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QUIET EYE TRAINING IN A VISUO-MOTOR CONTROL TASK

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RUNNING HEAD: PERCEPTUAL TRAINING

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Abstract

Introduction: Several researchers have reported the importance of maintaining a longer final fixation on the target (termed the quiet eye period, QE) prior to performing an aiming task. We present an innovative, perceptual training intervention intended to improve the efficiency of gaze behavior (i.e., QE) in shotgun shooting. **Methods**: A sample of 20 International-level, skeet shooters were assigned equally to one of two, matched-ability groups based on their pre-test shooting scores. A perceptual training group participated in a 4-step, pre-shot routine, alongside three video feedback sessions involving their own gaze behaviors and those of an expert model in an effort to influence positively QE behaviors. A control group received video feedback of performance, but without the addition of feedback on QE behaviors. Participants completed pre- and post-tests along with an 8-week training intervention. **Results:** The perceptual training group significantly increased its mean QE duration (397 cw 423 ms), employed an earlier onset of QE (257 cw 244 ms), and recorded higher shooting accuracy scores (62 cw 70 %) from pre- to post-test. Participants in the perceptual training group significantly reduced gun barrel displacement and absolute peak velocity on the post- compared to the pre-test, even though neither variable was overtly trained. A transfer test, based on performance during competition, indicated that perceptual training significantly improved shooting accuracy pre- to post-intervention. No pre- to post-test differences were observed for the control group on the measures reported. **Conclusion:** The results demonstrate the effectiveness of QE training in improving shooting accuracy and developing a more efficient visuo-motor control strategy. Findings have implications for future research on training visuo-motor behaviors, attention and gaze orientation during the performance of aiming tasks.

Key words: gaze behavior; kinematics; visuo-motor control; shotgun; eye movements

Introduction

Paragraph Number 1 Several researchers have examined the potential of training perceptual skill in sport. Williams et al. (24) suggested that perceptual training programs should not only highlight expert search patterns as models of performance but, in addition, include tasks which contribute to the development of the knowledge base underpinning effective visual search behaviors. Moreover, research in the area of perceptual training suggests that cognitive interventions that develop the knowledge base underlying skilled perception have more practical utility in facilitating the acquisition of expert performance than clinically based, visual skills training programs (28). In fact, researchers have shown that experts do not possess superior visual skills than novices per se (1,2,8,22). In this paper, we design and implement a training program to improve the efficiency of both the gaze and motor behaviors of International-level skeet shooters.

Paragraph Number 2 Williams and colleagues (23,27,28) have provided detailed and critical reviews of research related to perceptual training. These reviews have highlighted the potential of such programs, while at the same time identifying shortcomings in the literature. For example, several researchers have failed to include a placebo group and/or a control group; therefore any improvements in performance observed in these studies may be due to conformational bias or increased familiarization with the task, rather than the intervention itself. Furthermore, suitable transfer and/or retention tests have not been adequately employed to examine whether training facilitates performance in real-world contexts or if any improvements manifest themselves over an extended time period. Moreover, while the literature base focusing on perceptual training is not extensive, there have been hardly any attempts to use such training methods to try and improve performance in aiming tasks such as shooting.

Paragraph Number 3 The quiet eye (QE) is a gaze behavior first reported by Vickers (19) during an investigation involving National-level basketball players performing the basketball free throw. When compared to their less-expert counterparts, expert free-throw shooters employed significantly longer preparation and impulse phases of the shot and generated a greater frequency of fixations during the execution phase, compared to their near-expert counterparts. Furthermore, the duration of final fixation before initiation of movement was significantly longer in the expert compared to less-expert players. Vickers termed this final fixation on the target during the preparatory phase of movement the quiet eye period (QE). QE is defined as the final fixation or tracking gaze that is located on a specific location or object in the visuomotor workspace within 3° of visual angle (or less) for a minimum of 100ms. The onset of QE occurs prior to the final movement of the task, and the offset occurs naturally when the gaze deviates off the location or object. During this period, the performer is thought to set the final parameters of the movement to be executed. The key principle is that QE duration is proposed to be associated with the amount of cognitive programming required for successful aiming to a target (25).

Paragraph Number 4 The QE period has been shown to be a characteristic of higher levels of performance in a variety of sports-related contexts, including when aiming at a fixed target (7, 9,13,14,19,20,21), at moving/abstract targets (4,5,18,25), during interceptive timing tasks (3,12,26), and when engaged in tactical tasks (11). Moreover, experts have constantly exhibited both earlier onset and longer QE duration than less-expert performers in various tasks including tennis (16), ice hockey goaltending (11), shotgun shooting (4,5), the volleyball service return (3,12), basketball free throws (19), baseball batting (15), biathlon shooting (21) and dual-task auto-racing (10).

Paragraph Number 5 Causer et al. (4) were the first researchers to assess QE in the sport of shotgun shooting. Previously, researchers had focused predominantly on self-paced, static aiming tasks or tasks where objects approach the participant. Causer et al. (4) conducted a detailed analysis of the sub-disciplines of shotgun shooting to assess gaze behaviour and kinematic differences between elite and sub-elite shooters, as well as successful and unsuccessful shots. The elite shooters, in all three shotgun disciplines (skeet/trap/double trap), exhibited significantly longer QE durations and an earlier onset of QE compared to their sub-elite counterparts. Participants exhibited longer QE durations and an earlier onset of QE in successful compared to unsuccessful shots. The elite shooters demonstrated a more efficient gun barrel motion, as characterized by smaller gun barrel displacement and more efficient timing strategy. In the current study, we extend this original work by examining the key variables that mediate elite performance in shotgun shooting to see if they can be enhanced using a systematic QE-based training program. Thus far, and despite the significant growth in research on QE, few researchers have attempted to apply this new knowledge to improve performance on aiming tasks.

Paragraph Number 6 Adolphe et al. (3) were the first to examine whether QE could be trained by developing a 6-week training program with the intention of improving visual search behaviors and performance accuracy in a group of elite volleyball players passing to the setter area. A training program was designed in which athletes received video feedback in relation to their gaze behavior, followed by five training sessions on court. These sessions consisted of viewing their vision-in-action data and participation in a progression of exercises designed to improve QE tracking and performance, such as tracking a tennis ball, or detecting the ball coming from behind a barrier. In the vision-in-action paradigm, gaze and motor behaviors are recorded simultaneously as tasks are performed in situ, enabling researchers to objectively determine which characteristics are associated with successful and unsuccessful performances (18,19,25). After a one month gap from training, all athletes had an earlier tracking onset and improved their tracking duration. In addition to improving their QE characteristics, a number of other skills, which were not overtly trained, improved, such as a decrease in step corrections, and moving into a correct position more quickly. Although these researchers identified the potential of QE training in sport, there were several limitations to the work. These include a small sample size (only 3 receivers were included in the pre- to post- analysis) and the lack of a placebo or control group; improvements in gaze behaviors were, therefore, difficult to attribute solely to the visual training program.

Paragraph Number 7 Harle and Vickers (7) conducted a similar training intervention investigating the effect of training QE in basketball free throws. University-level basketball players received QE training over two seasons, compared to a control team who received no training. The QE training involved video modeling and feedback to help the athletes develop the same QE focus and motor control observed in elite performers. During the sessions, athletes were shown their gaze behavior on video, which was then compared to that of an elite model. Athletes were also given a pre-shot routine to follow while undertaking the free throw task. The participants in the experimental group improved their free throw accuracy by more than 22%, and training QE led to a more economical visuo-motor routine, as demonstrated by a longer duration of QE, a more stable QE on one location and a faster shot movement time. These results highlight the potential effectiveness of QE training programs, not only for improving gaze behaviors, but also in aiding self-organization of the skill without direct coaching. However, although control groups were involved in the study, only the intervention group participated in the pre- and post- test measures of gaze behavior. Therefore, any improvements in gaze behavior may have been due to familiarization, alternative coaching strategies or a number of other factors.

Paragraph Number 8 In the current paper, we aimed to address limitations in previous efforts to improve QE behaviors in aiming tasks. We employed a relatively long training period compared to those used by the majority of researchers in this area. This extended time period provided more time to accurately determine the effects of the training intervention. Another novelty was the measurement of performance in situ in the pre- and post-test, significantly increasing ecological validity. In the majority of previous studies, researchers have only identified individual variables to measure training effects. In this paper we consider performance more holistically, employing a variety of measures including visual gaze, kinematics and shooting accuracy. The inclusion of a control group allowed for direct comparisons to be made across groups, enabling strong, reliable conclusions to be drawn. The addition of an empirical measure of skill transfer by comparing shooting scores pre- and post-intervention enabled us to explore whether any observed improvements transfer to the competitive arena. Finally, we wanted to examine the efficacy of this type of intervention with truly elite, International-level athletes to identify whether perceptual training can lead to performance improvements at the highest level; potentially differentiating between 'podium' and 'non-podium' athletes.

Paragraph Number 9 The QE duration and onset, movement kinematics and shooting accuracy were measured pre- and post-training. Shooting accuracy scores were also recorded for the three competitions prior to, and three competitions post, training intervention in order to provide a measure of transfer to real-world environments. We hypothesized that QE durations would increase in the perceptual training group compared with the control group and that an earlier onset of QE would be evident. These predictions were based on the results of Harle and Vickers (7) and Adolphe et al. (3). As a result of these improvements in QE duration and onset, we hypothesized that shooting accuracy would significantly improve in the training group compared to the control group. A more marked improvement in shooting accuracy during competition in the perceptual training group compared to the control group post intervention was predicted. Since Adolphe et al. (3) reported a change in motor behavior as a result of quiet eye training, we hypothesized that any improvements in QE may indirectly organize the motor behaviors of the training group creating a more efficient task-related movement pattern. Specifically, based on data from Causer et al. (4), it was predicted that smaller horizontal gun barrel displacement on shot two, lower vertical gun barrel variability on shot one, and lower absolute peak velocity on shot two, would be evident in the training group post-intervention. No changes in kinematics were expected in the control condition.

Materials and methods

Participants

Paragraph Number 10 A sample of 20 International-level skeet shooters with a mean age of 24.5$\pm$4.4 years and having accumulated an average of 6.7$\pm$1.5 years of experience in shooting competition provided written informed consent prior to participation. The shooters were assigned to groups based on their initial performance on a pre-test into one of two, matched-ability groups of equal numbers. A group of control participants (n = 10) completed a pre- and post-test only. The training group (n = 10) underwent an 8-week intervention consisting of eight training sessions and three video feedback sessions. All shooters reported normal or corrected-to-normal visual acuity. Participants used their own personal shotguns and normal shooting attire.

All participants were required to follow the rules of the discipline during data collection, as stipulated by the International Shooting Sport Federation (ISSF). Participants were free to withdraw from testing at any stage and approval for the study was gained via the local Ethics Committee of the lead author's institution.

Measures

Eye movements

Paragraph Number 11 The visual search behaviors employed by participants were recorded using a mobile eye corneal reflection system (Applied Science Laboratories; Waltham, MA, USA, ASL Mobile Eye II). The mobile eye system employs a method known as 'dark pupil tracking' where the relationship between two features, the pupil, and a reflection from the cornea, are used to compute point-of-gaze within a scene. The mobile eye has a system accuracy of 0.5° visual angle, a resolution of 0.10° visual angle, and visual range of 50° and 40° in the horizontal and vertical planes, respectively.

Gun barrel kinematics

Paragraph Number 12 Video data were collected to calculate the coordinates of the gun barrel in order to provide a more comprehensive understanding of the shooting action. Two Cannon XM2 digital video cameras (Cannon, Tokyo, Japan) sampling at 50Hz and with a shutter speed of 1/150 were employed. The cameras were positioned 4.0m in front of the shooting station at an angle of 50° relative to the centre of the range with one camera on the left side of the range and the other on the right, at a height of 0.9m. The cameras were connected to a central computer by two extended firewire cables. The shutters were synchronized using a signal sent from the central computer. The cameras filmed simultaneously during each shooting trial. The shooting area was calibrated using a twelve point, three-dimensional frame (1.25x1.15x1.15m).

Procedure

Pre- and Post-tests

Paragraph Number 13 In the pre- and post-test, the mobile eye system was calibrated using nine points in the environment at the same distance as the clay flight. The calibration was conducted in situ while participants were in their ‘normal’ shooting stance. The participants were positioned on the skeet range at Station 4 to shoot the double target, shooting the high target first, and were required to shoot 15 pairs (30 shots in total). We collected data using the mobile eye system for the entire duration of the test session and accuracy of the calibration was checked periodically. The video cameras were activated to record the movement and the outcome of each shot. An inter-trial interval of 60-seconds was employed.

Protocol for Training QE

Paragraph Number 14 During each session, participants in the perceptual training group were guided through a four step routine, consisting of the following.

1. Stand at the station with the gun in the hold position (in a location you are able to replicate with little variability) and where there will be minimum horizontal gun barrel displacement, rotate your head towards the high tower and direct your gaze to a suitable target pick-up point position.

2. Using your normal routine, when ready, call for the targets.

3. Direct eye focus to the first target as quickly as possible, and track the target continuously until you pull the trigger. Following the execution of the first shot, become visually aware of the second target and direct your eye focus to it. Continually track the target, making sure the target is in visual focus before shooting.

4. Use a stable and consistent gun motion throughout the task, trying to keep the gun barrel at a constant velocity with no periods of high acceleration.

Paragraph Number 15 The routine was developed and refined after personal communications with a number of high-level International Shooting Sport Federation (ISSF)-qualified coaches. The routine was reinforced in the training environment, with the shooters employing the approach under both ‘dry’ (without ammunition) and ‘live’ (with ammunition) shooting practices. In both of these training environments, and throughout the intervention period, participants were asked to follow the four step routine on each shot.

Paragraph Number 16 On weeks 1, 3 and 6 both groups received a 30 minute video feedback session of performance, along with an example of an ‘expert shooter’. The participants in the perceptual training group received feedback on their QE characteristics in relation to the expert model. The video feedback involved outlining the need for earlier target detection and a prolonged period of tracking in order to accurately program an appropriate response action. This strategy was enforced by comparing onset of QE and QE duration on successful and unsuccessful trials, and then comparing these to the expert model. The expert model chosen had previously won medals at both Olympic Games and World Championships over a 15-year period and was ranked number 1 nationally at the time of data collection. The expert shooter demonstrated efficient and consistent gaze behaviors in conjunction with high shooting accuracy.

During this session, they viewed videos of ‘hits’ and ‘misses’ from their pre-test (week 1), and from the previous weeks training for week 3 and week 6. A total of five hits and five misses for each participant was viewed, along with ten expert trials. Differences in QE were identified and explained. The participants in the control group received videos of both their performances and that of the ‘expert shooter’ without any feedback or instruction in relation to QE characteristics. Participants in the control group were involved in ‘normal’ training for the same amount of time as those in the perceptual training group were undertaking their intervention and received the same number of trials during the acquisition phase. After the experiment period, and as part of a debrief, members of the control group were offered the same training intervention.

Transfer test

Paragraph Number 17 All participants were tracked pre- and post-intervention to enable competition scores to be recorded and compared. Scores from the three competitions directly before and after the training intervention were gathered; a combination of both international and domestic competitions. All of the competitions were within two months of the training intervention. A standard competition consists of 5 rounds of 25 targets each, making a total of 125 shots (scores in finals were not recorded). As a measure of transfer, we recorded mean percentage accuracy scores across all three competitions pre- and post-intervention.

Statistical analysis

Paragraph Number 18 Due to the high frequency of success on the first target, analysis of the second shot was deemed to be more relevant. Altogether, 10 shots (5 hits, 5 misses; both randomly selected from the sample) were identified for each shooter for further analysis on both the pre-and post-tests. The visual search data were analyzed frame-by-frame using Gamebreaker

(Sportstec, Camarillo, USA) software. The mean QE duration and onset were analyzed. The Onset of QE was defined as the time from the trigger pull on shot one, until the gaze stabilizes on the second target, and the tracking gaze is initiated. The QE duration was measured as the continuous tracking gaze from onset of QE to trigger pull on shot 2. The eye movements were logged manually from the video recordings and QE characteristics determined by frame counts. The objectivity of the eye movement data was established using intra-observer (98.8%) and inter-observer (97.9%) agreement methods. Altogether, 12% of the data were reanalyzed to provide these figures using the procedures recommended by Thomas et al. (17). For kinematic analysis, the video files were imported into the SIMI Motion 6 (SIMI Reality Motion Systems, Unterschleissheim, DE) analysis software. An average calibration error of 0.54% of screen size was found, SIMI software recommends an error range between 0 and 3% for accurate analysis. The gun barrel marker was manually tracked in both video recordings for five frames before the initiation of the movement and the following five frames after the completion of the shot were digitized.

Paragraph Number 19 After running a logistical regression analysis on data from Causer et al. (5), three main kinematic variables were seen to be consistently more efficient during successful shot outcome; horizontal axis displacement on shot 2, absolute peak velocity on shot 2 and vertical variability on shot one. The QE period and onset of QE were the main focus of the training program. However, the kinematic variables were measured to see if gaze behavior could indirectly influence motor behavior.

Paragraph Number 20 A separate two-way, mixed design ANOVA was used to analyze each of the main dependent measures with group (control, training) as the between-participants factor and test (pre-, post-) as the within-participants factor. The effect sizes were calculated using partial eta squared values (η_p^2) and Cohen's d as appropriate. The alpha level for significance was set at 0.05. If the sphericity assumption was violated, the Huynh-Feldt correction was used.

Results

Shooting accuracy

Paragraph Number 21 There was no significant main effect for group, $F_{1, 18} = 0.409$, $p > 0.05$, $\eta_p^2 = 0.02$. However, there was a significant main effect for test, $F_{1, 18} = 9.815$, $p < 0.01$, $\eta_p^2 = 0.35$, and a significant interaction between group and test, $F_{1, 18} = 28.562$, $p < 0.01$, $\eta_p^2 = 0.61$. Shooting accuracy improved from pre- (62.8$\pm$16.8%) to post-test (66.2$\pm$15.5%). The interaction effect showed that performance of the control group did not change significantly from pre- to post-test (d = 0.06), whereas participants in the perceptual training group significantly improved their accuracy over the training period (d = 0.54). The findings are presented in Figure 1.

Insert Figure 1 about here

Transfer to competition

Paragraph Number 22 There was no significant main effect for group, $F_{1, 18} = 3.434$, $p > 0.05$, $\eta_p^2 = 0.16$. However, there was a significant main effect for test, $F_{1, 18} = 14.407$, $p < 0.01$, $\eta_p^2 = 0.45$, and a significant interaction between group and test, $F_{1, 18} = 8.603$, $p < 0.01$, $\eta_p^2 = 0.32$. The competition scores significantly improved from pre- (90.0$\pm$3.4%) to post-test (92.9$\pm$3.7%). The interaction effect showed that the performance of the control group did not change significantly from pre- to post-test (d = 0.21), whereas participants in the perceptual training group significantly improved their competition scores over the intervention period (d = 1.73). The findings are presented in Figure 1.

QE duration

Paragraph Number 23 There was no significant main effect for group, $F_{1, 18}$= 3.120, $p > 0.05$, $\eta_p^2 = 0.15$. However, there was a significant main effect for test, $F_{1, 18}$= 12.580, $p < 0.01$, $\eta_p^2 = 0.41$, and a significant interaction between group and test, $F_{1, 18}$ = 14.729, $p < 0.01$, $\eta_p^2 = 0.45$. Longer QE durations were evident on the post- (411.0$\pm$26.8ms) compared to the pre-test (396.9$\pm$22.6ms). The interaction effect demonstrated that the control group's mean QE duration did not change significantly from pre- to post-test (d = 0.04), whereas the training group significantly improved its durations over the training period (d = 1.20). The findings are presented in Figure 2.

Insert Figure 2 about here

Onset of QE

Paragraph Number 24 There was no significant main effect for group, $F_{1, 18}$= 3.199, $p > 0.05$, $\eta_p^2 = 0.15$. However, there was a significant main effect for test, $F_{1, 18}$= 11.761, $p < 0.01$, $\eta_p^2 = 0.40$, and a significant interaction between group and test, $F_{1, 18}$ = 16.257, $p < 0.01$, $\eta_p^2 = 0.48$. An earlier onset of QE (250.6$\pm$14.9ms) was reported on the post-test when compared to the pre-test (257.6$\pm$10.9ms). The participants in the control group QE did not change significantly the time of onset of their QE from pre- to post-test (d = 0.11), whereas the participants in the training group significantly improved their durations over the training period (d = 1.20). The findings are presented in Figure 2.

Displacement of gun shot two (horizontal axis)

Paragraph Number 25 There was no significant main effect for group, $F_{1, 18}$= 1.462, $p > 0.05$, $\eta_p^2 = 0.08$. However, there was a significant main effect for test, $F_{1, 18}$= 34.888, $p < 0.01$, $\eta_p^2 = 0.66$, and a significant interaction between group and test, $F_{1, 18}$ = 21.462, $p < 0.01$, $\eta_p^2 = 0.54$. A smaller gun displacement was evident on the post-test (0.081$\pm$0.02cm) compared to the pre-test (0.094$\pm$0.02cm). The control group's mean displacement distance did not change significantly from pre- to post-test (d = 0.15), whereas the intervention group significantly decreased its gun barrel displacement over the training period (d = 0.65). The findings are presented in Table 1.

Insert Table 1 about here

Absolute peak velocity for shot two

Paragraph Number 26 There was no significant main effect for group, $F_{1, 18}$= 0.286, $p > 0.05$, $\eta_p^2 = 0.02$. However, there was a significant main effect for test, $F_{1, 18}$= 10.133, $p < 0.01$, $\eta_p^2 = 0.36$, and a significant interaction between group and test, $F_{1, 18}$ = 12.252, $p < 0.01$, $\eta_p^2 = 0.41$. Lower peak velocities were observed on the post- (0.85$\pm$0.08m/s) compared to the pre-test (0.88$\pm$0.07m/s). The control groups peak velocity did not change significantly from pre- to post-test (d = 0.05), whereas the intervention group significantly decreased its peak velocity over the training period (d = 0.63). The findings are presented in Table 1.

Variability of gun barrel shot one (vertical axis)

Paragraph Number 27 There were no significant main effects for group, $F_{1, 18}$= 0.524, p > 0.05, η_p^2 = 0.03, test, $F_{1, 18}$= 1.022, p > 0.05, η_p^2 = 0.05, or the group and test interaction, $F_{1, 18}$ = 1.014, p > 0.05, η_p^2 = 0.05.

Discussion

Paragraph Number 28 We attempted to develop a perceptual training program to improve the efficiency of both gaze and motor behaviors in elite, International-level skeet shooters. We hypothesized that as a result of our video-based intervention the training group would increase the duration of its QE period and have an earlier onset of QE when compared with the control group. These modifications to gaze behavior would promote an extended period for motor programming and arousal control, increasing the probability of a successful outcome. Therefore, as a result of these improvements in QE duration and onset, we hypothesized that shooting accuracy would improve significantly in the perceptual training group compared to the control group. Furthermore, based on results from Adolphe et al. (3), it was predicted that any improvements in QE may indirectly organize the motor behaviors of the training group creating a more efficient movement pattern.

Paragraph Number 29 As predicted, participants in the perceptual training group significantly improved their QE durations and employed an earlier QE onset on the pre-test compared to the post-test. However, the control group showed no improvements in either of these gaze characteristics. These data reinforce the results reported by Harle and Vickers (7) and Adolphe et al. (3). The current study, however, extends the research into a previously unknown area of perceptual training; using an external target that is required to be intercepted by an external object in a movement which is externally paced. The inclusion of a truly elite sample extends previous research, and demonstrates that athletes at the very highest level of competition can utilize perceptual training programs to increase performance and develop more efficient motor behaviors. These findings have important implications for the coaching of elite athletes in many sports, and potentially, for performers in other domains requiring effective eye and limb coordination, such as in arthroscopic surgery or in factory-line assembly tasks. In the current study, we utilized a relatively long training period compared to that employed by most other researchers in previous studies. This extended intervention period allowed more time to accurately determine the effects of the training intervention and, along with the measurement of performance pre- and post-tests in situ, provides a more representative replication of the training environment than used previously in similar training studies.

Paragraph Number 30 Previously, researchers examining gaze behaviors in shotgun shooting have shown longer QE periods to be linked to higher levels of shooting accuracy (4,5). Moreover, expert shooters have been reported to demonstrate both an earlier QE onset and a longer QE duration. It has been suggested that an earlier onset of QE enables shooters to process information about the flight of the clay earlier than the sub-elite shooters. This finding suggests that elite shooters are better at anticipating the release of the clay and attending to the most critical cues to initiate the correct response. As a result of the temporal constraints inherent in clay-target shooting, participants should detect the clay early and then to track it in an uninterrupted manner before pulling the trigger. This earlier onset, combined with a prolonged QE duration, provides the expert shooter an extended time period both for motor programming (goal directed control) and optimal arousal control, minimizing the effects of erroneous environmental cues (stimulus driven control) (6). The longer QE enables shooters to more accurately process the trajectory, direction and speed of the clay in relation to the gun barrel before selecting the correct response characteristics. The ability to train this perceptual skill could potentially have substantial implications for how motor skills are taught, learnt and trained at all levels from ‘grass roots’ up to international athletes.

Paragraph Number 31 Alongside the more efficient QE characteristics, we hypothesized that shooting accuracy would increase from pre- to post-test in the training group. As predicted, the training group significantly increased shooting accuracy from 63% in the pre-test to 77% in the post-test (d = 1.08). The control group, however, did not significantly improve shooting accuracy from pre- (63%) to post-test (61%) (d = 0.11). These results support data from Harle and Vickers (7) where basketball players improved their performance accuracy by 11.98% over one season, and by the end of the second season of training this improvement had increased to 22.6%. These results show the potential improvement that can be made in performance over a prolonged period of training. The results in the current study show significant improvements after an 8-week training period. Additional work is needed to examine whether an extended intervention period and incorporating this training it into a larger training macro-cycle could lead to even larger gains in performance.

Paragraph Number 32 In most previous studies, researchers have only identified individual variables in order to measure training effects. In this paper, we looked at performance more holistically by recording a number of measures of such as gaze, kinematics and shooting accuracy. In terms of the kinematic variables measured, there were significant changes exhibited by the perceptual training group. From pre- to post-test, the perceptual training group significantly decreased its gun barrel displacement and absolute peak velocity on shot two, although variability of the gun barrel on shot one was not significantly altered. These results illustrate that, although no direct training of the shooting technique was prescribed, the trained shooters exhibited a more efficient gun movement on the post- compared with the pre-test; this improvement was not seen in the control group. The importance of these variables in relation to performance in shotgun shooting was examined in a study by Causer et al. (5). The authors concluded that a smaller gun displacement along with the lower absolute peak velocities results in a more efficient gun motion, with no periods of high acceleration, as well as a more stable shot. The current study shows that by training QE, with a combination of video feedback and simple shooting routine, significant positive modifications to shooting technique can occur indirectly.

Paragraph Number 33 Aldophe et al. (3) reported similar findings after a 6-week QE training program which focused on ball tracking in volleyball. The athletes were shown video feedback of an 'expert' model of gaze behaviors, similar to the current study, alongside five 'on court' training sessions. Subsequent to the QE training, all the athletes had an earlier tracking onset and had improved their tracking duration, as well as some movement behaviors that were not overtly trained, including corrective steps and positioning. The authors concluded that knowing how to improve gaze and attention aids the self-organization of the skill without direct coaching of the motor behavior. Harle and Vickers (7) reported that QE training altered the relative timing of a basketball free throw, leading to the conclusion that a cognitive intervention precipitated the change in shooting mechanics. These results highlight the potential effectiveness of such training in focusing gaze and attention to key areas in order to enhance motor efficiency. This phenomenon requires further research to understand the mechanisms by which this indirect 'coaching' manifests itself and how the role of visual behavior interacts with this change in motor behavior. These findings may ultimately change how certain tasks are coached and trained with the importance of gaze behaviors in learning motor tasks significantly increased.

Paragraph Number 34 The inclusion of a control group, which was matched with the intervention group for training volume, allows direct comparisons to be made across groups. The results provide strong evidence that QE training led to a significant improvement in shooting accuracy over the training period. It is important to note that, even with the videos of the expert model and feedback of their own shooting, the participants in the control group failed to improve on any of the variables measured. The current study also included a strong measure of transfer from the training environment to real world competition. Unfortunately, the ISSF does not permit any non-standard equipment to be worn during competitions. Therefore, we were unable to capture the transfer of either QE characteristics or kinematics in the competition environment. Nonetheless, we were able to gather information on shooting accuracy from both domestic and international competitions. This information enabled us to ascertain whether any improvements in shooting accuracy were successfully transferred into the real competitive situation. The results indicated significant pre- to post-intervention improvements for the training group only. It therefore appears that the improvements in performance observed on the post-test transferred to the competitive arena.

Paragraph Number 35 Our results show a large discrepancy between performance scores in training (65.8±16.2%) and competition (91.5±4.3). In this study, we only utilized station 4 on the shotgun range, shooting a pair of targets; this is widely regarded as the most difficult scenario in the round. During competition, shooters take shots from a series of eight different stations, and shoot at single targets; these 'easier' scenarios increase the performance accuracy in the competition rounds. The ISSF does not provide data for each station independently of the overall score on each round of shooting. Consequently, we were unable to access performance data in competition that emerged from station 4 only, so potentially the training improvement may be larger than suggested by our current data. Overall, our findings illustrate the potential benefits that may be gained by integrating perceptual training programs into the training regimes of elite-level athletes.

Paragraph Number 36 In summary, we report significant improvements in visuo-motor control after an 8-week intervention program, as indexed by an earlier onset of QE, a prolonged QE duration and more economical gun barrel displacement and absolute peak velocity. The QE characteristics were successfully modified within a group of elite, International-level shooters. More importantly, however, these modifications led to increases in shooting accuracy pre- to post-test and in a measure of transfer involving a comparison of shooting scores in competitions pre- to post-intervention. Findings have implications for those examining the role of attention and gaze orientation in the organization of motor performance. In a more applied setting, the results identify a number of potential avenues for improving coaching strategies, including early gaze behavior training and video feedback to enhance performance.

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Legends for Figures/Tables

Figure 1. a) The mean performance accuracy (%) of the control and training groups in the pre-test and post-test; b) the mean competition scores (%) of the control and training groups in the three competitions prior to the training intervention, and three competition post training intervention.

Figure 2. a) The mean QE duration (ms) in the pre-test and post-test for control and training groups; b) the mean onset of QE duration (ms) in the pre-test and post-test for control and training groups.

Table 1. Mean and standard deviations for kinematic variables on pre- and post-test between control and intervention groups.