The Effect of Time Constraints and Running Phases on Combined Event Pistol Shooting Performance

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Abstract

The combined event is a crucial aspect of the modern pentathlon competition but little is known about how shooting performance changes through the event. This study aimed to identify (i) how performance-related variables changed within each shooting series, and (ii) how performance-related variables changed between each shooting series. Seventeen modern pentathletes completed combined event trials. An optoelectronic shooting system recorded score and pistol movement, and force platforms recorded centre of pressure movement 1 s prior to every shot. Heart rate and blood lactate values were recorded throughout the event. Whilst heart rate and blood lactate significantly increased between series ($p<0.05$), there were no accompanying changes in the time period which participants spent aiming at the target, shot score, pistol movement or centre of pressure movement ($p>0.05$). Thus, combined event shooting performance following each running phase appears similar to shooting performance following only 20 m of running. This finding has potential implications for the way in which modern pentathletes train for combined event shooting, and highlights the need for modern pentathletes to establish new methods with which to enhance shooting accuracy.

Keywords: modern pentathlon, body sway, pistol movement, fatigue

Introduction

The combined event is composed of two of the five disciplines which make up the modern pentathlon competition; pistol shooting and running. In its original format, as detailed by pre-2013 modern pentathlon rules, athletes must complete the following tasks:

20 m Run → Shooting Series 1 → 1 km Run → Shooting Series 2 → 1 km Run → Shooting Series 3 → 1 km Run

Within each shooting series athletes attempt to hit five targets as quickly as possible. Once this is achieved athletes immediately begin the next running phase. If five hits are not achieved within 70 s then athletes automatically begin the next running phase. The rules of the combined event have since been modified further, with athletes required to complete four 800 m running phases interspersed by four 50 s shooting series. Thus, whilst the event has been adapted, the concept of shooting accurately following bouts of exercise remains the same.

To date, few researchers have considered which aspects of the combined event have the greatest influence on success. Current findings suggest that success is determined primarily by shooting performance and not running speed (Le Meur, Hausswirth, Abbiss, Baup & Dorel, 2010; 2012). In their analysis of a World Cup competition, Le Meur et al. (2010) assigned athletes to one of three groups based on their overall combined event time. No significant differences in running times were found between any of the three groups. However, the athletes who completed the event in the shortest time took significantly fewer shots ($p<0.05$), and finished each shooting series more quickly than those who took longer to complete the event.

The findings of Le Meur et al. (2010) highlighted the importance of each shooting series to the combined event. This was further emphasised in a subsequent analysis (Le Meur et al., 2012), which reported that the pace of each running phase had no significant effect on overall event time ($p>0.05$). Moreover, by increasing the pace of the first two 1 km phases, athletes spent significantly longer shooting in the third series ($p<0.05$). Thus, the benefits of quicker running phases were counteracted by the increase in shooting time. These findings are crucial, as they highlight the importance of a successful shooting performance and the need for athletes to direct training towards methods of improving combined event shooting technique.

Whilst the research of Le Meur et al. (2010; 2012) undoubtedly produced interesting findings regarding the temporal characteristics of performance, it is now important to advance this research area. By including the effects of the combined event on the kinematic and kinetic variables associated with shooting, it will be possible to examine the processes behind a successful combined event shooting performance. The understanding of these processes has previously been achieved for precision shooting (Ball, Best & Wrigley, 2003; Dadswell, Payton, Holmes & Burden, 2013; Heimer, Medved & Spirelja, 1985; Mason, Cowan & Gonczo, 1990). One key finding from this research was the effect of movement on shooting performance, with pistol movement and body sway accounting for up to 37% and 40% of the variability in shooting accuracy respectively (Mason et al., 1990). Combined event performance, however, differs from precision shooting (Dadswell et al., 2013), as it has a greater target size and reduced shot times (Berrigan et al., 2006; Goonetilleke & Lau, 2009).

To the authors' knowledge, only one study has compared the processes related to combined event and precision shooting performance (Dadswell et al., 2013). Comparisons between the two events revealed that pistol movements and body sway were significantly greater for the combined event than for precision shooting (p<0.05). Correlations between pistol movements, body sway and shot score also differed between the two events, highlighting the different performance requirements. Performance was, however, only analysed within the first shooting series of the combined event, prior to the running phases. Each running phase, and its associated fatigue, is likely to further influence shooting performance and thus, the effect of each running phase on combined event shooting performance should also be considered.

Whilst there has been limited research into combined event shooting, some has considered the shooting performances of biathletes. Arguably, of all the shooting disciplines, biathlon is most similar to the combined event. Accepting the obvious performance differences between the two sports, biathlon can therefore provide an indication of the effect of exercise on shooting performance. In their analysis of biathlon, Hoffman, Gilson & Westenburg, (1992) reported that increasing exercise intensity negatively influenced shooting performance. An increase in intensity resulted in reduced scores and significantly fewer shots on target, alongside significantly increased shot-group diameter and rifle movements. These findings supported a popular strategy in biathlon whereby athletes reduce skiing velocity in the final approach to each shooting phase in an attempt to reduce fatigue and enhance shooting performance (Hoffman et al., 1992).

If the effect of exercise on shooting performance is found to be similar between biathlon and the combined event, then the tactics employed by biathletes to enhance shooting performance could also prove beneficial to modern pentathletes. However, in their analysis of the effect of exercise on the shooting performance of police officers, Brown, Tandy, Wulf & Young (2013) reported no significant correlations between pistol shooting performance and heart rate following changes in heart rate of 60 bpm. As such it is currently unclear whether the approach used by biathletes can transfer directly to the combined event.

Research Aims and Hypotheses

Previous research has considered the effect of biomechanical variables on shooting performance in the first series of the combined event (Dadswell et al., 2013). None, however, has considered the effect of either the 70 s time limit or the running phases on performance in each of the three shooting series. Therefore, the aims of this research were to: (i) identify any changes in performance-related variables within each shooting series; and (ii) identify any changes in performance between each shooting series. There were two hypotheses for this research. First, as the time remaining to complete each series reduced, shot time and shot score would significantly reduce and pistol movements and body sway would significantly increase. Second, average shot score would significantly decrease with each successive shooting series and average pistol movement and body sway would significantly increase.

Methods

Participants

Seventeen national development athletes (6 male, 11 female) (mean age 17.4 ±3.2 years, mass 59.4 ±8.7 kg, height 172.9 ±7.15 cm) completed the combined event task using their own pistol (4.5 mm calibre compressed air CO_2 single shot air pistol, weighing less than 1500 g). Written informed consent was obtained from all participants prior to testing and also from participant's parents for those athletes under 18 years of age. The study was approved by the local research ethics committee.

Tasks

Testing took place in a shooting range, conforming to ISSF shooting regulations, within the university's biomechanics laboratory. The sequence of tasks followed the order detailed by pre-2013 modern pentathlon rules. Each running phase required participants to complete two circuits of a 500m grass route directly outside the laboratory. Participants were instructed to complete each phase at a pace similar to that which they would use in competition. For each live fire shooting series participants stood 10 m from a mechanical combined event target.

Pistol Movements, Shot Location and Shot Time

Pistol movements over the final second before the shot, shot score, and shot time were recorded using a SCATT USB opto-electronic shooting system (SCATT, Moscow) positioned in front of the centre of the mechanical target. Data were recorded using SCATT Professional software following the procedure used by Dadswell et al. (2013).

Centre of Pressure Measurements

Two AMTI OR6-7-2000 force platforms (Advanced Mechanical Technology, Inc. Massachusetts), were used to record ground reaction force data throughout the aiming period of each shot. Participants stood with one foot on each platform whilst data were recorded following the procedure outlined by Dadswell et al. (2013). Centre of pressure location was calculated over 1 s prior to every shot.

Physiological Measurements

Three fingertip blood lactate (BLa) samples were obtained at the beginning of the event, and immediately following completion of the second and third shooting series. Blood lactate concentration was used to indicate the reliance on anaerobic metabolism throughout the event. Each sample was taken from the 5th digit of the loading hand, and analysed using a YSI 1500 SPORT Lactate Analyzer (YSI UK Limited). Heart rate values were recorded throughout the event using an Activio Sport System (Activio AB, Stokholm: version 2.1) wireless heart rate monitor sampling at 1Hz. This demonstrated how heart rate changed between each running and shooting series, in particular within each shooting series.

Data Analysis

In the combined event, the number of shots an athlete can take in order to achieve five hits within the 70 s time limit is unlimited. Participants therefore took a varied number of shots within each series. Consequently, analysis was based on the first six shots of each series to ensure homogeneity and that appropriate data were available for comparisons.

Shot score is not recorded on a combined event style of target, and so score was obtained from the SCATT system to a maximum of 10.9. All athletes were instructed to zero the system prior to testing to ensure that scores were as accurate as possible. Trace length, the distance moved by the aiming point of the pistol on the target (mm), was recorded in the final second before triggering. This was separated into movement along both the horizontal and vertical axes of the target in accordance with previous research (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990). Shot time (s), representing the length of time that the participant spent aiming at the target, was defined as the moment that the aiming point was in alignment with the target until the instance of the shot. Time spent aiming has been previously reported to be correlated with shooting accuracy (Mason et al., 1990; Mononen et al., 2003).

Two factors, separated into anterior-posterior (movement parallel with the target) and mediolateral (movement perpendicular to the target) components, were selected to represent centre of pressure movement: For each, range was calculated as the difference between the maximum and minimum co-ordinates of the centre of pressure (mm) over the final 1 s before the shot. Path length was calculated as the distance travelled by the whole body centre of pressure (mm). Each parameter has previously been used as an indicator of body sway in pistol shooting (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990). For each variable, data were obtained for 1 s prior to the shot.

Statistical Analysis

Due to the relatively small sample size, non-parametric tests were used to analyse group median data for each dependant variable. Median values and interquartile range (IQR), representing the middle 50% of values achieved across all participants, were selected as measures which would not be affected by skewed data. Where outliers were identified, the data were truncated. No gender differences were evident when comparing shooting performance, and so participants were analysed as a single group. Two sets of comparisons were performed, intra-series to identify the effect of the time remaining in which to achieve five hits, and inter-series to identify any changes in shooting performance following each running phase.

Wilcoxon Tests were used for intra-series comparisons between the maximum and minimum heart rate within each shooting series. Friedman's ANOVA tests were used to identify any changes in shot score, shot time, pistol movements (trace length) and centre of pressure movements (range and path length) over the first six shots within each series. Friedman's ANOVA Tests were also used for inter-series comparisons of each variable. For all comparisons, $p<0.05$ was considered statistically significant. Wilcoxon Tests using Bonferroni corrections were used for post hoc analysis of any significant results, with $p<0.016$ considered statistically significant.

Spearman's Rank Order Correlation Coefficients were performed between all variables for each series (shot score, shot time, horizontal and vertical trace length, anterior and posterior centre of pressure range and path length), making it possible to identify the association between each variable and shot score. By comparing the correlations between each series it was possible to further identify how performance changed between series. Group correlations were performed using data from the first six shots for all participants. The number of shots available for intra-individual correlations varied between participants. This was dependent on the minimum number of shots required to complete any of the three series for each participant. Due to the high number of correlations Bonferroni corrections were used, and as such, $p<0.007$ was considered statistically significant.

Results

Physiological Variables

Each participant experienced similar heart rate patterns throughout the event (see Figure 1). Heart rate increased during each 1 km run phase then significantly reduced within each shooting series ($p<0.05$) (see Table 2). Maximum and minimum heart rates were significantly greater for the second and third shooting series compared to series 1 ($p<0.016$). Despite no significant changes in 1 km run time

(p>0.05), BLa concentration significantly increased between each series (p<0.016) (see Table 2).

Figure 1 near here

Intra-Series Comparisons

No significant changes were recorded for shot time within any of the shooting series (p>0.05) (see Table 1). Each shot was completed within 0.9 s - 1.5 s (see Figure 2), and in series 3, whilst not significant, there was a progressive decrease in median shot time between shot 1 (1.3 s) and shot 4 (0.9 s).

Table 1 near here

Figure 2 near here

No significant changes in shot score were evident within any of the three shooting series (p>0.05) (see Table 1). Scores varied considerably within each series, with no evidence of a decrease in score as the series progressed (see Figure 2). For instance, in series 3, despite the progressive decrease in shot time, there was no corresponding decline in scores.

Horizontal and vertical pistol movements did not change significantly within any series (p>0.05). No significant changes were recorded for the anterior-posterior or mediolateral components of centre of pressure range or path length within any series (p>0.05) (see Figure 3).

Figure 3 near here

Inter-Series Comparisons

Neither shot time nor score changed significantly between each series ($p>0.05$) (see Table 2). Median shot time reduced by 0.2 s between series, while just 0.2 points separated each series' median score. IQR for shot score increased with each successive series as the success of participants varied more widely in the second and third series.

There were no significant changes in either horizontal or vertical pistol movements between series ($p>0.05$). Although not significant, greater vertical movements were produced in series 2 and 3 than for series 1 (see Figure 2). This was not evident for horizontal pistol movements.

Neither mediolateral nor anterior-posterior centre of pressure range changed significantly between series ($p>0.05$) (see Table 2). Again, whilst not significant, the smallest movements were recorded in series 1 for the majority of shots. Changes in path length were minimal and non-significant ($p>0.05$).

Table 2 near here

Correlations Between Variables

When correlations were performed using group data, no variables presented significant associations with score in any series ($p>0.007$). Thus, all further analysis focused on intra-individual correlations. Few participants demonstrated significant correlations between kinematic variables and score. Two participants presented significant negative correlations between score and horizontal trace length in series 3 (Participant 8: r -.970 $p<0.007$; Participant 10: r -.753, $p<0.007$). A third participant produced a significant negative correlation with shot time in series 2 (Participant 9: r -.882, $p<0.007$). These variables accounted for between 57% and 88% of the changes in score. However, the same correlations were not apparent in any of the other series for these participants. No other participants produced any significant correlations with shot score.

Discussion

This study had two aims, to identify changes in shooting performance within each series and to identify differences in shooting performance between each series following each additional 1 km run phase.

The first hypothesis was rejected, as the time remaining to complete each series appeared to have little impact on shooting performance. No significant changes were evident for shot time, score, pistol movement or body movement within any series. The hypothesis was based on the assumption that as the time remaining to achieve five hits reduced, participants would shoot more quickly, thereby reducing aiming time and leaving less time to complete aiming routines. However, with no evidence of reduced shot times, a consistent time period was available in which pistol and centre of pressure movement could be reduced. Thus, the degree of pistol movement across the target was comparable for each shot within every series.

The second hypothesis was also rejected, as neither score, pistol movement nor centre of pressure movement changed significantly between series. Thus, despite an increasing reliance on anaerobic metabolism throughout the event, shooting performance remained similar. Whilst these findings fail to support the hypothesis they do support the previous combined event research of Le Meur et al. (2010) who reported no significant change in shooting success or time per shot for any series (p>0.05). As such, shooting performance following 1 km series running appears similar to performances achieved following only 20m of running.

A potential explanation for the similarities in shooting performance across the three series is the increase in arousal associated with exercise. In their analysis of fatigue and shooting performance, Nibbeling et al. (2014) reported that an increase in arousal has the potential to reduce the effect of anxiety. Thus, in the combined event an increase in arousal may be sufficient to counteract any decrements in performance resulting from exercise-induced fatigue. This theory is further supported by the review of Lambourne and Tomporowski (2010), who reported consistent findings of an increase in cognitive test performance following exercise. Thus, factors which may have produced anxiety in series 1 may prove less influential to performance in series 2 and 3.

A further implication of the similarities between series is that, when developing shooting technique, shooting training in isolation could be effective in addition to combined run and shoot training. This is an important consideration, as greater shooting accuracy, not running performance, has been suggested to determine the most successful athletes (Le Meur et al., 2010). Many shots taken by participants in the current study were not on target and therefore athletes who can shoot accurately will have a considerable advantage over many of their competitors.

A key finding of the current research is the limited effect of each running phase on pistol shooting performance. This differs considerably to the effect of exercise on biathlon shooting performance (Hoffman et al., 1992), and indicates that reducing exercise intensity immediately prior to shooting, as used by biathletes, may not be an effective strategy in the combined event. Shooting performance appears to remain consistent throughout the combined event, despite the reduction in heart rate within each shooting series. This may be unsurprising, given the different methods of hold for a pistol and a rifle, with the rifle more susceptible to other physiological changes, such as heart rate. This seems likely, following the findings of Brown et al. (2013) who reported that, in pistol shooting, heart rate was not significantly correlated with either shooting accuracy or precision. Consequently, modern pentathletes should develop their own strategies when attempting to enhance shooting performance.

The limited effect of each running phase on centre of pressure movement was surprising and in contrast to previous findings. Previous investigations into centre of pressure movement following exercise have consistently reported an increase following exercise ($p<0.05$) (Bove et al., 2007; Hoffman et al., 1992; Nardone, Tarantola, Giordano & Schieppati, 1997; Niinimaa & McAvoy, 1983). It should be acknowledged, however, that not all studies were based on shooting performance, such as the research of Bove et al. (2007) and Nardone et al. (1997). Thus, the demands of combined event shooting are likely to be sufficient to destabilise the centre of pressure, even after minimal exercise, beyond that which occurs for the quiet stance tasks used by previous research (Bove et al., 2007; Nardone et al., 1997). Centre of pressure movements in series 1 of the combined event are significantly greater than those produced for the slower, precision event ($p<0.05$) (Dadswell et al., 2013). Thus, as movement is already elevated in comparison to more simple stance tasks, any additional increases following exercise will be less apparent than those observed for the more simple stances.

Shooting performance characteristics have been shown to be highly individual (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990). To ensure group analysis did not overlook individual variation, a supplementary statistical analysis was performed using data from four participants who required different numbers of shots to complete a series. Only one participant produced the expected decline in score with each series, and none demonstrated a significant increase in pistol or centre of pressure movements. Thus, neither group nor individual analysis provided support for the expected reduction in shooting performance following each 1 km run phase.

The individual data, whilst not producing any significant findings, did support the intra-individual analysis of shooting performance (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990). The performance of some participants varied little between series, consistent with the findings of the group analysis. However, none of the participants selected for individual analysis displayed the same trend as the group median for all dependant variables. For instance, score decreased with every series for one participant, with a reduction of 2.5 points between series 1 and 3. Thus, the highly individual nature of combined event pistol shooting means that the group median will rarely reflect each individual's response to the shooting task. Coaches should be cautious, therefore, when applying the findings from purely group-based analyses.

Intra-individual correlations revealed few significant associations between score and kinematic variables in any series. This suggests that there may be other performance variables not considered here, such as the location of the aim point on the target, which must also influence performance. In addition, the format of the event means that while some participants took up to eleven shots to complete a series, most only required between six and eight. Thus, few shots were available for correlations. Future research in which participants take a greater number of shots using the combined event shooting format could increase the likelihood of uncovering correlations between different variables. This would further enhance the understanding of the factors most critical to combined event shooting success. This would, however, require consideration of an appropriate method in which to maintain validity.

This study has revealed, for the first time, the limited effect of each running phase, and of the time remaining to complete each series, on combined event shooting performance. Whilst time pressures did not cause any changes in performance within each series, an additional consideration should be the success of other athletes during competition. However, the testing format required participants to shoot whilst standing on force plates. Consequently, each participant had to complete the trial individually albeit with a significant and large audience, including the experimenters and other participants, present throughout all trials. All other technical aspects of the event were identical to those in competition, but future research in which participants could compete alongside other athletes would be useful to investigate direct competition effects.

In conclusion, neither time constraints nor the effects of each running phase caused any significant changes in combined event shooting performance. These findings have potential implications for training, with the possibility that shooting training in isolation may be effective in addition to the complete event format. These results have also highlighted the unique performance requirements of the combined event in comparison to other shooting disciplines, such as biathlon. Consequently, modern pentathletes must establish unique methods to enhance shooting accuracy. This is important if athletes wish to enhance not only their combined event, but also overall competition performance. Finally, whilst both group and individual analysis failed to support the hypotheses it was apparent that group analysis alone is not sufficient to reflect the combined event shooting performances of all individuals.

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Table 1. Statistical comparisons from Friedman's ANOVA (X^2) between the first six shots within each shooting series for all dependent variables (n=17).

Table 2. Comparisons of all dependent variables between each shooting series.

HR = Heart rate BLa = Blood lactate

M-L = Mediolateral A-P = Anterior-posterior

† = significant reduction in heart rate within series ($p<0.05$)

* = significant difference between series ($p<0.012$)

Figure Captions

Figure 1 - Heart rate from one participant throughout the combined event. This pattern is representative of the heart rate pattern for all participants.

Figure 2 - Median group shot time (a), shot score (b), horizontal trace length (c) and vertical trace length (d). Data are taken from the first six shots within each series.

Figure 3 - Median group mediolateral (a) and anterior-posterior (b) centre of pressure range, and mediolateral (c) and anterior-posterior (d) path length. Data are taken from the first six shots within each series.