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Anticipation in Sharp Shooting: Cognitive Structures in Detecting Performance Errors

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ABSTRACT

Objectives: Expert motor performance of closed skills requires refined monitoring of external visual reference points and internal body signals. The primary objective of this study was to examine whether shooters at different skill can detect performance variations by attending to varied sources of signals.
Design: A mixed factorial design was used to examine the study's objectives. Specifically, awareness to performance in sharp shooting was examined via visual access or occlusion of visual feedback performed by skilled and less skilled shooters.
Method: Thirteen pistol shooters performed 60 rounds of live pistol shooting. A linear distance between the actual and estimated shots (LEE) was used as a dependent measure. Aiming the pistol was sustained for one of two-time intervals (2s and 6s) before allowing shooting. Half of the trials were performed under an occluded vision condition. Estimations of the shots' outcome and retrospective verbal reports were recorded immediately after completion of the task.
Results: The analyses revealed that less skilled shooters' estimation of performance was significantly hampered when they estimated performance errors in the occluded vision condition. Furthermore, skilled shooters reported access to more complex sources of knowledge and feedback for detecting performance errors than less skilled shooters.
Conclusions: Error-detection can be considered as an anticipatory skill in a self-paced sport in which the complexity of feedback resources available for detecting performance errors changes with acquired skill. This skill develops through skill acquisition and refinement.

1. Introduction

Performance of motor skills depends on detecting, perceiving, and using relevant sensory information (Schmidt & Lee, 2013). This may require special consideration in highly demanding situations when full access to sensory information is limited. For instance, when police officers engage in night street battle, or when visual information needed to perceive and detect errors is limited because the target is too distant, performers might not have full access to all sources of feedback needed to perform with the least risk for themselves and others involved.

Our study had two major goals concerning the detection of performance errors in sharp shooting, which is a self-paced sport. The primary goal of this study was to learn about how sharp shooters with different levels of skill differ in their use of visual feedback to detect performance errors and anticipate outcomes, which have been considered important in dynamic sports (e.g., Abernethy, 1990; Singer, Cauraugh, Chen, Steinberg, Frehlich & Wang, 1994). Our secondary goal was to examine the development of cognitive structures for error-detection at different levels of skill. By "cognitive structures", we mean the units of knowledge that performers gradually attain and store to increase the capacity of working memory in their domain of expertise (long-term working memory, LTWM, Ericsson & Kintsch, 1995).

The concept of expertise has been extensively studied in sharp shooting, differentiating elite and less skilled shooters on various factors and characteristics such as postural steadiness (e.g., Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Mononen, Konttinen, Viitasalo, & Era, 2007), rifle and pistol stability (e.g., Ball, Best, & Wrigley, 2003; Konttinen, Lyytinen, & Viitasalo, 1998), sight alignment and aiming skills (e.g., Causer, Bennett, Holmes, Janelle, & Williams, 2010; Goonetilleke et al., 2009), and physiological markers (e.g., Hatfield &

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Landers, 1983; Hillman, Apparies, Janelle, & Hatfield, 2000). However, no studies have examined shooters abilities in anticipating performance errors.

Error-detection is considered as an anticipatory skill in sharp shooting. Taking the perspective of closed-loop theory (Adams, 1971), error detection is achieved by comparing a perceptual trace with a goal state, detecting the degree of mismatch between the two, and adjusting future actions to reduce the mismatch. Thus, we view error detection as encompassing the perception and mismatch detection stages. In shooting, error detection is an act of anticipation because the perceptual trace informs the shooter about where the shot is likely to go at any given moment (too far right, left, etc.).

A wide range of studies in dynamic sports have attempted to address mechanisms by which anticipation contributes to the advancement of performance. For instance, anticipation requires athletes to pay attention to internal (e.g., proprioceptive) or external (e.g., opponent's body language or environment) feedback and to anticipate the information required for the next moves (Abernethy, Wood, & Parks, 1999; Tenenbaum, Levy-Kolker, Sade, Liebermann, & Lidor, 1996). Although studies of anticipation significantly contibuted to understanding of expert performance in dynamic sports, corresponding research in self-paced sports leaves is lacking. Self-paced sports, by nature, are different than dynamic sports, and thus applying the evidence from the latter to the former's settings may not even seem appropriate. The character of a dynamic sport (e.g., racquet sports, soccer, volleyball) requires athletes to anticipate the actions of other athletes, which often requires visual information as a critical or even sole source of feedback (e.g., Rowe & McKenna, 2001; Singer, et al., 1994). In contrast, in a self-paced sport (e.g., archery, rifle and pistol shooting), performers may need to attend to and monitor information they receive from their own body to anticipate and compensate for errors.

Lending plausibility to this assumption, many well-known skills in sharp shooting are consistent with the idea that non-visual information is extensively used by expert sharp shooters. Multiple studies have demonstrated that shooting proficiency is attained by reducing movement during certain shooting phases (Era et al., 1996; Konttinen, Lyytinen, & Era, 1999; Niinimaa & McAvoy, 1983) and that expert marksmen keep their weapon more stable than less skilled marksmen (Mononen, Viitasalo, Konttinen, & Era, 2007; Viitasalo, et al., 1999). Whereas both abilities can plausibly benefit from the use of interoceptive information, they can benefit from visual information as well. For instance, one may use the visual information when the gun is moving relative to the target as a signal that the gun must be held more stable.

To determine the relative use of visual and non-visual information at various skill levels, we must directly probe what information is used, rather than infer it indirectly. In the current study, we do this in two ways. First, we manipulate the availability of visual information, measuring the cost to performance when visual information is removed. Second, we employed verbal protocol analysis (e.g., Ward, Suss, Eccles, Williams, & Harris, 2011) to access the conscious use of different kinds of information during shooting. Verbal protocols also allow a window into the cognitive structures employed by sharp shooters, an issue we turn to below.

Our predictions regarding the cognitive structures developed by expert sharp shooters are drawn from the deliberate practice framework (Ericsson, Krampe, & Tesch-Römer, 1993). Specifically, we assumed that an efficient system of error-detection among sharp shooters develops over years of practice through the establishment of domain-specific long-term working memory (LTWM, Ericsson & Kintsch, 1995), first by forming simpler cognitive structures. We predict that visual feedback, such as the target, will be an adequate, yet simple, source of feedback, because it is the most available one at the early stages of learning. Over time, and with more practice, we expect that cognitive structures related to error-detection will become more complex by forming multiple layers of information encoded from multiple sources, including hand and body positioning, breath and heart rate, grip, trigger control, and more. Therefore, skilled sharp shooters may not solely rely on one source of feedback (e.g., visual) for detecting performance errors; rather, they will benefit from other sources of information which are accessible to them. On the other hand, sharp shooters at lower skill level are less likely to acquire adequate quantities of information because they lack working memory capacity to hold all information in mind at once. Based on this reasoning, we predict that the verbal reports of skilled sharp shooters will include both more thoughts than less experienced sharp shooters, reflecting more complex working memory structures.

In addition to allowing use of more simultaneous relevant information, increased working memory capacity also entails an enhanced ability to attend to relevant information while ignoring irrelevant distracting information. Attention is an ability positively related to working memory capacity and some have even argued that attention and working memory are not distinct cognitive abilities (D'esposito & Postle, 2015). The role of attention in sharp shooting was emphasized by Hatfield, Landers, and Ray (1987), who characterized elite rifle sharp shooting in terms of having focused attention on the target while disregarding environmental distractions. This leads us to predict that verbal reports of skilled sharp shooters will contain fewer distracting or irrelevant thoughts than less skilled sharp shooters.

To identify different types of verbal reports and to categorize them, we relied on two main resources. First, from previous studies that examined perceptual-cognitive skills such as decision making or anticipation (Ericsson & Kintsch, 1995; Ericsson & Ward, 2007; Ward, Ericsson, & Williams, 2013), we recognized verbal statements signified as "monitoring, prediction, planning, and evaluations." This categorization of verbal statements reflects the sequences of thought processing when making a decision or anticipating one's own or opponents' next moves. Then, based on sequences of the shooting task defined by Maxey (1984), (a) steady position; holding the weapon with minimal movement of the barrel along the x, y, and z-axes, (b) aiming; aligning the rifle sights with the target, (c) breath control; stopping the breathing cycle at the time of firing, and (d) trigger control; squeezing the trigger instead of pulling it), we defined the main categories of verbal statements relevant to error-detection as a form of cognitive structure that would include three phases: (a) *monitoring*, when the previous encoded knowledge of the task (e.g., front sight under the bull's-eye, hold the breath, squeeze the trigger) is recalled and serves as a guide for performing the task, (b) *evaluation,* when the executed task is compared with the expected outcome (e.g., sights are not aligned, or the elbow is not locked), (c) *estimation,* when the error or prediction of the outcome is made (e.g., felt like it went off on a down a bit). All these event-sequences can ultimately lead to adjustment of the detected errors if it is in a reasonable time frame before the trigger pull. Although it is expected that sharp shooters at varied skill levels would go through all phases to anticipate performance errors, the complexity (i.e., use of multiple sources of information and the quantity of the verbalized statements) and sources (i.e., internal vs. visual) of knowledge would differentiate skilled from less skilled sharp shooters.

1.1. Study's objectives

In the present study, we examined (a) how access to visual feedback affected the accuracy with which skilled and less skilled shooters detect performance errors, and (b) the difference between cognitive structures employed by sharp shooters at two distinct skill levels during error-detection.

To meet these aims, we employed a *visual occlusion paradigm* to manipulate access to visual feedback, comparing shot accuracy and estimation of performance errors when vision was occluded and when full vision was allowed. We assumed that applying the occlusion paradigm in a self-paced sport would enable examining sharp shooters's abilities to detect performance errors with and without access to visual feedback (e.g., Farrow, Abernethy, & Jackson, 2005; Wright, Pleasants, & Gomez-Meza, 1990). We also extended the time right before the trigger pull for 6 s (6s) and 2 s (2s) to magnify the effect of visual occlusion on estimation of performance errors.

If skilled sharp shooters increase their use of non-visual information for error detection, visual occlusion will result in more cost for less skilled than skilled sharp shooters, and this effect will be particularly strong in the 6s delay condition, when extended monitoring of non-visual information is required. Importantly, we measured not only shot accuracy, but estimated score and location of the shot. If skill sharp shooters are using interoceptive information as feedback indicating where the gun is pointing, they will be able not only to shoot skillfully, but also to accurately estimate the location of their shot.

Additionally, we employed a *verbal report protocol* to learn about thought processes underlying error-detection in sharp shooting. For decades, the study of verbal reports has broadly been employed in sports settings, shedding light on perceptual-cognitive processing relevant to expert performance using the expert-less skilled paradigms (Afonso, Garganta, McRobert, Williams, & Mesquita, 2014; Ericsson & Simon, 1980; North, Ward, Ericsson, & Williams, 2011; Savelsbergh, Williams, Kamp, & Ward, 2002; Ward, et al., 2011). We expected that obtaining verbal report data would allow to identify the complexity of the thought processes of sharp shooters at different skill levels when detecting performance errors.

We predicted that the complexity of cognitive structures for error-detection would increase with skill level. In fact, the sequence of thought processes relevant to error-detection in sharp shooting would consist of dissimilar structures at different skill levels; the more complex cognitive structures of shooting tasks would be verbalized at the higher levels of skill, while lower skill sharp shooters may detect performance errors relying on fewer sources of information. We also predicted that due to the complex mental representation of the shooting task among skilled sharp shooters, they would recall and report more on task-relevant thoughts such as monitoring and evaluating the task (e.g., body positioning or firearm positioning) than irrelevant thoughts (e.g., distracting thoughts or the study procedure) compared to their less skilled counterparts. A less developed mental representation of the task among less skilled sharp shooters, on the other hand, would make them more vulnerable to attending to task-irrelevant thoughts and report more of them than skilled sharp shooters.

2. Method

2.1. Participants

A power analysis was conducted to estimate the number of participants required for granting a marginal type-II error. Employing two skill-level shooters, four measures in a mixed repeated measures ANOVA with effect size *f(v)* set at 0.35, alpha at .05, and power *(1- β)* at 0.80, a total sample size of 14 was required. Fourteen skilled and less skilled sharp shooters were recruited from a private shooting range in the South-Eastern US to participate in this study (M_{age} = 51.57 years, SD_{age} = 16.28, 12 males and two females). One participant was excluded from the sample due to recording disturbances, making the sound unintelligible. Skilled participants (n = 7) were all male. They were selected from top-ranked shooters competing at the local and Inter-State shooting events. Less skilled sharp shooters (n = 6; four male and two female) were recreational shooters who underwent less structured training and completed at least one shooting course with 4 h of systematic training. This group of shooters was considered as less-skilled sharp shooters but not as novices or beginners. Informed consent was obtained from all participants.

2.2. Apparatus

Participants wore custom glasses with mechanical shutters that could be opened or closed by the experimenter with a remote control. Verbal reports were recorded via a single USB microphone (Longitech) that was connected to the simulation computer. A Sony HDR-CX200 camera, situated near the target, recorded images from the actual shots. Participants shot at the NRA Official 50 Foot target, 147.32 × 228.60 cm (58 × 90 inches) in size. The target included three rings in which each scored a different value. The most inner ring had a diameter of 10 cm (3.94 inches) and scored 10, the diameter for the middle ring was 20 cm (7.87 inches) and scored 8, and the most outer ring had a diameter of 30 cm (11.81 inches) and scored 5. Any hits outside this range was considered a miss hit (e.g., zero). Participants were familiar with this target and the scoring criteria since they have been using it for either the competition or the practice. Participants were not instructed on how or where to shoot and were allowed to freely choose their own routine. Instead, the emphasize was put on how well they could estimate the outcome of the shot Identical targets were also hung on a nearby wall within the participants' reach to mark the estimated location of each shot.

2.3. Procedure and shooting task

2.3.1. Setting

The study was held in a standard indoor private shooting range. Participants could use their own firearms which met the authorized equipment rules of NRA competitions (e.g., caliber, barrel length in addition to standard safety features). They were provided with protective equipment (e.g., ear protection devices) commonly used in live shooting ranges. All participants were given 60 rounds of ammunition with the same caliber.

2.3.2. Preparation

Demographic information (DI) for all participants was recorded prior to the experiment, including name, date of birth, contact information, and shooting experience (e.g., years of experience). They were then instructed on how to recall and verbalize thoughts when required. The instructions were written in a PowerPoint format and were designed according to Ericsson and Simon's (1980) examples. Participants were informed that they should recall the thoughts that would be generated immediately after the aiming phase until the completion of a trial. Only thoughts relevant to the awareness of performance or a detected error during the aiming and firing phases should be reported. Lastly, they put on the occlusion glasses, and the protective equipment.

2.3.3. Task

When the preparation was completed, the participants were instructed to perform the actual experiment. Each trial included three different phases: aiming, triggering, and estimation, with an additional phase for verbal report. Participants stood up behind a desk in a shooting line, 50 feet away from the target in a standing position. Before each trial, a recorded voice indicated whether vision would be occluded or un-occluded for that trial. Next, participants were given the chance to aim for 3 s. An auditory "beep" stimulus was then played, signaling the onset of a delay period of 2 s or 6 s during which vision was either occluded or un-occluded. A second beep signaled participants to fire with a 3 s deadline. After the 3 s firing period, participants were required to estimate the location of their shot by marking an identical target hung on the wall near their standing position. Participants were allowed 3 s to estimate their shot location prior to initiation of the next trial. For half of the trials, participants were given 15 s to retrospectively verbalize the sequence of the thoughts they could recall from the most recent trial. The task sequence and the corresponding stimulus onset asynchrony (SOA) are illustrated in Figure 1.

The task consisted of 60 trials grouped into four blocks, which were punctuated by 3–5 min breaks in between. Each block included two visual conditions (e.g., occluded vision vs. un-occluded vision), and two

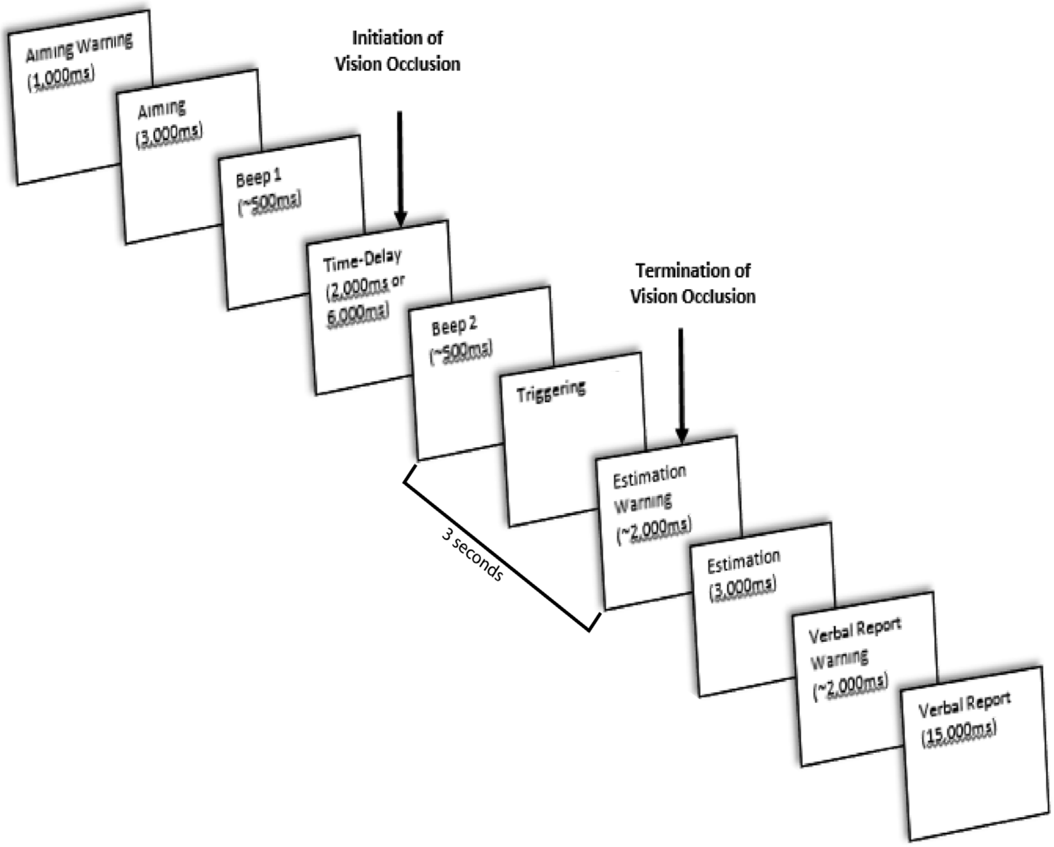

Figure 1. Task sequence of the study and corresponding stimulus onset asynchrony (SOA).

time-delay conditions (e.g., 2 s delay vs. 6 s delay), factorially combined in a 2 × 2 design to produce four equally probable conditions presented in a random order. Participants were instructed to give verbal reports for only half of the trials. The trials proceeded continuously according to a Matlab (R2015b) script using Psychtoolbox (version 3). Each participant took approximately an hour and a half to complete the study; half an hour for the preparation (instruction and set-up) and 1 h for the actual experiment.

3. Measures and data analyses

3.1. Quantitative measures

Two types of performance errors were calculated, the linear distance (in millimeters) between the actual shot location and the bullseye, henceforth "absolute error" (AE) and the linear distance between the actual shot location and the estimated location, henceforth "linear estimation error" (LEE).

3.2. Verbal reports

Prior to the experiment, participants were briefly instructed (10–15 min) on how to provide verbal reports, following the recommendations of Ericsson and Simon (1980) for collecting verbal reports in a non-reactive manner. Participants viewed a PowerPoint presentation that included examples with simple tasks where participants practiced how to simply recall and report only the sequence of the thoughts that emerged in their mind, rather than provide a higher-level interpretation of how the task was performed. We added more examples with some adjustments relevant to the shooting experiment. An example exercise follows:

Immediately after the answer to the following question is reported, start giving a retrospective report starting with the phrase, "The first thought I remember was …", as long as you can recall at least one thought. Otherwise say, "I can't recall any thoughts."

> Question: What is the fourth letter after N?
>
> Instruction: Please give a retrospective report starting with: "The first thought I remember was …"
>
> Interpretation: Had you summarized your thinking during the last question rather than reporting the sequence of actual thoughts, you might have said that "I found the letter R by counting through the alphabet." But, when people solve this problem out loud, they usually say a sequence of individual letters, such as N, then O, P, Q, before the answer, R. In this example, the retrospective report would have been just, "N, O, P, Q, R," since those were the actual thoughts while solving the problem.

Because we are interested in knowing the thoughts you had while performing the task, we wish to have the most complete sequences of thoughts you can accurately recall, instead of a summary of those thoughts.

The recorded verbal reports were mainly transcribed and segmented into three categories: *monitoring* (M), *evaluation* (EV), and *irrelevant* (I). We further subdivided each category into sub-categories. Examples of each sub-categories are provided in Table 1.

The first category, monitoring (M), coded statements relevant to attending to sensory information believed to be relevant for the task (BP, e.g., heart rate, and breathing control), firearm positioning (FP, e.g., sight alignment), and target recognition (TR, e.g., obtaining information for monitoring through the target). The first two sub-categories, BP and FP, were associated with both internal and visual sources monitoring the shooting task, while the last sub-category, TR, dealt with only visual sources of information. The second category,

Table 1
A summary of the main categories of verbal reports and the associated sub-categories and examples.

Categories	Sub-Categories	Example
Monitoring	Body Positioning (BP)	My elbow was locked.
	Firearm Positioning (FP)	I remember I lined up the front sight with the rear sights.
	Target Recognition (TR)	Acquire target, hold on target.
Evaluation	Visual feedback (VF)	My vision on target was fuzzy.
	Movement-Produced Feedback (PF)	I did not feel any movements in my hand.
	Anticipation (A)	It should have landed on the top left.
Irrelevant		The range noises were loud.

evaluation (EV), included statements reflecting the awareness of any deviations from the bull's-eye or the perfect body position at the time or a bit after engagement of the trigger. These statements technically include the awareness of an error through (a) an external source such as visual feedback, VF, (b) an internal source of feedback such as movement-produced feedback, PF, or (c) anticipation or predicting the outcome, A. Finally, the third category, irrelevant thoughts (I), consisted of irrelevant thoughts and statements related to study's procedure or distractions that could technically interfere with the attention needed for a superior performance.

Two trained students blind to the purpose of the study selected the meaningful statements and coded the segmented verbal reports about the categories presented in Table 1. Twenty percent of the coded statements made by each coder were selected and re-coded by a third coder, who was also blind to the study's questions. Inter-rater reliability was calculated, using Cohen's Kappa, and was reported for the first and the second coder as 87.4% and 89.2%, respectively.

3.3. Statistical analyses

Mixed Repeated Measures (MRM) ANOVAs were performed for AE and LEE. The analyses aimed at estimating the effects of visual conditions, time-delay conditions, and skill levels on the magnitude of actual scores and estimated errors. For the verbal protocol data, we performed a series of analyses including: Repeated measures MANOVA of the differences between skill levels in the number of reported statements during each shooting phase (i.e., categories of monitoring, evaluation, and irrelevant) under two visual conditions, and a one-way ANOVA comparing the complexity of verbalized thoughts at each skill level.

4. Results

4.1. Absolute errors

Absolute error (AE) was computed by averaging distances between the shots and the center of the target (e.g., bullseye) within each condition and block. A 2 (skill level) by 2 (visual occlusion) by 2 (time-delay) by 4 (blocks) repeated measures ANOVA was employed to compare performance across conditions and skill levels. Effects related to "block" were not of interest and will not be reported. The results verified that AE was significantly affected by time interval, F (1, 11) = 12.08, p = .005, $\eta_p^2 = 0.52$, in which sharp shooters had greater AE when the time-delay was longer (6 s), (M = 208.34, SD = 58.55, 95% CI [172.60, 244.08], $d = -0.77$). compared to when it was shorter (2 s), (M = 164.44, SD = 55.38, 95% CI [130.63, 198.24]). A significant main effect emerged for visual condition, F (1, 11) = 43.53, p < .005, $\eta_p^2 = 0.79$ and the two-way interaction effect of vision by skill level was also significant, F (1, 11) = 5.99, p = .032, $\eta_p^2 = 0.35$. Consequently, a one-way ANOVA was conducted to compare the shooting scores of two skill levels at each visual condition. The analysis revealed a significant difference between skilled and less skilled sharp shooters under the occluded condition, F (1, 11) = 6.01, p = .032. The mean comparison confirmed that skilled sharp shooters performed better (M = 193.36, SD = 56.87, 95% CI [140.67, 245.96]) than less skilled sharp shooters (M = 265.19, SD = 47.21, 95% CI [215.64, 314.73], $d = -1.37$). The difference between the two skill levels decreased under the un-occluded condition and resulted in a non-significant effect, F (1, 11) = 0.058, p = .814, ($M_{Skilled}$ = 139.41, $SD_{Skilled}$ = 35.63, 95% CI [106.45, 172.37], $M_{Less\ Skilled}$ = 147.60, $SD_{Less\ Skilled}$ = 81.87, 95% CI [61.68, 233.52], $d = -0.13$). These effects were qualified by a three-way interaction of time-delay by visual condition by skill-level, F (1, 11) = 9.57, p = .010, $\eta p^2 = 0.01$ (see Figure 2). Follow up one-way ANOVAs were conducted to test the effect of visual occlusion by time-delay at each skill-level. The shots of less skilled sharp shooters landed significantly farther from the target center under the occluded vision condition at 6 s time-delay (M = 322.50, SD = 67.90, 95% CI [261.42, 383.58]) than skilled sharp shooters (M = 215.86, SD = 68.02, 95% CI [159.31, 272.40]), F (1, 11) = 7.95, p = .017. The ANOVA results remained insignificant under the un-occluded condition for both 2 s delay, F (1, 11) = 0.31, p = .588, $M_{Skilled}$ = 129.11, $SD_{Skilled}$ = 35.42, 95% CI [96.35, 161.88] vs. $M_{LessSkilled}$ = 149.90, $SD_{LessSkilled}$ = 91.50, 95% CI [53.87, 245.93], and 6 s delay. F (1, 11) = 0.02, p = .901, $M_{Skilled}$ = 149.70, $SD_{Skilled}$ = 49.73, 95% CI [103.71, 195.70] vs. $M_{LessSkilled}$ = 145.30, $SD_{LessSkilled}$ = 74.01, 95% CI [67.64, 222.96]. These analyses confirm our hypothesis that visual occlusion is particularly detrimental to the performance of less skilled sharp shooters under longer time delays.

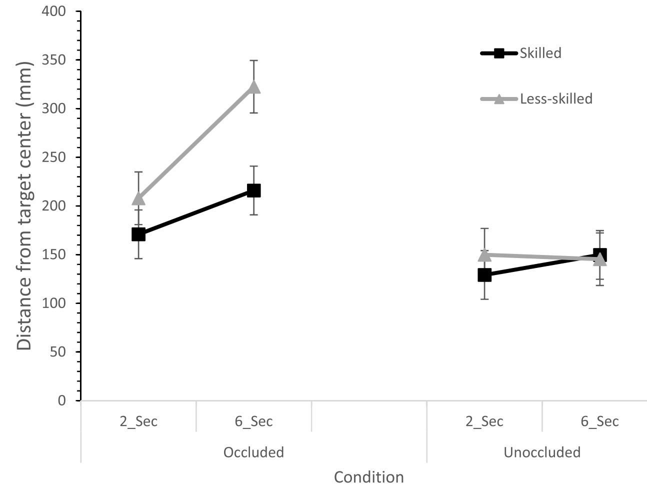

Figure 2. Means and SEs for actual scores (AS) by time-delay and visual occlusion. Note that the smaller values represent higher scores which are closer to the center of the target.

4.2. Linear estimation error (LEE)

A 2 (skill-level) by 2 (visual occlusion) by 2 (time-delay) by 4 (blocks) RM ANOVA revealed significant main effects for time-delay, F (1, 12) = 11.41, p = .006, $\eta p^2 = 0.51$, indicating a greater magnitude of LEE under the longer time-delay; (6 s), (M = 148.60, SD = 52.40, 95% CI [116.62, 180.59], compared to the shorter time delay (2 s), ($M_{2\ s}$ = 118.19, $SD_{2\ s}$ = 48.44, 95% CI [88.63, 147.64], $d = -0.60$). A significant main effect also emerged for visual occlusion, F (1, 12) = 30.47, p < .005, $\eta p^2 = 0.74$, in which sharp shooters displayed a larger LEE under the occluded condition (M = 165.04, SD = 38.67, 95% CI [141.44, 188.64] compared to the un-occluded condition (M = 101.76, SD = 62.65, 95% CI [63.52, 140.00], d = 1.22). Moreover, the visual occlusion by skill-level interaction was significant, F (1, 12) = 5.68, p = .036, $\eta p^2 = 0.34$. These effects were qualified by a three-way interaction of time-delay by visual condition by skill-level, F (1, 12) = 6.34, p = .029, $\eta p^2 = 0.37$, and presented in Figure 3. Follow

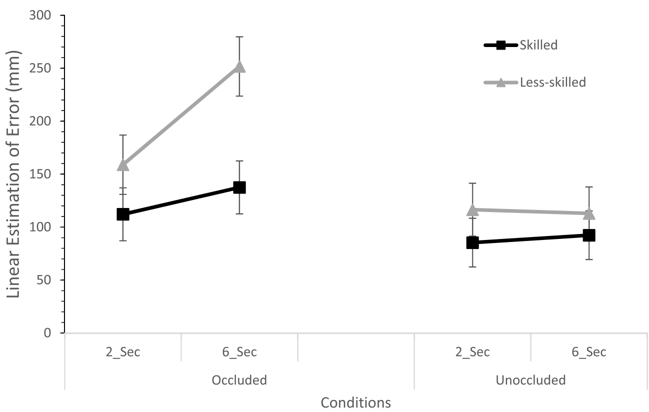

Figure 3. Means and SEs for LEE (mm) by time-delay, visual occlusion, and skill level.

up one-way ANOVAs test were conducted to test the effect of visual occlusion by time-delay at each skill-level. The analyses resulted in a significant interaction effect of visual occlusion by time-delay for less skilled sharp shooters under the occluded condition, F (1, 5) = 12.34, p = .017. Less skilled sharp shooters exhibited significantly greater error under the 6 s time-delay (M = 251.68, SD = 71.99, 95% CI [176.13, 327.23]) than at 2 s time-delay, (M = 137.46, SD = 33.15, 95% CI [106.81, 168.12]).

Thus, as predicted, the cost of visual occlusion was greater for less skilled than skilled sharp shooters and was particularly marked for the longer time delay which required extended monitoring of non-visual information.

4.3. *Verbal reports*

Verbal reports were coded as the number of statements that participants could recall from each of the subcategories presented in Table 1. ANOVAs using skill level, visual occlusion, and statement category were conducted separately for each phase. Time delay as a factor was omitted from the analyses due to non-significant effect. The descriptive overview showed that the skilled sharp shooters recalled and reported more thoughts compared to the less skilled sharp shooters in three categories: monitoring, error-detection, and time. Less skilled sharp shooters, however, reported more irrelevant thoughts compared to the skilled sharp shooters (see Table 2).

4.3.1. *Monitoring*

Three sub-categories were included in this category (M): *body positioning* (BP), *firearm positioning* (FP), and *target recognition* (TR). Compared to their less skilled peers, skilled sharp shooters recalled more thoughts relevant to body/hand and firearm positioning (e.g., movement-produced feedback), specifically when vision was occluded. This implies an awareness of the key elements of shooting performance such as positioning the hand, firearm, and trigger pull (e.g., "sights were lined up", "my elbow was locked", "relax try not to pull"). In contrast, less skilled sharp shooters produced more statements about the study's procedure and target recognition, implying attention and recall on simple and/or irrelevant cues (e.g., "I was waiting for the beep," target was blocked," "the range noises were loud").

A 2 (skill-level) by 2 (visual occlusion) by 3 (sub-category) RM MANOVA was performed to test the effect of the number of statements made in sub-category under the two visual conditions. The analysis revealed a significant subcategories main effect, F (2, 22) = 12.04, $p < .005$, $\eta p^2 = 0.52$, where the firearm positioning (FP) was stated most (M = 12.46, SD = 8.88, 95% CI [7.04, 17.89]), and the body positioning (BP) the least statements (M = 5.37, SD = 4.47, 95%, CI [2.64, 8.10], vs. target recognition (TR), (M = 6.95, SD = 4.79, 95% CI [4.03, 9.88]). A significant main effect emerged also for visual condition, F (1,11) = 7.89, p = .017, $\eta p^2 = 0.42$, where sharp shooters reported more statements under the un-occluded condition (M = 9.07, SD = 6.26, 95% CI [5.25, 12.90] compared to the occluded condition (M = 7.44, SD = 4.93, 95% CI [4.44, 10.45], $d = -0.29$). In addition, a two-way interaction of sub-category by skill-level, F (2, 22) = 5.61, p = .011, $\eta p^2 = 0.34$, and a significant two-way interaction effect of vision by skill-level emerged, F (1,11) = 10.20, p = .009, $\eta p^2 = 0.48$.

To better capture these results, RM ANOVAs for each skill level were performed separately. For the skilled sharp shooters, a significant main effect of subcategory emerged, F (2, 6) = 12.57, p = .001, $\eta p^2 = 0.68$. Bonferroni pairwise comparisons among the sub-categories revealed that firearm positioning (FP) was significantly ($p < .05$) greater (M = 16.43, SD = 8.86, 95% CI [9.06, 23.80]) than body position (M = 5.57, SD = 4.86, 95% CI [1.86, 9.28], p = .019), and target recognition subcategories (M = 6.07, SD = 4.78, 95% CI [2.10, 10.05], p = .050). The corresponding analyses for less-skilled sharp shooters was not significant (M_{FP} = 8.50, SD_{FP} = 8.85, 95% CI [0.54, 16.45], M_{BP} = 5.17, SD_{BP} = 4.46, 95% CI [1.16, 9.18], M_{TR} = 7.83, SD_{TR} = 4.78, 95% CI [3.54, 12.13]). The analyses indicate that skilled sharp shooters attended to the task-relevant features of firearm positioning (FP) more than other statements' categories and more than less-skilled sharp shooters (see Figure 4). Vision also emerged as a significant main effect for skilled sharp shooters, F (1, 6) = 14.11, p = .009, $\eta p^2 = 0.70$. Skilled sharp shooters reported more statements under the un-occluded condition (M = 11.09, SD = 6.24, 95% CI [5.90, 16.29]) than occluded condition (M = 7.62, SD = 4.91, 95% CI [3.54, 11.70]). The corresponding analyses for less-skilled sharp shooters resulted in non-significant effect ($p > .05$) (M_{Occ} = 7.28, SD_{Occ} = 4.91, 95% CI [2.87, 11.69] vs. M_{Unocc} = 7.06, SD_{Unocc} = 6.24, 95% CI [1.45,

Table 2
Descriptive values for the number of statements in each sub-category by visual conditions and skill level.

		Skilled				Novice			
		Occluded		Un-occluded		Occluded		Un-occluded	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Monitoring	BP	6.29	6.74	4.86	3.43	5.33	4.68	5.00	4.00
	FP	13.43	9.30	19.43	13.74	8.66	6.53	8.33	3.83
	TR	3.14	2.85	9.00	6.78	7.83	4.71	8.83	5.98
Evaluation	VF	1.57	1.61	1.14	1.46	1.00	0.63	1.66	2.25
	PF	13.57	12.75	12.14	6.15	9.50	4.32	9.67	5.82
	A	5.00	4.36	4.71	2.93	3.00	3.63	3.83	3.43
Irrelevant	SP	4.86	5.42	3.57	4.83	9.17	2.56	4.83	5.12

BP - body positioning, TR - target recognition, FP - firearm positioning.

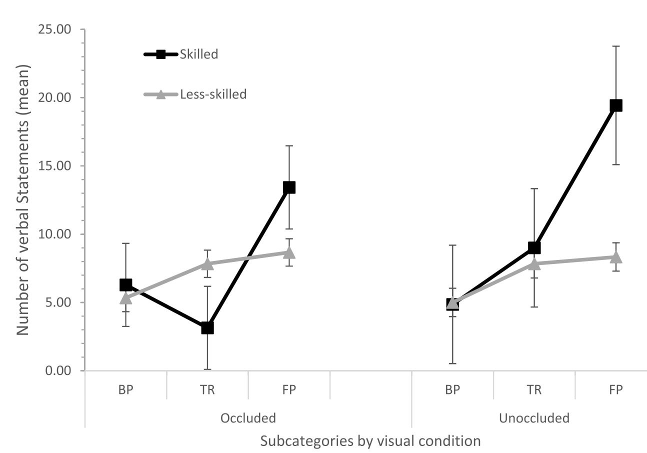

Figure 4. Means and SEs for monitoring sub-categories by visual occlusion and skill-level. BP - body positioning, TR - target recognition, FP - firearm positioning.

12.67]).

A one-way ANOVAs was performed to compare the number of target recognition (TR) statements between skill levels at each level of occlusion. The results indicated that less-skilled sharp shooters made significantly more statements in the TR sub-category, F (1, 11) = 4.90, p = .049 specifically when vision was occluded (M = 7.83, SD = 4.71, 95% CI [2.89, 12.77]) than skilled sharp shooters (M = 3.14, SD = 2.85, 95% CI [0.50, 5.78], see Figure 4). The analysis indicate that less-skilled sharp shooters used less complex sources of knowledge (e.g., information perceived from the target), even in absence of visual feedback.

To summarize, skilled sharp shooters exhibited greater reporting of knowledge of the shooting task using multiple sources of information than less skilled sharp shooters. Less skilled sharp shooters' thought processes also reflected a higher level of reports on visual sources such as target recognition (TR) compared to the skilled sharp shooters.

4.3.2. Evaluation

This category consisted of three sub-categories: awareness of errors using visual feedback (VF), awareness of errors using movement-produced feedback (PF), and anticipation of outcomes (A). A 2 (skill-level) by 2 (visual occlusion) by 3 (sub-category) RM MANOVA revealed only one significant main effect for sub-category, F (2, 22) = 18.04, $p < .005$, $\eta p^2 = 0.62$. Bonferroni tests revealed that sharp shooters reported significantly more thoughts using movement-produced feedback (M = 11.22, SD = 7.01, 95% CI [0.11, 1.23]) compared to the visual feedback (M = 1.34, SD = 1.25, 95% CI [0.11, 1.23]), and anticipation subcategories (M = 4.13, SD = 3.27, 95% CI [0.11, 1.23]). This effect did not interact with skill level.

5. Discussion

The primary aim of this study was to examine the importance of visual feedback in detecting performance errors at two skill levels of sharp shooting. First, we assumed that the removal of visual feedback and the extension of time to 6 s would hurt less skilled sharp shooters' functioning in both scoring and estimating their errors more than their skilled counterparts. Then, the developed mental representation of the shooting task amongst skilled sharp shooters was predicted to be linked to greater retrieval of information from relevant and complex sources than less skilled sharp shooters, who were expected to access simpler and more external sources of information.

Overall, the higher accuracy in the un-occluded than the occluded condition indicated that receiving visual feedback about hand positioning and the target improved shooting accuracy and facilitated awareness of performance. However, when vision was occluded, less skilled sharp shooters were the ones who suffered more in both accuracy and LEE, specifically when the time-delay extended to 6 s. Both shooting accuracy and LEE results suggest that the skilled shooters were better able to use non-visual information to hold the gun steady. The finding that both skill-level shooters performed similarly under the full vision condition, but not under occluded vision, suggests that the skilled shooters were able to maintain aim in the absence of visual information, but the unskilled shooters were thrown off considerably. It seems likely, therefore, that the skilled shooters were able to take advantage of non-visual information unavailable to the unskilled shooters, resulting in steady aim maintenance.

The LEE result further supports the use of non-visual information during aiming. To estimate LEE, it is necessary to maintain a representation of the target and a representation of the gun's point relative to the target. When vision is occluded, two sources of information about the gun's point are available: (1) prior to visual occlusion, both visual and non-visual information are used for pointing the gun, and (2) during visual occlusion, only non-visual information is used for this aim. Shooters of both levels could have used both sources of information but, given the apparent similarity in the ability of the two skill-level shooters to use vision, the superior LEE of the skilled shooters rely on non-visual mental representations for aiming and hand positioning which are not sufficiently established in the less skilled shooters, resulting in limited ability to anticipate the location of the shot.

Although accuracy and LEE were not statistically different in the two skill-level shooters except when vision was occluded, in our view, this should not be overstated. Skilled shooters showed a small advantage in LEE even with full vision (d = 0.45) and the differences in the occluded condition also attest to differences in skill. Furthermore, the skilled shooters in this study were not experts (none of the skilled shooters had attained high level ratings in the US Practical Shooting association), and the unskilled shooters could not be considered novice either; thus, the two skill-level shooters can be thought of as intermediate shooters with different levels of experience. However, the large differences under the occluded condition were evident due to a nascent ability to use non-visual information that developed over many years of experience but might not have been fully utilized under full vision. Little is known about the time course and training requirements for acquisition of genuine expertise in marksmanship. It is possible that further training with an expert instructor could be required to use all available sources of information rather than the one that is easiest to access.

The use of non-visual information is also attested by differences between skill levels in thought patterns during shot execution and error assessment. When vision was occluded, skilled sharp shooters concentrated more on multiple sources of information and reported more on firearm position (FP) than their less skilled counterparts, who still relied on visual sources of information and reported more on target recognition (TR). It appears that, when vision was occluded, the thoughts of less skilled sharp shooters changed very little: they reported simple visual information encoded while they could still see the target. The analyses of our data in the monitoring category support previous studies in which skilled performers generated more thoughts when performing a perceptual-cognitive task than less skilled performers (e.g., Ward, Williams, & Bennett, 2002; Williams, Ford, Eccles, & Ward, 2011). The narrower analyses of monitoring categories indicated that skilled sharp shooters mainly concentrated on monitoring firearm positioning, which likely requires information from multiple sources. In contrast, less-skilled sharp shooters allocated their attention largely to visual feedback (target recognition) and irrelevant thoughts (the study's procedure). This is attributed to the development of a mental representation of the shooting task which progresses over time with practice (Anderson, 1982; Ericsson & Kintsch, 1995; Williams et al., 2011). Moreover, the less developed attentional capacity of less skilled performers prevented them from attending to, or hold, multiple pieces of information in their mind at once (e.g., Kleider, Parrott, & King, 2010; Moore, Clark, & Kane, 2008), and therefore they reported more on irrelevant thoughts (study procedures) and the most available information (target recognition).

A common concern regarding verbal protocol analysis is that it is a reactive measure, altering the strategy of the respondent (e.g. Gagne & Smith, 1962). Whereas it is beyond the scope of this paper to resolve this controversy, we note that this technique has been used previously to study skilled actions in sports (Afonso et al., 2014; Arsal, Eccles, & Ericsson, 2016; Charness, Reingold, Pomplun, & Stampe, 2001; Roca, Ford, McRobert, & Williams, 2013; Ward et al., 2011), including the self-paced sport of golf. Furthermore, Fox et al. (2011) performed a meta-analysis of 94 studies using a variety of different tasks, comparing silent performance to performance with concurrent verbal reports. When verbal reports were obtained using the guidelines of Ericsson and Simon (1980, see Methods), no effect of verbal reports was found, including during the performance of non-verbal tasks.

Like previous evidence regarding the importance of anticipatory skills to execution of superior performance (e.g., McMorris & Colenso, 1996; Savelsbergh, et al., 2002; Tenenbaum, Sar-El, & Bar-Eli, 2000; Ward et al., 2002; Williams, 2000), our study distinguished skilled from less skilled sharp shooters in terms of advanced awareness and cognitive abilities in detecting performance errors. Access to visual feedback benefited both skilled and less skilled shooters, but its removal hurt the performance of the skilled sharp shooters less. This result is consistent with a heightened ability to use non-visual information in the skilled group.

In this study, we focused on the use of perceptual feedback as part of an overall process of error detection. We acknowledge, however, that further decomposition of error detection into component processes is possible. For instance, some might prefer to reserve the term “error detection” for the detection of mismatch between the goal state and the perceptual trace rather than including the initial establishment of the perceptual trace. In our view, this is largely a matter of terminology and it is not our intention to make a strong theoretical claim to conflate these sub-processes into a single construct.

5.1. Conclusion, limitation, and future directions

The findings of this study revealed that error-detection can be considered an anticipatory skill in self-paced sports where highly skilled performers may not rely on one single source of feedback to estimate performance errors, and instead, have multiple options they can fall back on when information is incomplete. Our data are consistent with the hypothesis that visual feedback plays a key role in representations of the shooting task formed early in learning, and that these representations are gradually developed and refined over years of practice by integrating other sources of sensory information. At higher levels of expertise, the need for visual feedback is reduced and reliance on body position increases. Integration of multiple feedback sources is particularly important for shooters who perform under situations with less access to visual feedback, such as police officers.

We are not certain whether the current findings generalize to dynamic tasks, as the nature of dynamic tasks is different. In dynamic sports, anticipation of upcoming events requires consideration of external feedback regarding changing conditions, such as opponent’s movements (e.g., Huys et al., 2009; Tenenbaum et al., 2000). Further research must distinguish the role of internal and external feedback in anticipation of the outcomes in dynamic tasks. Despite the small number of participants, our study detected differences in the complexity of the feedback sources that skilled and less skilled sharp shooters could attend to detect their performance errors. Interestingly, skilled sharp shooters were superior not only in predicting the location of their shot without vision but reported more relevant thoughts when monitoring performance without vision, which reflects an improved capability in anticipation of performance error even under limited sources of information. Overall, these results are particularly important for designing instruction tailored to specific skill-levels, facilitating the transition to superior performance.

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