-testing. One week was chosen for the post testing as this would be the maximum amount of time top-level shooters might go without training before an event due to travel.
Data Analysis

Integer score and shot group diameter were recorded for each subject for pre-test and post-test. Performance variables were calculated based on 20 shots. Stability variables were not collected for 3 smallbore pre-tests and 5 air rifle pre-tests due to software errors. Ten acceptable trials were randomly selected for each subject to calculate stability variables. Data were analyzed in MATLABv2008b (Mathworks, Natick, MA) using custom written code. No filters or smoothing was applied to the data before analyzing as the BiofeedTrak does not smooth the data during real-time feedback. The time of shot was manually selected for each trial using a barrel velocity graph (Figure 3.5). As this peak velocity included an acceleration component, seven frames before the peak were excluded from the analysis. All time variables were related back to this point. The barrel velocity was measured in the X (ML), Y (AP) and Z (vertical). Center of pressure was calculated for each foot in both the X and Y axis. All variables were calculated 0.3 s, 1 s and 3 s preceding the shot. Data is presented as means ± standard deviation for groups and individuals. No significance testing was performed due to the limited sample size available for analysis.
Figure 3.5. Manual selection of time of shot using an interactive graph of velocity versus frame number. Note the cursor is positioned near the peak velocity indicating the shot. The interactive code returns the frame number of the peak velocity within ± 2 frames.
Chapter Four: Results

The purpose of this study was to investigate the effects of augmented real-time auditory feedback on shooting performance in top-level shooters. This chapter will include three sections: 1) Stability Variables, 2) Shot Performance Variables, 3) feedback Training.

Stability Variables

Postural Stability

Comparison of center of pressure values from pre-testing to post-testing in the anterioposterior and mediolateral directions are reported in Table 4.1. Values above zero indicate an increased measure of center of pressure (i.e. no improvement). One improvement in stability was observed in the 1 s before triggering in the feedback group during air rifle. No other improvements were observed at any other time periods for either events, but instead increased up to 2.69 mm.
Table 4.1. Changes in center of pressure (mm) in mean ± SD from pre-test to post-test for both groups.

<table>
<thead>
<tr>
<th>Anterioposterior (mm)</th>
<th>3 s</th>
<th>1 s</th>
<th>0.3 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback Smallbore</td>
<td>1.40 ± 1.37</td>
<td>0.53 ± 0.413</td>
<td>0.88 ± 0.80</td>
</tr>
<tr>
<td>Feedback Air</td>
<td>0.24 ± 0.19</td>
<td>-0.03 ± 0.027</td>
<td>0.04 ± 0.40</td>
</tr>
<tr>
<td>Non-feedback Smallbore</td>
<td>0.54 ± 0.19</td>
<td>0.76 ± 0.121</td>
<td>0.66 ± 0.51</td>
</tr>
<tr>
<td>Non-feedback Air</td>
<td>0.58 ± 1.10</td>
<td>0.70 ± 0.771</td>
<td>0.87 ± 0.83</td>
</tr>
<tr>
<td>Mediolateral (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback Smallbore</td>
<td>2.64 ± 1.61</td>
<td>2.50 ± 1.55</td>
<td>1.73 ± 1.02</td>
</tr>
<tr>
<td>Feedback Air</td>
<td>1.02 ± 0.39</td>
<td>0.96 ± 0.39</td>
<td>0.64 ± 0.27</td>
</tr>
<tr>
<td>Non-feedback Smallbore</td>
<td>2.23 ± 1.17</td>
<td>1.94 ± 0.95</td>
<td>1.63 ± 0.94</td>
</tr>
<tr>
<td>Non-feedback Air</td>
<td>2.69 ± 1.11</td>
<td>2.62 ± 0.88</td>
<td>1.99 ± 0.60</td>
</tr>
</tbody>
</table>

Rifle Stability

Changes in rifle barrel stability varied between groups and tests (Figure 4.1).

Positive values represent higher barrel speeds during post-testing indicating no improvements in barrel stability. Two events are noteworthy in this figure. The feedback group had a decrease in barrel velocity 3 seconds preceding the shot during air rifle testing.
The feedback and non-feedback groups decreased barrel speed as the shot developed in both smallbore and air rifle. The non-feedback and feedback group had an increase in barrel speed of 1.3 mm/s and 0.6 mm/s, respectively, at 3 s to shot during post-testing. The increase in post-test barrel speeds were maintained throughout shot development. The non-feedback and feedback groups had post-test values of 0.4 mm/s and 0.5 mm/s, respectively, higher than pre-test values 0.3 s from triggering (Figure 4.2).
Figure 4.2. Mean barrel speed (mm/s) for pre-test (thin line) and post-test (thick line) for feedback (solid line) and non-feedback group (dashed line) in smallbore (X). The standard deviations for the feedback for 3s, 1s and 0.3s were 0.017 mm, 0.628 mm, 0.217 mm and 1.329 mm, 0.875 mm, 0.623 mm, in the pre-test and post-test, respectively. The standard deviations for the non-feedback group for 3s, 1s and 0.3s were 1.842 mm, 1.174 mm, 1.046 mm and 1.111 mm, 0.924 mm, 0.695 mm, in the pre-test and post-test, respectively.

Decreases in barrel speed during air rifle testing were observed for both groups during shot development. The non-feedback group had an increased barrel speed 3 s from shot from 6.5 mm/s during the pre-test to 7.3 mm/s during the post-test. The increased
barrel speed was also observed at 1 s to shot, however, the increase was eliminated at 0.3 s to shot. The feedback group had a slight decrease of 0.2 mm/s in barrel speed at 3 s to shot in the. No improvements at 1s or 0.3 s to shot were observed.

**Figure 4.3.** Mean barrel speed (mm/s) for pre-test (thin line) and post-test (thick line) for feedback (solid line) and non-feedback group (dashed line) in air rifle (▲). The standard deviations for the feedback for 3s, 1s and 0.3s were 0.037 mm, 0.150 mm, 0.214 mm and 0.501 mm, 0.555 mm, 0.892 mm, in the pre-test and post-test, respectively. The standard deviations for the feedback for 3s, 1s and 0.3s were 0.172 mm, 0.076 mm, 0.109, and 0.737 mm, 1.06 mm, 0.323 mm in the pre-test and post-test, respectively.
Performance Variables

The mean shot score (± SD) during the testing for both groups is recorded in Table 4.2. Mean shooting score (±SD) was the same for the feedback and non-feedback groups in air rifle, 10.1 ± 0.5 points. Air rifle pre-test mean scores were similar with the non-feedback group having a higher mean with 9.7 ± 0.6 points than the feedback group, 9.6 ± 0.8 points. The feedback group was able to increase shot score in both air rifle and smallbore, 0.1 points and 0.3 points, respectively, after feedback training. The variability between shots was also reduced for this group. The non-feedback group decreased 0.1 points in air rifle and remained unchanged in smallbore during post-testing.

Table 4.2. Mean shot score (± SD) for the feedback and non-feedback group for the 20 record shot pre-test and post-test in air rifle and smallbore. The maximum score possible is 10.9.

<table>
<thead>
<tr>
<th>Air</th>
<th>Group</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback</td>
<td>10.1 ± 0.5</td>
<td>10.2 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>Non-feedback</td>
<td>10.1 ± 0.5</td>
<td>10.0 ± 0.5</td>
<td></td>
</tr>
<tr>
<td>Smallbore</td>
<td>Feedback</td>
<td>9.6 ± 0.8</td>
<td>9.9 ± 0.5</td>
</tr>
<tr>
<td>Non-feedback</td>
<td>9.7 ± 0.6</td>
<td>9.7 ± 0.7</td>
<td></td>
</tr>
</tbody>
</table>

In regards to integer score, the feedback group had a higher mean score during air rifle pre-testing compared to the non-feedback group. During training sessions average group integer scores fluctuated with no predictive pattern. The feedback group increased air rifle post-test mean integer score by 0.6 points. Mean integer score in air rifle post-testing for the non-feedback group decreased by 1.5 points (Figure 4.4).
Figure 4.4. Integer score for 20 record shots reported as means for each pre-test (SD: FB=±3.1; NFB=±3.5), training sessions (SD: FB=±2.5; NFB=±4.5) and post-test (SD: FB=±2.5; NFB=±5.7) in air rifle (▲) for the feedback (solid line) and non-feedback (dashed line) groups.

The results from the smallbore pre-test and post-test are reported in Table 4.3. The feedback and non-feedback group had similar scores during the pre-test. Both the feedback and non-feedback groups were able to increase mean integer score for the post-test by 6.0 points and 2.2 points, respectively. The variability in score for the non-feedback group also increased.
Table 4.3. Mean integer score (± SD) for the feedback and non-feedback group for the 20 record shot pre-test and post-test in smallbore. The maximum score possible is 200 points.

<table>
<thead>
<tr>
<th>Smallbore</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback</td>
<td>183.6 ± 3.6</td>
<td>189.6 ± 3.8</td>
</tr>
<tr>
<td>Non-feedback</td>
<td>183.8 ± 5.4</td>
<td>186.0 ± 9.4</td>
</tr>
</tbody>
</table>

The feedback group had a small average shot group diameter (SGD) of 7.7 mm compared to the non-feedback group with 8.1 mm during air rifle pre-testing. During training session 1 and training session 2 the feedback group lowered their SGD to 6.4 mm and 6.3 mm, respectively. The feedback group was able to lower the SGD to 7.1 mm during post-testing, a difference of 0.5 mm from pre-testing. Air rifle post-test SGD increased for the non-feedback group by 0.3 mm to 8.4 mm (Figure 4.5).
Figure 4.5. Shot group diameter (mm) for 20 record shots reported as means for each pre-test (SD: FB=±1.9 mm; NFB=±2.0 mm), training sessions (SD: FB=±1.1 mm; NFB=±1.9 mm) and post-test (SD: FB=±1.9 mm; NFB=±2.0 mm) in air rifle (▲) for the feedback (solid line) and non-feedback (dashed line) groups.

Results from the smallbore testing indicated larger changes in SGDs. The feedback group was able to reduce the mean SGD by 2.5 mm as well as decrease variability within the group. No changes in SGD were observed for the non-feedback group during the post-test.
Table 4.4. Mean shot group diameter (mm) (± SD) for the feedback and non-feedback group for the 20 record shot pre-test and post-test in smallbore.

<table>
<thead>
<tr>
<th>Smallbore</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback</td>
<td>11.3 ± 1.8</td>
<td>8.7 ± 1.3</td>
</tr>
<tr>
<td>Non-feedback</td>
<td>10.3 ± 1.3</td>
<td>10.4 ± 3.2</td>
</tr>
</tbody>
</table>

Feedback Training

Training feedback limit were initially set from values based on air rifle pre-test results. $F_Z$ limits were maintained at a range of 5 N for all training sessions. Figure 4.6 illustrates the feedback limits for barrel speed during the training sessions. All subjects completed their last session with a barrel speed feedback limit less than or equal to 2 mm/s.
Subject’s attitude towards the feedback training and use of the system after the study are recorded in Table 4.5. With regards to the non-feedback group, only one subject, Subject 1, decided to train with the system following the study. During the study the subject was compliant with completing training sessions in the requested time. One training session using only barrel speed feedback was completed by the subject after the study. Subjects 4, 7 and 8 did not utilize the training system. During the study, these
three subjects were frequently reminded to complete the training sessions in a timely manner.

Subject 2, 3, and 6 were interactive with the researcher during training session. These subjects would ask questions about actions that affected monitored variables would request harder limits. Subject 5 and 9 were indifferent to the process and would wait for the researcher to ask if the limits needed to be lowered. Within the feedback group two subjects, Subjects 2 and 6, choose to train twice a week with the system for 2 weeks after completion of the study.

It should be noted that the choice to use the system after the completion of the study may have been influenced by subject’s participation in post-season competition.

Subjects 2, 4, and 5 did not compete in additional collegiate matches following the study.

Table 4.5. Subject’s opinion of feedback training and use of system after study for those in feedback (FB) and non-feedback (NFB) groups.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Group</th>
<th>Opinions on training</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NFB</td>
<td>Used system after study, but only barrel feedback with air rifle</td>
</tr>
<tr>
<td>2</td>
<td>FB</td>
<td>Interactive during training, did not use system after study</td>
</tr>
<tr>
<td>3</td>
<td>FB</td>
<td>Interactive during training, used system after study, but only barrel feedback with smallbore</td>
</tr>
<tr>
<td>4</td>
<td>NFB</td>
<td>Did not use system after training</td>
</tr>
<tr>
<td>5</td>
<td>FB</td>
<td>Not interactive during training, did not use system after study</td>
</tr>
<tr>
<td>6</td>
<td>FB</td>
<td>Interactive during training, used system after study, but only barrel feedback with smallbore</td>
</tr>
<tr>
<td>7</td>
<td>NFB</td>
<td>Did not use system after training</td>
</tr>
<tr>
<td>8</td>
<td>NFB</td>
<td>Did not use system after training</td>
</tr>
<tr>
<td>9</td>
<td>FB</td>
<td>Not interactive during training, did not use system after study</td>
</tr>
</tbody>
</table>
Summary

Following 4 weeks of training no meaningful improvements in postural or rifle barrel stability were observed for either group. Some stability variables reported indicated a decrease in stability during the post-tests for both air rifle and smallbore.

No meaningful changes were observed for either group in air rifle based on performance variables. Mean integer score was increased in both groups during the smallbore post-test. The feedback group was also able to increase mean shot score and decrease SGD in smallbore.

The feedback system was able to adjust for the specific skill level of each subject and their performance during training. Subject’s attitude towards training along with participation in post-study competitions was a good determinant of participation in feedback training following the study.
Chapter Five: Discussion

The purpose of this study was to investigate the effects of augmented real-time auditory feedback on shooting performance in top-level shooters. This chapter will include a brief summary of the purpose and hypotheses of this study. The results of the study will be discussed, as well as how it fits within current research available. Finally, limitations of the study and a summary are presented.

Purpose and Hypotheses

Precision shooting requires synchronization of multiple sensory systems to facilitate success. Currently there is a lack of innovative training techniques that instruct athletes how to develop their skills to progress to the next level. The use of auditory feedback may provide athletes the opportunity to develop better postural and barrel stability. This in turn may create better performance in terms of quality of shots and aggregate score.

It was hypothesized that the group that received auditory feedback during training would 1) decrease postural and barrel sway, 2) increase performance based on shot outcome, and 3) decrease shot group diameter while the non-feedback group remained unchanged.
Stability Variables

Postural Stability

Previous studies in precision shooting have identified postural stability as one of the prerequisites to a successful shot. The influence of postural sway on shot outcome is greater in novice shooters than elite shooters. In elite shooters, postural stability can be correlated to shot outcome after completion of intra-individual analysis. The specific stability variable and time periods are highly individualized to each shooter. The hypothesis that postural sway would decrease in the feedback group was not supported by the data. In fact, many of the values recorded during the post-tests indicated a decrease from pre-test levels. However, the values were still within acceptable ranges for their skill level.

Subjects in both groups obtained center of pressure measures similar to those reported by Era et al. (1996) for top-level shooters and Ball et al. (2003) for elite shooters. The absence of increased postural stability may be due to the skill level of subjects used in the study. Minimal improvement is possible for these athletes because of their ability to maintain high levels of postural stability before the start of the study.

Rifle Barrel Stability

The ability to increase rifle barrel stability is the second major prerequisite to a successful shot. Unlike postural stability, barrel stability is correlated to shot outcome regardless of skill level. In this study few changes were observed in barrel stability for
the feedback and non-feedback group. The feedback group did improve barrel stability 3 s to shot in air rifle (Figure 4.1).

As with postural stability the lack of improvement may be due to the skill level of participants. Previous studies report rifle stability in different measures than the ones used in this study. However the trends in stability reported for these subjects are similar to those reported by Konttinen et al. (1998). Elite shooters were able to decrease rifle barrel amplitudes by 4 mm during the 7.5 s before a shot to an amplitude of approximately 9 mm. In this study subjects in the feedback group were able reduced vertical (Z) and horizontal (X) barrel velocities from 7.2 mm/s and 4.7 mm/s, at 3 s to shot, respectively, to 3.3 mm/s and 2.2 mm/s at 0.3 s to shot, respectively. This trend in rifle stability was also seen in the non-feedback group.

**Performance Variables**

Improvements in skill can be observed in performance variables such as shot outcome and shot group diameter. This is important particularly in top-level shooters who already possess excellent postural and rifle stability. Increases in performance must then come from other areas such as reduction in triggering error or selection of shots.

**Shot Outcome**

Shot outcome will be discussed as mean shot score and mean integer score. Mean shot score refers to the quality of shot the athlete is firing. Mean integer is a measure of performance without regard to the quality of shots fired. Although these two variables are
similar they relay information about areas that need to be trained. For example mean shot score will describe the quality of the shots not scored as 10 points.

The feedback and non-feedback groups were evenly paired in regards to mean shot score for the 20 record shot air rifle pre-test. Minimal change was made in either group during the air rifle post-test. The mean shot score of 10.0 ± 0.5 points and 10.2 ± 0.4 points (Table 4.2) for the non-feedback and feedback group, respectively, are comparable to mean shot scores reported by Ball et al. (2003) of 10.1 ± 0.3 points and Konttinen et al. (2000) of 9.67 ± 0.77 points for elite shooters.

The smallbore post-test revealed that the feedback group was able to increase mean shot score and decrease variability. Four of the five subjects in the feedback group had mean shot scores of 10.0 points or higher. Only two of the four members of the feedback group had mean shot score of 10.0 points or higher. No smallbore scores for elite shooters are currently available in the literature.

As with mean shot score, no improvements were observed in either group during post-testing in air rifle for the mean integer score. However, the feedback group maintained the same mean integer score during the post-test and the non-feedback group decreased their mean integer score. Both groups demonstrated an increase in performance during smallbore post-testing, with the feedback group increasing mean integer score by 6.0 points. The results support the hypothesis that the feedback group would be able to increase shot outcome, but only in smallbore. The increase in smallbore scores alone is thought to be because smallbore scores tend to be lower than air rifle scores. Therefore, increases in performance are better detected because of the larger margin for improvement.
**Shot Group Diameter**

Shot group diameter is a measure of the athletes aiming hold during shooting. Smaller shot group diameters indicate more advantageous aiming hold. This is especially important in event finals when shots are scored using a decimal system. Shots closer to the center of the target are awarded more points with the maximum being 10.9 points for a single shot.

Following training the non-feedback group was unable to decrease mean shot group diameter for either event. In air rifle the feedback group had a slight decrease in mean shot group diameter. The most impressive change was the decrease of the mean shot group diameter for smallbore by the feedback group. These results support the third hypothesis that feedback group would decrease shot group diameter after feedback training.

It is interesting to note the decrease in shot group diameter for the feedback group during the first two training sessions (Figure 4.5). The decrease may be caused by the increased intensity of the training sessions. Subjects were forced to maintain high levels of focus while trying to silence the auditory feedback. This state of intensity is similar to what Konttinen et al. (1998) describes as a “state of alert immobility”, which allows shooters to exert more effort when the rifle barrel is unstable to try and increase control.

No other studies have used shot group diameter as a measure of increased performance. Therefore values recorded during this study can not be compared to confirm that these results are typical of top-level shooters.
**Feedback Training**

Providing augmented feedback to athletes during training sessions can provide information that would otherwise not be available. In this study, augmented auditory was provided to subjects in the feedback group based on postural and rifle barrel stability. Despite the absence of drastic changes in stability or performance variables, small changes were observed. Improvements in mean shot score, mean integer score and mean shot group diameter for the feedback group during smallbore testing lends support for feedback training in events other than air rifle.

While some improvements were made, the degree of improvement was not comparable to those found by Konttinen et al.’s (2004) study using novice shooters. While the scores reported for the feedback group during the post-test and retention tests were higher than the other groups, the scores were lower than the scores of the subjects in this study. The feedback group in Konttinen et al.’s group had post-test air rifle shot scores of approximately 7.5 points. Both groups in this study had post-test air rifle mean shot scores higher than 10.0 points. The high skill-level of the subjects used in this limited the range for possible improvements.

The effectiveness of training was influenced by the subject’s perception of feedback training. Some subjects were indifferent to the process and merely performed the tasks as they were instructed to. Other subjects were excited about the feedback training and were interactive with the researcher during training sessions. These subjects would inquire about the influence of different actions on the feedback system. They would also request more challenging feedback limits to use during training. Empirical
observation of those that were more interactive seemed to perform better not only during post-testing but during collegiate matches.

All subjects were provided with the opportunity to train for the remainder of their season following the completion of the study. Three subjects participated in feedback training after the study from feedback; one from non-feedback. Subjects were allowed to personalize the feedback they were provided. Interestingly, each subject independently asked to receive only rifle barrel speed feedback during training sessions. While no results were recorded, impressive results were observed while using only rifle barrel speed feedback training. The desire to receive feedback for only the barrel may lend support to Konttinen et al.’s (2000) observation that postural and barrel stability are controlled as one unit in top-level shooters. In other words, received feedback about rifle barrel stability allowed for subjects to monitor the condition of both variables.

The use of only rifle barrel speed feedback could also be due to the sensitivity of the force plates. The setup of the force plate for this study allowed for a resolution of 0.007 N. However, system noise lead to feedback limits for $F_Z$ to never be lowered below a 5 N range. Despite stability values below this the continual fluctuation of force values would never allow for the system to silence. In addition, feedback based on postural stability may be redundant because postural sway would affect rifle stability. The force plates used were piezo-electric, and the use of other technology such as strain gauge plates may yield sufficient sensitivity.
Summary

Based on the information gathered, stability variables were not useful measure of change in performance due to feedback training. This is most likely due to the high skill-level of the subjects used in this study. Their elite levels of both postural and rifle barrel stability did not allow for meaningful changes in stability variables. Increasing the sampling rate to include the 300-400 ms before a shot may increase the relevance of rifle barrel stability.

The inclusion of performance variables was useful in this study as it indicated changes in performance not observed by stability variables. Pre-test values were similar for both groups in terms of mean shot score, mean integer score and mean shot group diameter. No changes were found in air rifle, but changes in smallbore were found for both groups related to mean integer score. The feedback group was also able to decrease mean shot group diameter during smallbore testing. This finding suggests that air rifle testing may not be sensitive enough to changes in performance when testing top-level athletes. The inclusion of smallbore testing should be considered for future studies involving top-level athletes.
Chapter Six: Summary

Conclusions

Precision shooting requires synchronization of multiple sensory systems to facilitate success. Currently there is a lack of innovative training techniques that instruct athletes how to develop their skills to progress to the next level. A review of literature indicated that the two main components for successful performance are good postural stability and rifle barrel stability. Based on this information an auditory feedback training system was created to provide athletes the opportunity to develop better postural and barrel stability. This in turn would create better performance in terms of quality of shots and aggregate score. Three research hypotheses were formed to test the effectiveness of auditory feedback training in precision shooting. They were:

1. After feedback training, subjects will decrease postural and barrel sway and the control group will remain unchanged.
2. After feedback training, subjects will increase performance based on shot outcome and the control group will remain unchanged.
3. After feedback training, subjects will decrease shot group diameter and the control group will remain unchanged.

It was concluded that following 4 weeks of training no meaningful improvements in postural or rifle barrel stability were observed for either group. However, changes in performance variables were observed during smallbore testing. The non-feedback group
was able to improve mean integer score. The feedback group was able to improve mean integer score and shot group diameter.

Recommendations for Future Research

The methods used to provide real-time auditory feedback to subjects during air rifle training should be applied to other studies investigating smallbore training. Previous studies have utilized only air rifle testing due to the limitations of available facilities. It is apparent from this study that air rifle testing may not be sensitive enough to detect changes in performance in top-level shooters. Although similar, the standing position in smallbore is different than air rifle and warrants its own investigation of the particular components that create success.

Researchers should expand their investigations past postural and rifle barrel stability. The versatility of Motion Analysis Corporation’s BioFeedTrak software allows for examination of nearly any imaginable aspect of shooting kinematics and kinetics. Studies involving other components of successful shooting such as head placement on the rifle stock, trigger pull or natural point of aim could be of benefit to both novice and top-level shooters. Following more thorough investigation of auditory feedback training, a commercial produced product could be created to allow a wider population of shooters to benefit from the advantages of feedback training.
Appendix 1: Informed Consent

Consent to Participate in a Research Study

Effects of augmented real-time auditory feedback on top-level precision shooting performance

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study about training with auditory feedback. You are being invited to take part in this research study because you are a collegiate level or higher shooter (e.g. NCAA Rifle team member, USA Shooting National Team member), currently training and have been for at least the last 2 months, and are between the ages of 18-30 years. If you volunteer to take part in this study, you will be one of about ten people to do so.

WHO IS DOING THE STUDY?

The person in charge of this study is Stacy M Underwood of University of Kentucky in the Department of Kinesiology and Human Science. She is being guided in this research by Dr. David R Mullineux [Advisor]. There may be other people on the research team assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

By doing this study, we are looking at the benefits of training with auditory feedback. This study may provide information about more effective training methods for the sport of precision shooting.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

If you are injured, otherwise unhealthy or any other reason deemed by the investigator to affect your wellbeing or the research integrity then you may be excluded from participating in this study.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research procedures will be conducted at UK Barker Hall Rifle Range (UK BHRR). You will need to come to UK BHRR 10 times during the study. Two visits will last approximately 1.5 hours and eight visits will last approximately 45 minutes. The total amount of time you will be asked to volunteer for this study is 9 hours over the next 6 weeks.

WHAT WILL YOU BE ASKED TO DO?

You will be asked perform a 20 record shot test in both air rifle and smallbore before training begins. You should follow your normal competition routine before the test. For the next four weeks, you have a 50:50 chance of being assigned to receiving feedback or no feedback on your performance during training. You will be required to shoot air rifle for approximately 45 minutes, two days a week for four weeks. If you are in the feedback group each training session will include a warm up, feedback training and cool down. If you are not in the feedback training group you will shoot 20 record shots as you normally would. You should continue to train normally for other events you participate in. At the end of the four weeks you will be asked to perform a 20 record shot test in both air rifle and smallbore one week after completing the final training.
session. You should follow your normal competition routine before the test. After completing the tests you will be offered the chance of feedback training if you were not in the feedback group.

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?**

There is always a chance that participation in research studies may harm you. We will do everything we can to keep you from being harmed. There is a chance that you may become dependent on the auditory feedback. This dependency may negatively affect your performance. You may end your participation in the study at any time if you feel that your performance is being affected. In addition to the risks listed above, you may experience a previously unknown risk or side effect.

**WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?**

There is no guarantee that you will get any benefit from taking part in this study. There are possible benefits to both precision shooting in general and you. For shooting, a better appreciation of whether training with auditory feedback can improve shooting outcome will be provided. This information will allow you the opportunity to evaluate the usefulness of this new technology to your training regimen. You will be provided with copies of your data, including results of the weight distribution, rifle barrel stability and shot group size.

**DO YOU HAVE TO TAKE PART IN THE STUDY?**

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

**IF YOU DON’T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?**

If you do not want to be in the study, there are no other choices except not to take part in the study.

**WHAT WILL IT COST YOU TO PARTICIPATE?**

There are no costs to you for participating in the study. All expenses associated with visiting the research visits are your responsibility. Expenses for any care or treatment that might be necessary if you become hurt or becomes sick while taking part in this study are also your responsibility.

**WHO WILL SEE THE INFORMATION THAT YOU GIVE?**

We will keep private all research records that identify you to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. Your individual results will not be provided to the Head Coach of the Rifle Team. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. All electronic data will be stored on password protected computers or data storage devices, and all paper hard copies and consent forms will be
stored in secured locked cabinets in the University of Kentucky Biodynamics Laboratory. Only the investigators will have access to these materials. Officials of the University of Kentucky may look at or copy pertinent portions of records that identify you.

**CAN YOUR TAKING PART IN THE STUDY END EARLY?**

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.

The individuals conducting the study may need to withdraw you from the study. This may occur if you are not able to follow the directions they give you or if they find that your being in the study is more risk than benefit to you.

**WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?**

If you believe you are hurt or if you get sick because of something that is due to the study, you should call Stacy M Underwood at 714-928-7826, immediately. Stacy Underwood will determine what action, if any, that is best for you at that time.

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

The medical costs related to your care and treatment because of research related harm will be your responsibility.

You do not give up your legal rights by signing this form.

**WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?**

You will receive a profile of your body sway and barrel movement while aiming. You will not receive rewards for participation.

**WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?**

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Stacy M Underwood at 714-928-7826. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

**WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT MY DECISION TO PARTICIPATE?**

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

**WHAT ELSE DO YOU NEED TO KNOW?**

This study will partially fulfill academic degree requirements for the investigator, Stacy M Underwood.
Signature of person agreeing to take part in the study

Printed name of person agreeing to take part in the study

Name of [authorized] person obtaining informed consent

Date

Date
Appendix 2

(Questionnaire administered by researcher)

Researcher’s initials:__________ Date:_________ Subject #:_________

Height:_____________ Mass:_____________

1. Gender: Male/Female
2. Member of the NCAA Rifle team/ USA Shooting National Team/other? Y / N [exclude if N]
3. Any current injuries requiring suspension of shooting training or considered to adversely affect shooting performance? Y/ N [exclude if Y]
4. Available and willing to complete the 6 week study? Y / N [exclude if N]
5. Race: American Indian/Alaskan Native  Black/African American  Asian Hispanic/Latino
   Native Hawaiian/ Pacific Islander  White/Caucasian  Other or unknown
6. Date of Birth:_______ [exclude if not 18-30 yrs old]
7. Training experience:____________ [exclude if less than two months]
8. Highest score in a registered match: Air Rifle______ Smallbore _____ (exclude if less than 580 and 575, respectively)
9. Average match score over last year: Air Rifle_____ Smallbore______ (exclude if less than 575 and 565, respectively)
10. Date informed consent signed:________ [exclude if unable to understand, or did not sign]
Appendix 3: Data Capture Sheet

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| Shot Group Diameter |   |   |   |   |   |   |   |   |   |    |
| Score (integer) |   |   |   |   |   |   |   |   |   |    |

Average-Best 10 shots (feedback Limits - Training group only, from Pre-test)

| Fz (-3s) |   |   |
| Barrel Speed (-3s) |   |   |
References


Vita

Stacy Marie Underwood

Date of Birth: May 29th, 1984
Place of Birth: Mission Viejo, California

Education B. S. University of Nebraska-Lincoln, College of Education and Human Science

• Major: Education and Human Science