

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

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24 **Abstract**

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

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

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48 **Introduction**

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

53 20 m Run → Shooting Series 1 → 1 km Run → Shooting Series 2 → 1 km
54 Run → Shooting Series 3 → 1 km Run

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

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

71 The findings of Le Meur et al. (2010) highlighted the importance of each
72 shooting series to the combined event. This was further emphasised in a subsequent

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

80 Whilst the research of Le Meur et al. (2010; 2012) undoubtedly produced
81 interesting findings regarding the temporal characteristics of performance, it is now
82 important to advance this research area. By including the effects of the combined
83 event on the kinematic and kinetic variables associated with shooting, it will be
84 possible to examine the processes behind a successful combined event shooting
85 performance. The understanding of these processes has previously been achieved for
86 precision shooting (Ball, Best & Wrigley, 2003; Dadswell, Payton, Holmes &
87 Burden, 2013; Heimer, Medved & Spirelja, 1985; Mason, Cowan & Goncz, 1990).
88 One key finding from this research was the effect of movement on shooting
89 performance, with pistol movement and body sway accounting for up to 37% and
90 40% of the variability in shooting accuracy respectively (Mason et al., 1990).
91 Combined event performance, however, differs from precision shooting (Dadswell et
92 al., 2013), as it has a greater target size and reduced shot times (Berrigan et al., 2006;
93 Goonetilleke & Lau, 2009).

94 To the authors' knowledge, only one study has compared the processes
95 related to combined event and precision shooting performance (Dadswell et al.,
96 2013). Comparisons between the two events revealed that pistol movements and
97 body sway were significantly greater for the combined event than for precision

98 shooting ($p < 0.05$). Correlations between pistol movements, body sway and shot
99 score also differed between the two events, highlighting the different performance
100 requirements. Performance was, however, only analysed within the first shooting
101 series of the combined event, prior to the running phases. Each running phase, and
102 its associated fatigue, is likely to further influence shooting performance and thus,
103 the effect of each running phase on combined event shooting performance should
104 also be considered.

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

117 If the effect of exercise on shooting performance is found to be similar
118 between biathlon and the combined event, then the tactics employed by biathletes to
119 enhance shooting performance could also prove beneficial to modern pentathletes.
120 However, in their analysis of the effect of exercise on the shooting performance of
121 police officers, Brown, Tandy, Wulf & Young (2013) reported no significant
122 correlations between pistol shooting performance and heart rate following changes in

123 heart rate of 60 bpm. As such it is currently unclear whether the approach used by
124 biathletes can transfer directly to the combined event.

125 Research Aims and Hypotheses

126 Previous research has considered the effect of biomechanical variables on
127 shooting performance in the first series of the combined event (Dadswell et al.,
128 2013). None, however, has considered the effect of either the 70 s time limit or the
129 running phases on performance in each of the three shooting series. Therefore, the
130 aims of this research were to: (i) identify any changes in performance-related
131 variables within each shooting series; and (ii) identify any changes in performance
132 between each shooting series. There were two hypotheses for this research. First, as
133 the time remaining to complete each series reduced, shot time and shot score would
134 significantly reduce and pistol movements and body sway would significantly
135 increase. Second, average shot score would significantly decrease with each
136 successive shooting series and average pistol movement and body sway would
137 significantly increase.

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139 **Methods**

140 Participants

141 Seventeen national development athletes (6 male, 11 female) (mean age 17.4
142 \pm 3.2 years, mass 59.4 \pm 8.7 kg, height 172.9 \pm 7.15 cm) completed the combined
143 event task using their own pistol (4.5 mm calibre compressed air CO₂ single shot air
144 pistol, weighing less than 1500 g). Written informed consent was obtained from all
145 participants prior to testing and also from participant's parents for those athletes

146 under 18 years of age. The study was approved by the local research ethics
147 committee.

148 Tasks

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

156 Pistol Movements, Shot Location and Shot Time

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

162 Centre of Pressure Measurements

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

168 Physiological Measurements

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

178 Data Analysis

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

184 Shot score is not recorded on a combined event style of target, and so score
185 was obtained from the SCATT system to a maximum of 10.9. All athletes were
186 instructed to zero the system prior to testing to ensure that scores were as accurate as
187 possible. Trace length, the distance moved by the aiming point of the pistol on the
188 target (mm), was recorded in the final second before triggering. This was separated
189 into movement along both the horizontal and vertical axes of the target in accordance
190 with previous research (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990).
191 Shot time (s), representing the length of time that the participant spent aiming at the
192 target, was defined as the moment that the aiming point was in alignment with the

193 target until the instance of the shot. Time spent aiming has been previously reported
194 to be correlated with shooting accuracy (Mason et al., 1990; Mononen et al., 2003).

195 Two factors, separated into anterior-posterior (movement parallel with the
196 target) and mediolateral (movement perpendicular to the target) components, were
197 selected to represent centre of pressure movement: For each, range was calculated as
198 the difference between the maximum and minimum co-ordinates of the centre of
199 pressure (mm) over the final 1 s before the shot. Path length was calculated as the
200 distance travelled by the whole body centre of pressure (mm). Each parameter has
201 previously been used as an indicator of body sway in pistol shooting (Ball et al.,
202 2003; Dadswell et al., 2013; Mason et al., 1990). For each variable, data were
203 obtained for 1 s prior to the shot.

204 Statistical Analysis

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

214 Wilcoxon Tests were used for intra-series comparisons between the
215 maximum and minimum heart rate within each shooting series. Friedman's ANOVA
216 tests were used to identify any changes in shot score, shot time, pistol movements

217 (trace length) and centre of pressure movements (range and path length) over the
218 first six shots within each series. Friedman's ANOVA Tests were also used for inter-
219 series comparisons of each variable. For all comparisons, $p < 0.05$ was considered
220 statistically significant. Wilcoxon Tests using Bonferroni corrections were used for
221 post hoc analysis of any significant results, with $p < 0.016$ considered statistically
222 significant.

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

234 **Results**

235 Physiological Variables

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

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

243 ***Figure 1 near here***

244 Intra-Series Comparisons

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

249 ***Table 1 near here***

250 ***Figure 2 near here***

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

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

260 ***Figure 3 near here***

261 Inter-Series Comparisons

285 changes in score. However, the same correlations were not apparent in any of the
286 other series for these participants. No other participants produced any significant
287 correlations with shot score.

288 **Discussion**

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

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

302 The second hypothesis was also rejected, as neither score, pistol movement
303 nor centre of pressure movement changed significantly between series. Thus, despite
304 an increasing reliance on anaerobic metabolism throughout the event, shooting
305 performance remained similar. Whilst these findings fail to support the hypothesis
306 they do support the previous combined event research of Le Meur et al. (2010) who
307 reported no significant change in shooting success or time per shot for any series

308 ($p>0.05$). As such, shooting performance following 1 km series running appears
309 similar to performances achieved following only 20m of running.

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

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

327 A key finding of the current research is the limited effect of each running
328 phase on pistol shooting performance. This differs considerably to the effect of
329 exercise on biathlon shooting performance (Hoffman et al., 1992), and indicates that
330 reducing exercise intensity immediately prior to shooting, as used by biathletes, may
331 not be an effective strategy in the combined event. Shooting performance appears to

332 remain consistent throughout the combined event, despite the reduction in heart rate
333 within each shooting series. This may be unsurprising, given the different methods of
334 hold for a pistol and a rifle, with the rifle more susceptible to other physiological
335 changes, such as heart rate. This seems likely, following the findings of Brown et al.
336 (2013) who reported that, in pistol shooting, heart rate was not significantly
337 correlated with either shooting accuracy or precision. Consequently, modern
338 pentathletes should develop their own strategies when attempting to enhance
339 shooting performance.

340 The limited effect of each running phase on centre of pressure movement was
341 surprising and in contrast to previous findings. Previous investigations into centre of
342 pressure movement following exercise have consistently reported an increase
343 following exercise ($p < 0.05$) (Bove et al., 2007; Hoffman et al., 1992; Nardone,
344 Tarantola, Giordano & Schieppati, 1997; Niinimaa & McAvoy, 1983). It should be
345 acknowledged, however, that not all studies were based on shooting performance,
346 such as the research of Bove et al. (2007) and Nardone et al. (1997). Thus, the
347 demands of combined event shooting are likely to be sufficient to destabilise the
348 centre of pressure, even after minimal exercise, beyond that which occurs for the
349 quiet stance tasks used by previous research (Bove et al., 2007; Nardone et al.,
350 1997). Centre of pressure movements in series 1 of the combined event are
351 significantly greater than those produced for the slower, precision event ($p < 0.05$)
352 (Dadswell et al., 2013). Thus, as movement is already elevated in comparison to
353 more simple stance tasks, any additional increases following exercise will be less
354 apparent than those observed for the more simple stances.

355 Shooting performance characteristics have been shown to be highly
356 individual (Ball et al., 2003; Dadswell et al., 2013; Mason et al., 1990). To ensure

357 group analysis did not overlook individual variation, a supplementary statistical
358 analysis was performed using data from four participants who required different
359 numbers of shots to complete a series. Only one participant produced the expected
360 decline in score with each series, and none demonstrated a significant increase in
361 pistol or centre of pressure movements. Thus, neither group nor individual analysis
362 provided support for the expected reduction in shooting performance following each
363 1 km run phase.

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

375 Intra-individual correlations revealed few significant associations between
376 score and kinematic variables in any series. This suggests that there may be other
377 performance variables not considered here, such as the location of the aim point on
378 the target, which must also influence performance. In addition, the format of the
379 event means that while some participants took up to eleven shots to complete a
380 series, most only required between six and eight. Thus, few shots were available for
381 correlations. Future research in which participants take a greater number of shots

382 using the combined event shooting format could increase the likelihood of
383 uncovering correlations between different variables. This would further enhance the
384 understanding of the factors most critical to combined event shooting success. This
385 would, however, require consideration of an appropriate method in which to
386 maintain validity.

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

398 In conclusion, neither time constraints nor the effects of each running phase
399 caused any significant changes in combined event shooting performance. These
400 findings have potential implications for training, with the possibility that shooting
401 training in isolation may be effective in addition to the complete event format. These
402 results have also highlighted the unique performance requirements of the combined
403 event in comparison to other shooting disciplines, such as biathlon. Consequently,
404 modern pentathletes must establish unique methods to enhance shooting accuracy.
405 This is important if athletes wish to enhance not only their combined event, but also
406 overall competition performance. Finally, whilst both group and individual analysis

407 failed to support the hypotheses it was apparent that group analysis alone is not
408 sufficient to reflect the combined event shooting performances of all individuals.

409

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

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

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506 HR = Heart rate BLa = Blood lactate

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

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

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

511

Figure Captions

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

514

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

517

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