The Effect of Cognitive Workload on Shooting Performance and Quiet Eye Duration

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Abstract

This study explored the effect of cognitive workload on shooting performance and quiet eye duration (QED) using a Stroop based handgun-shooting task (Stroop shooting). Furthermore, the difference between the reverse Stroop effect and the traditional Stroop effect when shooting based on the Attentional Control Theory was assessed. The methods used were partially based on previously published research by Wood, Vine, and Wilson (2016). Ten experienced shooters went through three shooting conditions (baseline shooting, traditional Stroop shooting, and reverse Stroop shooting) while equipped with eye tracking glasses to record eye movement. One-way ANOVA with repeated measures showed that the mean shooting performance was the best in the baseline condition as well as it yielded the longest QED compared to both experimental conditions. No significant difference was found between reverse Stroop shooting and traditional Stroop shooting. The study provides insights in how the Stroop task and eye tracking can be used to assess shooting performance and quiet eye duration in controlled laboratory setting.

*Keywords:* quiet eye, quiet eye duration, shooting performance, Stroop task, cognitive workload.
The Effect of Cognitive Workload on Shooting Performance and Quiet Eye Duration

For individuals to be able to perform well when under pressure, a lot more is needed than the required physical skill. Throughout the years, cognitive psychology has enabled us to theorize which cognitive features are at play when performing different tasks. In performance psychology, where scientists focus on enhancing performance in sports and other pressurized domains using psychological principles, it has become evident that our mental abilities are no less important than our physical abilities (Davies, Matthews, Stammers, & Westerman, 2013). These mental abilities include being able to inhibit mental distraction and to stay focused while performing the desired skill, as well as to control your eye movements (Wood, Vine, & Wilson, 2016). For the past decades, this has become a topic of interest in sport psychology and law enforcement research in relation to aiming and shooting efficiency (Nibbeling, Oudejans, & Daanen, 2012). In both of these domains, individuals deal with situations where the best possible performance is required and the stakes are high. Therefore, it has become important to find ways to assess mental processes during performance of a task, as well as ways to implement mental training in physical skill training (Vine & Wilson, 2011).

For police officers, errors in decision making and shooting accuracy in line of duty can result in significant cost, injuries, and even fatality. In basic firearms training, cadets are taught to fixate first at their weapon and then at the target (Vickers & Lewinski, 2012). Vickers and Lewinski suggested that these training standards should be revised so that rookies would be taught to fixate at the target and then align their weapon in line with the gaze. They argued that this gaze control would make the aiming method similar to what elite athletes do when aiming at a far target and would promote better shooting performance and cognitive control under pressure (Vickers & Lewinski, 2012). This gaze control method has been established in sport psychology and performance psychology as the quiet eye.
The Quiet Eye

The quiet eye (QE) is a cognitive feature that stands for the final fixation of the eyes before performing a goal-directed motor action towards an optimal target (e.g., bulls eye, golf hole, basketball ring) (Vickers, 1996). It is defined as the fixation that commences at least 100ms before an execution of a motor task (e.g., shooting, swinging, throwing) to when the eyes gaze away from the target by more than three degree visual angle for more than 100ms (Wilson, Causer, & Vickers, 2015). In this period of time, it is suggested that sensory information is incorporated with the cognitive mechanisms to plan and orchestrate the desired motor behavior (Vickers, 1996). Therefore, the QE is a perception-action variable, as it contains both internal gaze measures as well as the motor behavior of the individual (Vickers, 2011). With increased eye tracking technology that can measure fixations in various situations using head mounted lightweight glasses, QE research has made an impact in sports performance, shooting performance in law enforcement (Nieuwenhuys & Oudejans, 2010; Nieuwenhuys, Savelsbergh, & Oudejans, 2015), and even surgery performance of surgeons (Causer, Vickers, Snelgrove, Arsenault, & Harvey, 2014).

Research findings suggest that the longer the QE period while aiming at a target, the better the actual performance (Vickers, 2011). A meta-analysis from 2007 shows that longer quiet eye duration (QED) is one of the three most important cognitive features of motor expertise, with the other two being the target fixation itself and to control the amount of fixations made (Mann, Williams, Ward, & Janelle, 2007). Extended QED is therefore considered to be a cognitive skill of expert performers in aiming tasks. In a simulated police shooting experiment where officers were to determine whether a human target had a gun or a cell phone, and then shoot at the target if it had a gun, experienced police officers had a longer QED than rookie officers (Vickers & Lewinski, 2012). In the experiment, rookie police officers were more likely to make a rapid eye movement saccade towards their gun
before shooting at the human target when it had a gun. Doing that, the rookies fixated only 34% of the time on the target, resulting in poor shooting efficiency and longer reaction time. Not only is it important to start the QE onset as early as possible, but it is also suggested that picking up target information as late as possible is better for shooting accuracy and to control for increased cognitive workload (de Oliveira, Oudejans, & Beek, 2006).

**Cognitive workload**

Extended QED increases the odds that the brain has the time it needs to organize the mechanisms used to plan and control an effective motor action (Vickers, 2011). Based on the *Attentional Control Theory* (ACT), efficiency is determined by the effectiveness of individuals performing a task as well as the cognitive effort they invest in the task (Eysenck, Derakshan, Santos, & Calvo, 2007). In a controlled laboratory setting, participants efficiency can be measured by creating a conflict between a goal directed action involving a far aiming task, such as shooting, and a secondary salient stimuli (Wilson, Wood, & Vine, 2009). According to the ACT, by invoking increased cognitive workload, efficiency will decrease, as a cognitive investment is made in our *central executive*, which is a vital part of our *working memory*. The main functions of the central executive is to handle our attention control, shifting between tasks, as well as controlling our impulse and response inhibition (Tulving, 1972).

According to Vine and Wilson (2011), perhaps the best explanation for the underlying neural mechanisms of the quiet eye in regards to the ACT, are the two attentional systems; the goal-directed attentional system and the stimulus-driven attentional system coined by Corbetta and Shulman (2002). The goal-directed system focuses on the relevant task at hand while the stimulus-driven system responds to an emerging salient stimulus, that may or may not be relevant to the task at hand (Wilson, et al., 2009). These two systems battle for mental resources in the central executive and do not interact (Corbetta & Shulman, 2002). The ACT
acknowledges that impairment and increased load on the central executive, increases the influence of the stimulus-driven attentional system and thereby disrupting the balance between the two systems (Eysenck et al., 2007). In high stake situations for police officers and far aim shooting of athletes, this kind of cognitive workload can impede performance on a perception-action task, e.g., eye movement errors towards a cue, and delayed initiation of anti-saccade movements (Barrett, Tugade, & Engle, 2004).

Two studies (Wilson, Vine, & Wood, 2009; Wilson, Wood, & Vine, 2009), found that increased cognitive workload resulted in more fixations, decrease in QED and less accuracy for participants in both soccer penalties and basketball free throws. In a later soccer penalty study, Vine and Wilson (2011) hypothesized that based on their results, that longer QED resulted in a more robust balance between goal-directed processing and stimulus driven processing. As longer QED results in longer goal-directed processing, it prevents the increased cognitive workload from the stimulus driven processing to take over, and thereby establishing balance (Vine & Wilson, 2011). In line with these results, Neuwenhuyns and Oudejans found that police officers that were trained in aim shooting under high anxiety conditions, were more calm in a post-test with high anxiety as they had longer QED compared to the control group (Nieuwenhuys & Oudejans, 2010). Indicating that those officers had more control over the goal directed attention system in contrast to the control group as anxiety interrupts the balance between the two attentional systems.

**Stroop interference**

A popular method to assess attention- and executive control of behavior by increasing cognitive workload in controlled conditions is the *Stroop task* (Stroop, 1935). In the *traditional Stroop task*, participants are supposed to report the color of a word that is presented to them, no matter what the word actually says. The error or the response delay in reporting the color when it is incongruent with the word (e.g., the word **BLUE** is presented in
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red), as compared to when the word and the color are congruent (e.g., BLUE, written in blue), is known as Stroop interference (Kane & Engle, 2003). Even though participants are told to either ignore the word, the irrelevant information is automatically selected for cognitive analysis, and therefore interferes with the target response, resulting in increased cognitive workload (Davies et al., 2013).

Working memory capacity (WMC) is a predictor of individuals performance on the Stroop task (Kane & Engle, 2003). However, both people with high-WMC and low-WMC may experience Stroop interference, but to not to the same degree (Hutchison, 2011). This effect can also be created with the reverse Stroop effect (Durgin, 2000). That is when participants are supposed to report what the word is saying, regardless of its color (e.g., if the word BLUE is written in red, participants would say “blue”). According to Durgin (2000), the reverse Stroop interference should be mimimized compared to the traditional Stroop interference as reading the word visually guides the participant to the correct response. Using a Stroop based handgun shooting task, Wood et al. (2016), found that participants in a low-WMC group had impaired shooting performance and reduced QED in a reverse Stroop task. However, the high-WMC group was not affected by the interference of the reverse Stroop, indicating that the cognitive workload induced by the reverse Stroop task was not enough to affect the high-WMC group (2016). A study comparing the two methods in clinical setting also demonstrated more detrimental effect of the traditional Stroop task compared to the reverse Stroop task (Ikeda et al., 2013).

Current study

Most QE research has focused on in situ experimental design, where participants are put in realistic or anxiety causing situations (e.g., Nieuwenhuys et al., 2015; Vickers & Lewinski, 2012). The following study was an exploratory study with the interest of assessing the effectiveness of using Stroop based handgun shooting task in a far aim-shooting situation.
to measure QED in a controlled environment. Furthermore, based on Vickers and Lewinski (2012), there was an interest to see if the methods used in the current study could be a subject to far aim handgun training of police cadets in the future. The aim of this study was to control as much as possible while using a realistic firearm to try to determine to which extent a Stroop task affected participants shooting performance and QED. Based on the recommendations of Eysenck et al. (2007), the experiment was conducted in a laboratory setting under controlled conditions, as they increase the possibility to reliably measure the cognitive processes at hand.

To the best of knowledge, this is the second study to use the Stroop task as a method to assess QED and shooting performance. Wood et al. (2016) assessed the connection between individual differences in WMC and anxiety on the QE using a Nerf gun in a reverse Stroop based handgun-shooting task. The current study had randomized conditions with the reverse Stroop task, as well as the traditional Stroop task, to evaluate if there was a difference between the two methods as implied in previously mentioned research. Furthermore, instead of a Nerf gun, a soft air gun was used, for more accurate shooting performance measures. From now on, Stroop based handgun shooting task will be referred to as Stroop shooting.

Based on the aforementioned literature, the following hypotheses were made:

1. Shooting performance will be significantly better in the baseline condition compared to the traditional Stroop shooting and reverse Stroop shooting conditions.
2. Participants will have longer QED during baseline shooting compared to traditional Stroop shooting and reverse Stroop shooting.
3. QED will predict the shooting performance of participants.
4. Shooting performance and QED will be worse in the traditional Stroop shooting condition compared to reverse Stroop shooting condition.
Method

Participants

A convenience sample of experienced shooters was used for this study. Participants were chosen with a snowball method through individuals with shooting experience. Novice shooters have less cognitive space for effective task execution as e.g., anxiety of shooting a gun for the first time and having never done target shooting limits their attentional resources (Nibbeling et al., 2012). Experienced shooters have basic shooting skills automated, allowing for more focus on the effect of increased cognitive workload on shooting performance and quiet eye duration (QED). Therefore, participants had to report their shooting experience to determine if they were fit for participation, as pilot testing showed that no previous shooting experience might affect the data. Inexperienced shooters in pilot testing of the study tended to squint more, and were more focused on the actual act of shooting a gun, rather than aiming. After excluding data from five participants due to lack of eye movement data obtained, data from ten male participants in the age range of 23-60 years old ($M$: 30.5, $SD$: 11.28) was extracted for further analysis. No compensation for the participation was provided, and there was no demographical exclusion criterion. All participants had to sign an informed consent before the commencement of the experiment (Appendix A).

Design

The study was a quantitative within-subject repeated measures design. The study included three independent variables: baseline shooting, traditional Stroop shooting and reverse Stroop shooting. The two Stroop shooting conditions were randomized to prevent practice effect. In each condition participants shot 16 rounds. Shooting performance and QED were the two dependent variables respectively.

Baseline shooting. In the baseline condition, participants got instructions on the screen in front of them to focus on a (+) sign in the middle of the screen and then shoot at a
target that would appear one by one in each of the four corners of the white wall in front of them (Figure 1). Based on the method of Wood et al (2016), the (+) appeared for 2 seconds, followed by 2 seconds of the target. These time standards were used in all three conditions.

![Figure 1](image1.png)

*Figure 1.* In the baseline shooting condition participant would focus on the plus sign in the middle and then aim at the target that would appear in one of the four corners and try to shoot as quickly and as accurately as possible.

**Traditional Stroop shooting.** In the traditional Stroop shooting condition, participants were instructed to focus on the *color of a word* in the middle of the screen that appeared for 2 seconds. Then, four targets would appear on the white wall in front of them for 2 seconds, and they were to shoot at the target that corresponded the color of the word (Figure 2).

![Figure 2](image2.png)

*Figure 2.* Traditional Stroop shooting. Here, the word BLUE is presented in red. In this example, the correct action would be to shoot at the RED target.
Reverse Stroop shooting. In the reverse Stroop shooting, participants were instructed to focus on the meaning of the word, and to ignore the color the word was written in. When the targets came up, they were to shoot at the corresponding target (Figure 3).

![Figure 3. Reverse Stroop shooting. Here the word YELLOW is presented in blue. In this example, the correct action would be to shoot at the YELLOW target.](image)

Measures

Cognitive workload. Cognitive workload of participants was determined in three ways. First and second, cognitive workload was determined by the difference in shooting performance and QED between the baseline condition and each Stroop conditions. Lastly, participants answered the Self-Assessment Manikin (SAM) to assess self-perceived cognitive workload of participants before and after the experiment (Appendix B) (Bradley & Lang, 1994). It is a 9-point scale across three dimensions.

Shooting performance. Shooting performance was determined by the mean discrepancy between the middle of the target (the bulls eye) and the actual hits made by the participants using the air gun in each condition. The closer to the bulls eye of targets, the better the performance. A millimeter ruler was used to measure the discrepancy. If participants did not hit the target sheet, a distance of 20 cm was registered, as it was the shortest distance from bulls-eye to the end of the target sheet.

Quiet eye duration. Based on theory, the QED was defined as the final fixation on
the target before pulling the trigger and until the eye gazes a way by at least 3 visual degrees, measured in milliseconds (Vickers, 1996). Instances when participants were not fixating on the target, or shooting before establishing the quiet eye (point shooting), were not registered for QED. The QED was measured using a Tobii Pro Glasses 2 mobile eye tracker that both measures the fixations and had the gun in sight in the scene camera on the glasses. Using this method, the exact time of the shooting within every fixation was found, as the trigger pull was visible, as well as the sound of the gun going off using the eye tracker audio.

**Instruments**

**E-Prime.** The program E-Prime (Schneider, Eschman, & Zuccolotto, 2002) was used to design the experiment that was then projected on a white wall in front of them. The order of the Stroop conditions was randomized by E-Prime.

**Soft air gun.** For aim shooting, a 90mm semi-automatic soft air handgun of the model WE-G001A-B-17-A-BK-GEN3 from the company We Model CO., LTD was used. The gun is 200mm in length and weighs 800 grams and is charged with gas to shoot the pebbles. Using this kind of pistol increased validity of the study as it makes the shooting more realistic than other simulated shooting methods, e.g. Nerf gun, water pistol, computer keyboard. For the studies purpose, the gun was tested for accuracy. From a series of five shots at a target the same size as used in the experiment, there was a spread of 30mm, which was considered acceptable for the study.

**Eye tracking.** Lightweight Tobii Pro Glasses 2 were used for eye tracking. The glasses are fit with four eye cameras (two for each eye) and a scene camera. The data from the eye tracker could be analyzed with the Tobii Pro Lab that accompanied the glasses. In the Tobii Pro Lab, it was possible to analyze eye data, scene video data and audio from the recordings. For preliminary results, a fixation criterion was set in Tobii Pro Lab. Based on
Nyström and Holmqvist (2010), a fixation was detected by the eye tracker if the gaze of the participant was stable for 120 ms within 1.2 degrees of visual angle.

**Procedure**

Participants arrived one-by-one to the laboratory. When a participant arrived he was presented with an informed consent containing all the information about the experiment and one sheet of the Self-Assessment Manikin (SAM). He was asked to read through the informed consent thoroughly and sign if he wanted to go through with the experiment. After the signing of the informed consent, he answered one of the SAM’s and then handed both the papers back to the researcher.

Before the commencement of the experiment, all participants were briefed on the handgun, safety measures and the procedure of the experiment. Due to safety reasons, the researcher loaded the gun and handed it to the participant and made sure that nothing was in the way and that the participant would never point the gun at himself, nor the researcher. The participant was then instructed to shoot 3 shots at a practice target to get the feeling of the gun.

For the experiment itself, the participant was positioned in a chair with a headrest five meters from a white wall created by sheet covered cardboard boxes. The reason for using a chair with a headrest was to prevent head movements. If participants moved their heads to a certain extent, the Tobii Pro Glasses 2 would not be able to gather eye-tracking data. A projector in the middle of the room projected instructions and targets on a white wall in front of the participant. The researcher put the eye tracker on the participant and adjusted accordingly and then calibrated the eye tracker.

Before each condition, the participant was reminded to keep his head still on the headrest and instructed to shoot as accurately and as fast as possible. When the participant had read and understood the instructions for each condition, the researcher would start the
condition.

The recording of the Tobii Pro Glasses 2 was not stopped between each condition unless there was some issue concerning the glasses. To ensure that the eye tracking data was good, the participant was asked to fixate in each of the corner of the wall in front of him between conditions, and the researcher determined if the calibration was still good, based on the video observation.

After each condition, each shot on the target paper was marked with red (baseline condition), green (experimental condition 1), and blue (experimental condition 2) pens. This was done so that the shots fired in each condition could be identified for comparison in shooting performance. After the final experimental condition, the participant was asked to answer the second SAM in order to see the difference in self-perceived cognitive workload. The participants were then debriefed and thanked for their participation in the study.

Data analysis

A one-way analysis of variance (ANOVA) with repeated measures was used to assess difference in shooting performance and QED between each participant with a significance level of $\alpha = .05$. For further analysis on performance between the three conditions, a planned contrast and Bonferroni Post hoc analysis was used. For statistical analysis, IBM SPSS Statistics was used as well as Tobii Pro Lab for eye tracking data.

Results

Descriptive statistics

Gaze data based on the Nyström & Holmqvist criterion (2010) demonstrated a mean of 56 fixations ($SD = 11.41$) across the three conditions. Of these fixations, a mean of eight quiet eye instances were recorded based on Vickers (1996). The Self-Assessment Manikin did not reveal any significant difference in self-perceived cognitive workload pre ($M = 3.75$, $SD = 1.59$) and post experiment ($M = 3.95$, $SD = 1.77$).
Hypothesis 1

The first hypothesis was that shooting performance would be better in the baseline shooting condition compared to the reverse Stroop shooting condition and the traditional Stroop shooting condition. Figure 4 shows the shooting performance of participants measured as the mean distance from the center of the target in centimeters, shorter distance meaning better performance. Analysis using one-way repeated measures ANOVA illustrated a significant difference in shooting performance between the three conditions, $F(2, 18) = 6.6, p = .007, \eta_p^2 = .423$.

![Figure 4. Shooting performance (Cm) for each shooting condition](image)

A pairwise comparison using Bonferroni post-hoc test revealed a significant difference in shooting performance between baseline shooting ($M = 6.34$ cm, $SD = 2.8$) and traditional Stroop shooting ($M = 8.14$ cm, $SD = 3.69$). There was not a significant difference between reverse Stroop shooting ($M = 6.82$ cm, $SD = 2.59$) and the other conditions.

Hypothesis 2

The second hypothesis was that quiet eye duration (QED) would be longer in the baseline shooting condition compared to the reverse Stroop shooting condition and the
traditional Stroop shooting condition. QED was the longest in the baseline condition \((M = 851\text{ ms}, SD = 205)\) compared to traditional Stroop shooting \((M = 839\text{ ms}, SD = 152)\) and finally reverse Stroop shooting \((M = 820\text{ ms}, SD = 140)\). However, there was no significant difference in QED between the three conditions, \(F(2, 18) = .116, p = .891, \eta_p^2 = .013\). With this extremely small effect size using the Cohen’s \(d\) (Cohen, 1988), the observed power for the analysis was .06.

**Hypothesis 3**

The third hypothesis was that QED would predict shooting performance. There was no significant correlation found between QED and shooting performance in any of the three conditions.

**Hypothesis 4**

Finally, testing the difference in QED and shooting performance between reverse Stroop shooting and traditional Stroop shooting, a pairwise comparisons using Bonferroni post hoc test demonstrated a non-significant difference between reverse Stroop shooting performance \((M = 6.82\text{ cm}, SD = 2.59)\) and traditional Stroop shooting performance \((M = 8.14\text{ cm}, SD = 3.70)\), \(p = .201\). Furthermore, it also showed non-significant difference in QED between reverse Stroop shooting \((M = 820\text{ ms}, SD = 140)\), and traditional Stroop shooting \((M = 839\text{ ms}, SD = 152)\), \(p = 1\).

**Discussion**

The aim of current study was to see if Stroop shooting could be used to assess quiet eye duration (QED) and shooting performance in a controlled laboratory setting. Furthermore, an interest was at hand to examine the benefits of using this setting as a potential aim-shooting training for rookie police officers. In contrast to previously mentioned studies, the current study did not provide support for its hypotheses. Only one hypothesis of four was partially supported with significant results, while others were not.
Hypotheses

Hypothesis 1 and 2 stated that shooting performance would be better and that quiet eye duration would be longer during the baseline condition compared to reverse Stroop shooting and traditional Stroop shooting. Participants had overall better shooting performance and longer quiet eye duration in the baseline shooting condition compared to the other two. The difference between the baseline condition and traditional Stroop shooting was significant, but not reverse Stroop shooting. Greater sample size may have yielded significant results between all conditions but based on the results, the findings of the study did not provide any support to the Attentional Control Theory.

The lack of difference in the quiet eye duration between the three conditions may be the result of a number of factors. As demonstrated in the descriptive statistics, the mean instances of the quiet eye were 8 of the overall 56 fixations across conditions. Not only does this mean a low percentage of quiet eye instances in the whole experiment, but it also means that the instances varied across participants and conditions. One participant may have had seven instances of the quiet eye with the mean of 500 ms in the reverse Stroop condition while having only one instance of the quiet eye in the traditional Stroop condition with the duration of 950 ms, giving a false implication for the results. Of 16 shots, it is better to have a few instances of the quiet eye rather than only one long one. However, the interest of this study was quiet eye duration, not the frequency of the quiet eye, but it still needs to be taken into account.

The results from the Self-Assessment Manikin indicated that the cognitive workload inflicted during the experimental conditions was not that much that it would cause participants to perform that much worse compared to the baseline condition. In previously mentioned articles, anxiety was inflicted on participants, and The Mental Readiness Scale Form-3 (Krane, 1994) used to measured state anxiety of the participants (Vine et al., 2011;
Wood et al., 2016). For this experiment, no anxiety was inflicted so the SAM was chosen to measure cognitive workload.

Some uncontrollable factors may have affected the gaze data, e.g., runny eyes of a participant due to a cold, which affected the participants’ eye measures. Lastly, it varied how participants aimed with their eyes. The Tobii Pro Glasses 2 records both eye with two cameras, ensuring the best measure possible. Therefore, if a participant only aimed with one eye, the measure would evidently suffer as the eye tracker only gets a part of the information it needs to be as accurate as possible.

Hypothesis 3 stated that quiet eye duration would predict shooting performance, that is, longer quiet eye duration would yield better shooting performance. No significant correlations were found between the quiet eye duration and shooting performance between conditions. This may be the result of the lack of difference between the inflicted cognitive workload in the conditions. As the SAM results indicated, even though increased workload was inflicted, and the shooting results showed that participants had the best performance in the baseline condition, it was not done so to a significant degree. For the experiment, the time of 2000 ms for the participants to aim and shoot at the target based on (Wood et al., 2016) was maybe too long. It was observed that in the experimental conditions, participants were able to make gaze mistakes but still have time to fixate at the correct target and shoot with accuracy. It should have been taken into account that in the experiment from 2016 there was also an anxiety feature where participants where shot with foam bullets Russian roulette style while aiming at the targets, thereby further distracting participants by increasing their state anxiety (Wood et al., 2016).

Finally, hypothesis 4 stated that shooting performance and quiet eye duration would be better in the reverse Stroop condition compared to the traditional Stroop condition. Contrary to the predictions, there was no significant difference found in shooting
performance and quiet eye duration between reverse Stroop shooting and traditional Stroop shooting. However, the mean distance from the bulls-eye in the reverse Stroop shooting condition \( (M = 6.85 \, \text{cm}) \) was closer to the baseline condition \( (M = 6.2 \, \text{cm}) \) than the traditional Stroop shooting condition \( (M = 8.14 \, \text{cm}) \). As mentioned in Durgin (2000), this may be because of the visual guidance nature of the reverse Stroop, yielding less cognitive workload than in the traditional Stroop task. In contrast, the quiet eye duration was longer during traditional Stroop shooting. Those results contradict the predictions for the hypothesis as well as previous results on the comparison between the reverse Stroop and traditional Stroop (Ikeda et al., 2013; Ikeda, Hirata, Okuzumi, & Kokubun, 2010). As this is the first time the traditional Stroop task has been used in a shooting experiment, as well the results were not significant, they are not a subject for generalizability and need to be replicated.

**Limitations**

The study had a number of limitations. First, a bigger sample size would have been needed for more variability in quiet eye duration and shooting performance scores. The original sample size was larger than ten participants, but due to technical errors, and a change of eye tracking glasses, the sample size was decreased. Even though the latest eye tracking gear was used, measuring gaze behavior when individuals are performing a motor behavior can be troublesome. Second, the instructions participants got were direct and concise, however, there was a difference in how well participants complied with these instructions, resulting in missing data. On the same thought, even though it was considered strength to control for head movements, it was not the primary choice of methods. During pilot testing, a significantly more data was lost due to individual differences in standing, squinting and head movement. It is therefore a threat to its real life application to have the participants sitting down, as individuals tend to not sit while aiming and shooting, making the current study a
context or task specific. Third, even though participants had shot a gun before, they had never done this type of shooting before and had to adjust to this foreign shooting setting. It took participants some time to get in to a rhythm of this kind of shooting and after the baseline condition, they had gotten used to the design as well as the time they had to aim at the target to shoot. Randomizing the baseline condition with the other two conditions could have prevented this effect, as they were randomized. Fourth, and perhaps the greatest limitation was that a link between quiet eye duration for specific shots was not provided as is possible with basketball (Wilson et al., 2009), dart throwing (Nibbeling et al., 2012) and handgun shooting where more external cameras are utilized (Nieuwenhuys et al., 2015). This was not possible due to the distance from the targets, as the scene camera Tobii Pro Glasses 2 were not able to pick up exactly where each shot went.

**Future research**

For future research it would be interesting to see this experiment being replicated, taking into account all methodological issues and proposed solutions as well with larger sample size. Furthermore, it would be ideal to divide participants into groups depending on their expertise, which has been a popular method in aforementioned quiet eye research (Vickers & Lewinski, 2012; Vine et al., 2011; Wood et al., 2016).

Based on Vickers & Lewinski (2012), it would be interesting to implement this experiment in firearm training in a police academy. Police academy instructors as well as students could provide valuable insights on the design.

Future research should also add reaction time to the design, as the Stroop effect is either an error or delayed response or both (Stroop, 1935). To do this, it would be possible to present the word and the targets on the screen at the same time, and measure the reaction time from when the targets arrive until when the eyes have found the right target.
Conclusions

In closing, this study was the second known to use Stroop based handgun shooting task as a method to assess shooting performance and quiet eye duration, and the first one to use the traditional Stroop task. It failed to demonstrate significant results, but did however provide valuable methodological insights for future studies in this line of research. It is a wish that the interest in quiet eye duration and its application in sports and high-pressure situations continues as technology that allows its further exploration is getting better every day.
References


Appendix A

Informed consent

Research Study: The Effect of Cognitive Workload on Shooting Performance and Quiet Eye Duration


You have been asked to participate in a research study. On this sheet is information about the study and what is required of you as a participant. If there is anything unclear to you, please ask the researcher. Furthermore, you are kindly asked to not commence participation unless you understand your role and that you have had enough time to read over the instructions.

Purpose: The purpose of this study is to assess the effect of increased cognitive workload on shooting performance and Quiet Eye Duration during controlled shooting.

Your assignment: Your participation involves shooting three 15 rounds with an air gun at targets in three different conditions wearing a mobile eye tracker. A short pause will be made between each condition. All practical things such as loading of the gun will be made by the experimenter. The experimenter will explain all steps and give further instructions.

Time and location: The experiment takes approximately 15 minutes per participant. It will be conducted in the dep. of Psychology at Lund University, Paradisgatan 5P, 221 00 Lund.

Possibility of risk and/or inconvenience. You should not experience any risk or inconvenience during the participation in this study. Should you experience minor risk or inconvenience you are kindly asked to let the research know.

Confidentiality and discretion: No personal information will be acquired for this study. All collected data will be labeled with a participant’s number and are untraceable to individual participants.

Right to terminate participation: You have the full right to terminate participation at any point in the study without any consequences. Even though you sign this written consent, you are not required to finish this study to the end.

I hereby confirm I have read the aforementioned information on the study The Effect of Cognitive Workload on Shooting Performance and Quiet Eye Duration. I am fully aware of my role as a participant and my rights.

Signature and date: __________________________________________________________
Age: _____
Researcher Signature: ______________________________________________________
Appendix B

Du skall besvara följande frågor genom att kryssa över den bild som bäst representerar hur du känner dig just nu. Det går även bra att kryssa i rutorna mellan figurerna.

Hur känner du dig?

Hur positiv/negativ känner du dig just nu?

![Diagram of positive, neutral, and negative feelings]

Positiv  Neutral  Negativ

Hur upphetsad/lugn är du

![Diagram of excited, neutral, and calm]

Upphetsad  Neutral  Lugn

Hur kontrollerad/hur mycket kontroll upplever du att du har?

![Diagram of controlled, neutral, and out of control]

Kontrollerad  Neutral  I kontroll