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## Postural adjustments preceding string release in trained archers

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1 **Title page**

2 **Postural adjustments preceding string release in trained archers**

3

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## 16 **Abstract**

17 Optimal postural stability is required to perform in archery. Since the dynamic consequences  
18 of the string release may disturb their postural equilibrium, archers should have integrated  
19 them in their motor program to optimize postural stability. This study aimed to characterize  
20 the postural strategy archers use to limit the potentially detrimental impact of the bow release  
21 on their postural stability and identify characteristics that may explain a better performance.  
22 Six elite and seven sub-elite archers performed a series of 18 shots at 70 meters, standing on  
23 two force plates. Postural stability indicators were computed during the aiming and the  
24 shooting phase using the trajectory of the center of pressure. Two postural strategies were  
25 defined, as whether they were triggered before (early) or after (late) the string release time.  
26 Both groups used anticipated postural adjustments, but elite archers triggered them before  
27 the string release more often and sooner. Scores differed between the two groups, but no  
28 differences were found between early and late shots. Trained archers seem to have finely  
29 integrated the dynamic consequences of their bow motion, triggering anticipated postural  
30 adjustments prior to the string release. However, it remains unclear whether this anticipation  
31 can positively influence the performance outcome.

32

33

## 34 **Highlights**

- 35 • The current study focuses on postural control of highly trained archers during the  
36 aiming and shooting phases.
- 37 • Because the string release is voluntary triggered, archers use anticipatory postural  
38 adjustments to reduce its consequences on their postural equilibrium.
- 39 • The main difference between the postural adjustment performed during anticipated  
40 and non-anticipated shots is the release timing onset.
- 41 • Anticipating the string release postural perturbation indicate archers have finely  
42 integrated its dynamic consequences in their motor program but it does not seem to  
43 influence the performance outcome.

44

## 45 **Keywords**

46 Biomechanics, Motor Control, Performance, Archery, Balance

47

48

# 1.Introduction

49 Olympic archery is a sport requiring to shoot arrows with a recurve bow at a target located 70  
50 meters away [1]. To achieve both accuracy and precision, elite archers are trained to stand  
51 upright as quietly as possible while aiming at the target. Indeed, natural whole-body  
52 oscillations observed during standing prior to string release may result in aiming error and  
53 therefore reduce the shooting performance [2]. But precisely shooting arrows is not only  
54 about aiming. When archers release their fingers, the string propels the arrow in the direction  
55 of the target with less than 16 ms of string and arrow contact [3]. For modern bows, the recoil  
56 kinetic energy is estimated at around 0.2 J, which leads to a recoil velocity of about 250 mm/s  
57 [4]. This bow recoil can potentially disturb archers' postural equilibrium and contribute to  
58 poorer shooting performance [5]. Yet, how elite archers deal with the consequences of this  
59 voluntary triggered movement and whether or not their postural strategy has an impact on  
60 their shooting performance remains unclear.

61 Postural control serves two main purposes: orientation and balance [6]. When all forces  
62 applied on a body are balanced, it can be assumed that its postural balance is regulated by the  
63 displacement of the center of pressure to maintain the vertical projection of the center of  
64 mass within the base of support [7]. According to the simple and widely used inverted  
65 pendulum model [7], when postural balance is challenged by motion of the center of mass in  
66 one direction, the center of pressure has to move in the same direction and with larger  
67 amplitude to keep the center of mass projection within the base of support. When the center  
68 of mass motion comes from a self-generated voluntary movement, i.e. an 'internal'  
69 perturbation, the postural control strategy is thought to be pro-active [8,9]. This means that  
70 the dynamic consequences of the forthcoming perturbation are predicted and therefore

71 integrated in the following motor response plan. Thus, the dynamic consequences of the  
72 movement perturbation on posture can be minimized through anticipatory postural  
73 adjustments [8,10,11], starting before the movement onset [12], to maintain both postural  
74 orientation and balance [13].

75 In archery, a shot is generally divided into two main phases: i) an aiming phase, where the  
76 archer aims at the target while maintaining an upright quiet standing posture, and ii) a  
77 shooting phase, where the string is released and the arrow flies toward the target [1]. These  
78 phases are separated by the clicker fall. The clicker is a metallic device mounted on the bow  
79 riser to optimize bow draw length consistency [1]. Its fall emits a sound, signaling to the archer  
80 that the correct bow draw length has been reached. Archers are taught to release the string  
81 only after hearing this sound, and a shorter duration between the clicker fall and the string  
82 release was linked to increased performance [14]. Like reacting to the clicker fall, postural  
83 stability is a feature that can be trained and improved through regular practice [15,16]. In  
84 standing shooting disciplines like archery [14,17–20], rifle [21–24] or biathlon (standing  
85 shooting) [25], analysis of postural balance during the aiming phase showed that better  
86 performance in skilled shooters compared to less skilled counterparts could be explained by  
87 smaller postural sway characteristics. However, very few studies characterized postural  
88 balance during the shooting phase, leaving the question of how skilled shooter minimize the  
89 dynamic consequences of their shooting activity on postural stability partially unanswered. In  
90 air pistol shooting, electromyographic analysis revealed the presence of anticipatory postural  
91 adjustments specific to the direction of the movement and muscular activity starting up to  
92 100 ms before the shooting onset [26]. Yet, their mechanical contribution to postural balance  
93 have never been characterized in archery.

94 The goal of our study is to characterize the postural strategy used by trained archers to limit  
95 the potentially detrimental effect of the string release on postural balance and determine  
96 whether or not this has a positive influence on performance. Since trained archers release  
97 their string voluntarily, we first hypothesized that anticipatory postural adjustments will be  
98 triggered in the direction of the bow recoil, to limit its dynamic impact on postural balance,  
99 and that these anticipatory postural adjustments will be finely timed with the clicker fall.  
100 Second, since anticipatory postural adjustments can be trained to limit the detrimental  
101 consequences of self-generated perturbation on postural balance [16], we hypothesized that  
102 anticipatory postural adjustments characteristics will be mechanically more efficient in elite  
103 archers than in sub-elite archers, showing a better dynamic postural control that could  
104 partially explain performance difference between the two levels of expertise.

105

## 106 **2. Material and Methods**

### 107 2.1. Participants

108 Thirteen archers participated in this study. Six participants (3 males, 3 females, age  $27.0 \pm 4.7$ ,  
109 height  $174.3 \pm 8.2$  cm, mass  $80.6 \pm 27.2$  kg) were recruited in the French National elite training  
110 center and were placed in the elite group ( $16.0 \pm 1.9$  years of practice), according to the  
111 following inclusion criteria: over 10 years of archery practice and at least one participation to  
112 a senior international outdoor archery competition (European Championships, World Cup  
113 stages, World Championships, Olympic Qualifiers or Olympic Games) in the year prior to the  
114 experiment. Seven participants (4 males, 3 females, age  $16.5 \pm 4.9$ ,  $169.2 \pm 3.6$  cm, mass  $59.7$   
115  $\pm 4.8$  kg) were recruited in a next-generation training center and were placed in the sub-elite  
116 group ( $8.0 \pm 1.8$  years of practice), according to the following inclusion criteria: less than 10

117 years of archery practice and never competed at a senior international outdoor archery  
118 competition. For both populations, the exclusion criteria was to not have suffered of any injury  
119 6 months prior to the experiments. The experiment was approved by the department local  
120 ethics committee and conducted with the informed and written consent of all participants.

## 121 2.2. Experimental design

122 Each participant first completed their usual competitive warm-up routine for 15 minutes.  
123 Warm-up routines included exercises mobilizing upper limbs joints and muscles followed by  
124 taking a dozen of shots at a standard 10-ring competition target face of 122 cm diameter,  
125 located at the Olympic distance of 70 meters. During the experiment, each participant was  
126 asked to shoot 18 arrows on that same target, in the same conditions (no wind). Participants  
127 executed every shot using their own recurve bow, equipped with stabilizers and sight, as well  
128 as their own arrows. Participants started every trial with both feet on the ground, wearing  
129 shoes. Before taking a shot, participants stepped on two force plates, by placing each foot on  
130 one of the two (Figure 1A). When installed, participants could shoot one arrow at their own  
131 pace. Once the arrow reached the target, participants stepped out of the force plate and  
132 started over. The score of each arrow was collected.

## 133 2.3. Instrumentation

134 To compute the center of pressure before and during the shot, we used the ground reaction  
135 forces and torques from two force plates (600x500x50 mm, Kistler 9260AA6, Winterthur,  
136 Switzerland) sampled at 1000 Hz. The force plates were placed next to each other and oriented  
137 so that the mediolateral axis was aligned with the shooting direction and the anteroposterior  
138 axis was the axis orthogonal to the shooting direction (Figure 1A). Signals from the force plates  
139 were retrieved using Bioware software (Kistler 2812A, version 5.3.2.9), filtered with a 3<sup>rd</sup> order



140 Butterworth low-pass filter with a 6 Hz cutoff frequency [14] and used to process the global  
141 center of pressure coordinates according to Kistler recommendations.

## 142 **FIGURE 1 ABOUT HERE**

143 To identify characteristic instants relative to the different phases in archery, we filmed every  
144 shot with a high-speed camera (Photron FASTCAM Mini UX100 type 800K-C-16G, Tokyo, Japan)  
145 sampled at 1000 Hz. The camera was placed 2 m away from the participant, filming the bow  
146 riser on the clicker's side (Figure 1B). Force plates and the high-speed camera were  
147 synchronized using a BNC trigger port on the data acquisition system (Kistler DAQ 5691A,  
148 Winterthur, Switzerland). Each measurement started with an external wired trigger button  
149 pressed by an experimenter.

## 150 2.4. Postural stability

### 151 2.4.1 Temporal identification

152 Images from the high-speed camera were used to identify two decisive instants: the clicker  
153 falling time and the string release time. Here, the clicker falling time was identified as the first  
154 image where the clicker touched the bow riser (Figure 1B right), and the string release time  
155 was identified as the first image where the arrow tip moved towards the target. To compute  
156 each participant's reaction time, the clicker falling time was subtracted to the string release  
157 time. Postural stability of participants during the aiming phase was characterized on a period  
158 of 1 second prior to the clicker falling time [14]. This time interval was chosen as a minimum  
159 duration prior to the clicker fall observed for all the participants between aiming at full draw  
160 and releasing. The shooting phase was considered to be the period starting after to the clicker  
161 falling time until 0.5 second after the string release time.

### 162 2.4.2 Postural stability during the aiming phase

163 During the aiming phase, six postural stability indicators were computed [27]: the mean  
164 ( $d_{mean}$ ) and root mean square distance ( $d_{rms}$ ) around the mean center of pressure, the mean  
165 ( $v_{mean}$ ) and maximum velocity ( $v_{max}$ ) of the center of pressure, in both the mediolateral and  
166 anteroposterior axis as well as in the  $Oxy$  plane; the sway amplitude ( $A$ ) only in both  
167 mediolateral and anteroposterior directions; and finally the 95% confidence ellipse area  
168 ( $A_{95\%}$ ) in the  $Oxy$  plane.

#### 169 2.4.3 Postural stability during the shooting phase

170 A center of pressure displacement away from the target was observed in the mediolateral  
171 shooting axis in every trial (Figure 2). This mediolateral center of pressure movement onset  
172 ( $t_0$ ) was computed as the instant from the clicker falling time when the participant's sway  
173 velocity in the mediolateral axis crossed a threshold set at two standard deviations above  
174  $v_{mean}$  measured during the aiming phase. To characterize the postural strategy during the  
175 shooting phase, we assessed the center of pressure trajectory on a period of 0.5 second after  
176  $t_0$ .

177 For analysis purposes, we used the timing of  $t_0$  to characterize the archers' postural strategy.  
178 If  $t_0$  occurred prior to the string release which constitutes the perturbation onset, the postural  
179 strategy was labelled as "early", otherwise it was labelled as "late". Usage of either one or the  
180 other strategy was quantified in each group.

#### 181 2.5. Statistical analysis

182 A total of 230 shots (elite  $n = 107$ , sub-elite  $n = 123$ ) were successfully recorded and  
183 analyzed. Normality of the different dependent variables was tested with a Shapiro-Wilk test.  
184 Since those were not normally distributed, results are presented with medians and  
185 interquartile ranges unless said otherwise. For all the center of pressure indicators measured  
186 during the aiming phase, two variables were extracted to account for intra-individual

187 variability. First, results of all 18 trials from one archer were averaged and then averaged  
188 among all the archers from a same group (elite  $n = 6$ , sub-elite  $n = 7$ ). Second, the standard  
189 deviation of all 18 trials for one archer was computed, followed by the standard deviation of  
190 all archers from a same group. These two results (average and standard deviation) were then  
191 compared for each center of pressure indicator using a non-parametric Mann-Whitney U test  
192 between the two groups.

193 Reaction time and  $t_0$  were compared using Kruskal-Wallis tests with two factors (Group: elite  
194 vs sub-elite and Strategy: early or late), with Dunn-Sidak tests as post-hoc. Differences in  
195 percentage of use of the early or the late strategy between the two groups were evaluated  
196 using a Fisher's exact test.

197 Since every archer had a different distribution of early and late shots, to avoid any individual  
198 influence on the group results, the center of pressure trajectories during the shooting phase  
199 were averaged to form one continuous timeseries representative of each archer (elite  $n = 6$ ,  
200 sub-elite  $n = 7$ ) in each strategy. Then, one dimensional statistical parametric mapping (1D  
201 SPM) [28], using non-parametric two sample t-tests [29], was conducted to analyze the  
202 influence of expertise within strategies and strategy within groups, and to identify any  
203 differences in the continuous mediolateral center of pressure trajectory after  $t_0$ .

204 Score distributions were not normal, according to a Shapiro-Wilk test. Therefore, non-  
205 parametric Mann-Whitney U test was used to compare score performance between both  
206 groups and both postural strategies. Additionally, a Kruskal-Wallis test was performed to  
207 compare the effect of the strategy on the performance score for each group, with Dunn's test  
208 used as post-hoc with a Holm-Bonferroni correction. For all statistical tests, a  $p < 0.05$  was  
209 set for significance. Data processing was performed using customized routines written in  
210 Matlab (version R2021b, The MathWorks, Natick, USA) and the open source spm1d Matlab

211 package<sup>1</sup> (version M.0.4.8). Statistical analysis was conducted using the open source statistical  
212 software JASP (version 0.16.4, Amsterdam, Netherlands).

## 213 3. Results

### 214 3.1 Postural stability during the aiming phase

215 Averaged center of pressure indicators and their respective variability calculated during the  
216 aiming phase are presented in Table 1 with the results of their statistical comparison between  
217 the two groups. For the averaged results no differences were found between the two groups,  
218 except for  $d_{mean}$  and  $d_{rms}$  that were smaller in the elite group compared to the sub-elite  
219 group in both the anteroposterior axis and the  $Oxy$  plane, as well as  $AAP$  ( $p < 0.05$ ). For the  
220 variability results no differences were found between the two groups, except for  $v_{max}$  that  
221 was larger in the elite group compared to the sub-elite group in both the mediolateral axis  
222 and the  $Oxy$  plane ( $p < 0.05$ ).

### 223 TABLE 1 ABOUT HERE

### 224 3.2 Postural stability during the shooting phase

225 Kruskal-Wallis test indicated evidence of differences between the pairs of group/strategy for  
226 reaction time ( $H(3) = 28.1, p < 0.001$ ) and  $t_0$  ( $H(3) = 174.9, p < 0.001$ ). The elite group had a  
227 shorter reaction time compared to the sub-elite group ( $146 \pm 12$  ms versus  $156 \pm 15$  ms,  $p <$   
228  $0.001$ ). Within strategies, reaction time was shorter in the elite group compared to the sub-  
229 elite group for the early strategy only ( $145 \pm 11$  ms versus  $157 \pm 14$  ms,  $p = 0.02$ ). Within  
230 groups, no difference was found for the reaction time between early and late strategies (both  
231  $p > 0.05$ ). Within groups,  $t_0$  occurred significantly sooner in the early than in the late strategy

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<sup>1</sup> <https://spm1d.org>

232 for both the elite ( $23 \pm 38$  ms versus  $163 \pm 24$  ms,  $p < 0.001$ ) and the sub-elite archers ( $119 \pm$   
233  $37$  ms versus  $180 \pm 26$  ms,  $p < 0.001$ ). Within strategies,  $t_0$  occurred sooner in the elite group  
234 compared to the sub-elite group for the early strategy only ( $p < 0.001$ ).

235 **FIGURE 2 ABOUT HERE**

236 The early and late strategy were used by every archer regardless of their level of expertise.  
237 However elite archers used the early strategy more often than the sub-elite group (82 trials  
238 out of 107 or  $77 \pm 16$  % versus 73 trials out of 123 or  $59 \pm 17$  % of early shots, respectively,  
239  $p = 0.007$ ).

240 The 1D SPM analysis (Figure 3) showed no difference among groups or strategies for the  
241 center of pressure trajectory in the mediolateral axis for a period of 0.5 seconds after  $t_0$  ( $p >$   
242  $0.05$ ).

243 3.3 Scores

244 The elite group scored higher ( $9.2 \pm 0.8$  (mean  $\pm$  SD)) than the sub-elite group ( $8.9 \pm 1.0$ ),  $p =$   
245  $0.03$ . However, no differences were found for scores between the trials where an early  
246 strategy was used ( $9.0 \pm 0.8$ ) and where a late strategy was used ( $8.9 \pm 1.1$ ) nor when scores  
247 of early and late strategies were compared within groups (all  $p > 0.05$ ).

248 **FIGURE 3 ABOUT HERE**

## 249 **4. Discussion**

250 The objective of this study was to characterize the postural strategy used by trained archers  
251 to limit the potentially detrimental effect of string release on postural balance and determine  
252 whether this strategy could explain differences in performance outcome between two levels  
253 of expertise. As expected, all archers displayed anticipatory postural adjustments in the  
254 shooting direction and with greater amplitude than the balance perturbation. Moreover,

255 these anticipatory postural adjustments were finely timed with the clicker fall, especially in  
256 elite archers but with no evident impact on scoring performance. These results suggest that  
257 the mechanical consequences of the bow recoil are finely integrated into the motor program  
258 released for the shooting phase.

259

#### 260 4.1 Postural stability during the aiming phase

261 During the aiming phase, three averaged postural sway indicators ( $d_{mean}$ ,  $d_{rms}$  and  $A_{AP}$ )  
262 were smaller in the elite group compared to the sub-elite group for the anteroposterior  
263 component (Table 1). The variability analysis showed there was no difference between groups  
264 for those three indicators (Table 1), confirming the difference in the averaged results is not  
265 due to intra-individual variance. This suggests that the determinant axis for postural stability  
266 during aiming in trained archers is not the shooting direction axis but the one perpendicular  
267 to it. In a bipedal standing posture, the base of support is generally smaller in the  
268 anteroposterior than in the mediolateral direction and actions of the mono-articular ankle  
269 muscles, such as the soleus and tibialis anterior, are mainly responsible for accurate  
270 movement of the center of pressure in the anteroposterior direction [7]. In the mediolateral  
271 direction, stronger hip muscles are thought to be responsible for center of pressure sway  
272 control [7]. This can explain that even in young adults, larger postural sway characteristics are  
273 found in the anteroposterior axis than in the mediolateral axis in quiet standing postures [27].  
274 Thus, fine postural balance control for elite archers seems to be principally controlled in the  
275 anteroposterior direction [24,25]. The difference between the elite group and the sub-elite  
276 group corroborates previous results showing that reduced center of pressure sway during  
277 aiming is positively correlated with expertise and performance in archery [14,17–20], akin to  
278 other shooting disciplines [21–25]. Along with these studies, we support the view that elite

279 archers perform better than non-elite archers partly because they reduce the anteroposterior  
280 oscillation of their center of pressure during the aiming phase.

281 Only one indicator (mediolateral component of  $v_{max}$ ) showed a larger variability among  
282 archers from the elite group compared to the sub-elite group (Table 1). This increased  
283 variability can be explained by the onset distribution of the mediolateral center of pressure  
284 movement of elite archers ( $t_0$ ) that sometimes occurred before the clicker falling time (Figure  
285 2) and may have been caught as the maximal center of pressure velocity of the aiming phase  
286 in our analysis.

## 287 4.2 Postural stability during the shooting phase

### 288 4.2.1. An anticipated postural strategy finely integrating the mechanical consequences of the 289 string release

290 Releasing the string frees the potential energy accumulated in the bow limbs, inducing a recoil  
291 movement of the bow [4]. From a bow recoil velocity estimated at 0.26 m/s [4], a string and  
292 arrow common motion time of 16 ms during the internal ballistic phase [3] and assuming a  
293 rigid body system including both the archer and the bow, we estimated the displacement of  
294 the system center of mass at approximately 4 mm in the direction opposite to the target.

295 According to the inverted pendulum model, widely used to study the mechanics of postural  
296 control [7], this recoil caused by the recoil motion of the bow may threaten the mechanical  
297 balance conditions achieved during the aiming phase. To keep balancing the pendulum, a  
298 center of pressure movement towards the back leg is necessary to slow down the center of  
299 mass motion and restore postural balance. For all participants and in all trials, we observed  
300 that the center of pressure indeed moves away from the target, with an amplitude between  
301 15 to 20 mm, which is about 8 to 10 times larger than oscillations measured during the aiming  
302 phase (1.9 mm) and 4 to 5 times larger than the estimated center of mass displacement caused

303 by the bow recoil perturbation. Besides, the mediolateral center of pressure sway amplitude  
304 remains consistent within groups and strategy (Figure 2 & Figure 3). Because our participants  
305 were all trained archers, they are used to experience the mechanical consequences of string  
306 release and therefore seem able to generate anticipatory postural adjustments finely  
307 matching the spatial characteristics of an expected postural perturbation [30,31].

308 The string release is extremely short (< 16 ms of string and arrow contact [3]). Even though  
309 the center of pressure is assumed to move without inertia, its motion depends on the  
310 contraction of postural muscles that have a certain latency [7]. Therefore, lower-limb muscle  
311 contractions should be initiated before the shooting onset [26] so that the center of pressure  
312 can be closer to the maximum recoil amplitude at the string release time (between 30 and 66%  
313 here, Figure 2). In a large majority of trials (67% for all participants),  $t_0$  preceded the  
314 perturbation and occurred only 23 ms after the clicker fall on average in elite archers, which  
315 is below any postural reflex latency response (~40 ms [32]). The distribution of  $t_0$  were also  
316 quite small in both groups (< 40 ms). Together, these results suggest motor commands  
317 responsible for the center of pressure recoil motion were pre-programmed beforehand [8,9]  
318 and released at a similar dedicated timing. By initiating a large center of pressure movement  
319 preceding the perturbation, our study suggests that trained archers attempt to release pre-  
320 programmed anticipatory postural commands that aim to counteract the mechanical  
321 consequences of the string release to maintain balance. The high reproducibility in the timing  
322 release of this postural strategy also suggests that archers have finely integrated [33] the  
323 timing of the string release in their shooting motor commands.

324

325 4.2.2. Expertise makes archers trigger their postural strategy sooner



326 When the temporal delay of  $t_0$  was removed, both groups exhibited the same postural  
327 response in terms of mediolateral center of pressure movement (Figure 3). This result suggests  
328 that sub-elite archers have integrated the spatial characteristics of the bow recoil perturbation  
329 in their motor program. Both groups of archers did trigger the string release after hearing the  
330 clicker fall sound in the range of reaction times following expected auditory stimuli (120-160  
331 ms [34]). However, the release of the anticipatory postural adjustments did not seem to be  
332 timed with the same event in the two groups. Elite archers seemed to release their postural  
333 strategy at two distinct temporal instants (Figure 2). The shots labelled as early were released  
334  $23 \text{ ms} \pm 38 \text{ ms}$  after the clicker fall, which is about 130 ms before the string release; whereas  
335 the shots labelled as late were released  $163 \pm 24 \text{ ms}$  after the clicker fall, which is about only  
336 15 ms after the string release. With  $77 \pm 16 \%$  of early shots, our results suggest elite archers  
337 aim to release their postural strategy with the clicker fall. On the contrary, sub-elite archers  
338 seemed to release the same postural strategy in terms of amplitude, but closer to the string  
339 release only. In the latter group, the shots labelled as early were released  $119 \text{ ms} \pm 37 \text{ ms}$  after  
340 the clicker fall, which is about 30 ms before the string release; whereas the shots labelled as  
341 late were released  $180 \pm 26 \text{ ms}$  after the clicker fall, which is about 30 ms after the string  
342 release. The timing between the mediolateral center of pressure movement onset in early  
343 shots and string release is much shorter than anticipatory postural adjustments measured in  
344 predictable perturbation condition (100-150 ms range [35]) and its proximity to the late shots  
345 (60ms) point toward an anticipating postural strategy timed on one event, suggesting sub-  
346 elite archers are anticipating the string release event more than the clicker fall. This  
347 observation questions our arbitrary choice to use the perturbation as a temporal threshold to  
348 categorize early and late shots, which seems less suitable for the analysis of postural strategy  
349 in sub-elite archers than in elite archers (Figure 2). In the same way that anticipatory postural

350 adjustments are developed and improved through extensive training in sports requiring  
351 enhanced postural control such as slacklining or gymnastics [15], our findings suggest that  
352 elite archers have updated their internal models of postural control [36] whereas adolescent  
353 sub-elite archers may suffer from sensorimotor representation that are not completely  
354 mature [37,38] due to shorter experience [15] and/or biological maturation not fully  
355 completed [39].

356 As expected, the performance score was higher for the elite group compared to the sub-elite  
357 group [20], but scores between the early and late strategies within these groups did not show  
358 any statistical differences, despite being slightly higher for the early strategy. Therefore, an  
359 anticipatory postural strategy released sooner does not seem to have an influence in the  
360 performance score. However, in this study the participants shot only 18 arrows which is not  
361 sufficient to ascertain if those postural strategies differences would indeed affect the global  
362 score in competition [40]. In a world elite event archer shoot 72 arrows just in the qualification  
363 round. According to a model proposed of losing 1.4 points per ranking place [41], such slightly  
364 lower score per arrow (0.2 points) can translate into the loss of 10 ranking places, which would  
365 harden the matchup for the face-off rounds.

#### 366 4.3. Limitations

367 Studying elite level athletes comes with inherent difficulties, such as the limited number of  
368 participants and their tight schedule compatibility. Only trained archers participated in this  
369 study, which may limit the generalization of our results to all archers. Measuring the postural  
370 stability of the same group of young archers years later after full maturation of their body  
371 schema and/or biological maturation, as well as in beginner archers may better clarify how  
372 the postural strategy described here is learned and can be trained. Electromyography  
373 measurements, often used in anticipated postural adjustments studies [10,11,13] were not

374 considered in order to conduct the experiment without disturbing the archer's shooting  
375 sequence. Further experiments with muscular activity monitoring devices could pinpoint  
376 which muscles are pre-activated prior to the string release and complement the  
377 understanding of this anticipatory strategy.

#### 378 4.4. Conclusion

379 By releasing pre-programmed anticipatory postural adjustments at a desired instant during  
380 their shooting sequence, trained archers seem to have fully integrated the characteristics of  
381 the balance disturbance of the string release on their whole-body upright posture. Elite  
382 archers seem to time the releasing of this anticipatory strategy with the clicker fall, whereas  
383 younger sub-elite archers time the releasing of this strategy rather with the string release  
384 instant. However, this difference in timing between the two levels of expertise did not allow  
385 to conclude as to whether releasing this strategy sooner helps increases performance.

386

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## 393 **Declaration of interest statement**

394 The authors report no competing interests.

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# 506 Tables

507 Table 1 Postural stability indicators computed during the aiming phase and compared between the two groups. Abbreviations stand for: mean ( $d_{mean}$ ) and  
 508 root mean square distance ( $d_{rms}$ ) around the mean center of pressure, the mean ( $v_{mean}$ ) and maximum velocity ( $v_{max}$ ) of the center of pressure, the  
 509 sway amplitude ( $A$ ) and the 95% confidence ellipse area ( $A_{95\%}$ ). ML = mediolateral (shooting) direction. AP = anteroposterior direction. \* $p < 0.05$

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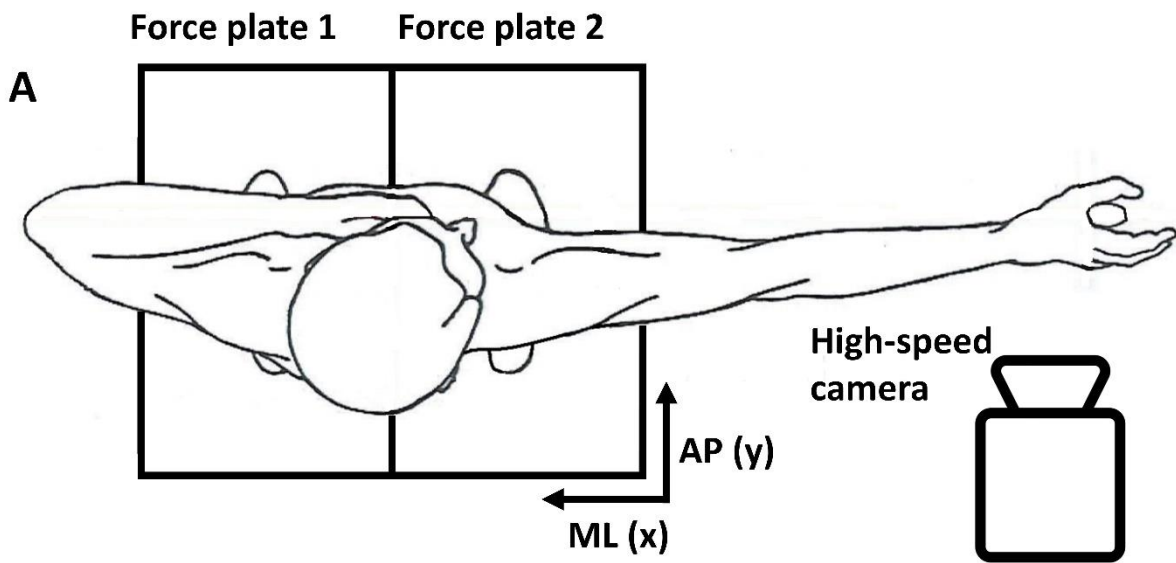
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|              |                               | Averaged indicators |                   |              | Variability indicators |                   |              |
|--------------|-------------------------------|---------------------|-------------------|--------------|------------------------|-------------------|--------------|
|              |                               | elite (n = 6)       | sub-elite (n = 7) |              | elite (n = 6)          | sub-elite (n = 7) |              |
|              |                               | median (IQR)        | median (IQR)      | $p$          | median (IQR)           | median (IQR)      | $p$          |
| ML Direction | $d_{mean}$ ML (mm)            | 0.41 (0.15)         | 0.43 (0.22)       | 0.73         | 0.17 (0.01)            | 0.14 (0.09)       | 0.30         |
|              | $d_{rms}$ ML (mm)             | 0.49 (0.18)         | 0.51 (0.28)       | 0.63         | 0.19 (0.03)            | 0.17 (0.11)       | 0.45         |
|              | $v_{mean}$ ML (mm/s)          | 6.84 (3.85)         | 7.52 (5.2)        | 0.84         | 1.51 (1.01)            | 1.3 (1.04)        | 0.84         |
|              | $v_{max}$ ML (mm/s)           | 32.54 (13.85)       | 23.66 (16.75)     | 0.30         | 24.13 (8.73)           | 4.22 (4.37)       | <b>0.01*</b> |
|              | $A$ ML (mm)                   | 1.98 (0.85)         | 1.95 (1.2)        | 0.95         | 0.86 (0.20)            | 0.65 (0.58)       | 0.37         |
| AP Direction | $d_{mean}$ AP (mm)            | 0.70 (0.12)         | 0.86 (0.14)       | <b>0.04*</b> | 0.46 (0.11)            | 0.48 (0.10)       | 0.37         |
|              | $d_{rms}$ AP (mm)             | 0.83 (0.12)         | 1.03 (0.16)       | <b>0.04*</b> | 0.53 (0.12)            | 0.52 (0.14)       | 0.53         |
|              | $v_{mean}$ AP (mm/s)          | 5.04 (0.49)         | 6.52 (2.16)       | 0.18         | 1.58 (0.47)            | 1.47 (0.56)       | 0.98         |
|              | $v_{max}$ AP (mm/s)           | 15.18 (2.43)        | 20.13 (7.86)      | 0.23         | 5.36 (1.84)            | 4.62 (2.92)       | 0.73         |
|              | $A$ AP (mm)                   | 2.72 (0.41)         | 3.60 (0.40)       | <b>0.04*</b> | 1.64 (0.36)            | 1.38 (0.33)       | 0.99         |
| Oxy plane    | $d_{mean}$ (mm)               | 0.94 (0.10)         | 1.13 (0.07)       | <b>0.04*</b> | 0.43 (0.14)            | 0.44 (0.13)       | 0.53         |
|              | $d_{rms}$ (mm)                | 1.04 (0.10)         | 1.25 (0.07)       | <b>0.02*</b> | 0.48 (0.16)            | 0.47 (0.14)       | 0.63         |
|              | $v_{mean}$ (mm/s)             | 9.80 (3.16)         | 11.08 (6.11)      | 0.63         | 2.14 (0.91)            | 2.1 (1.29)        | 0.95         |
|              | $v_{max}$ (mm/s)              | 27.07 (10.69)       | 20.56 (14.09)     | 0.37         | 23.94 (4.14)           | 4.99 (2.39)       | <b>0.01*</b> |
|              | $A_{95\%}$ (mm <sup>2</sup> ) | 7.59 (3.01)         | 8.90 (4.09)       | 0.23         | 5.85 (1.67)            | 4.92 (1.81)       | 0.63         |

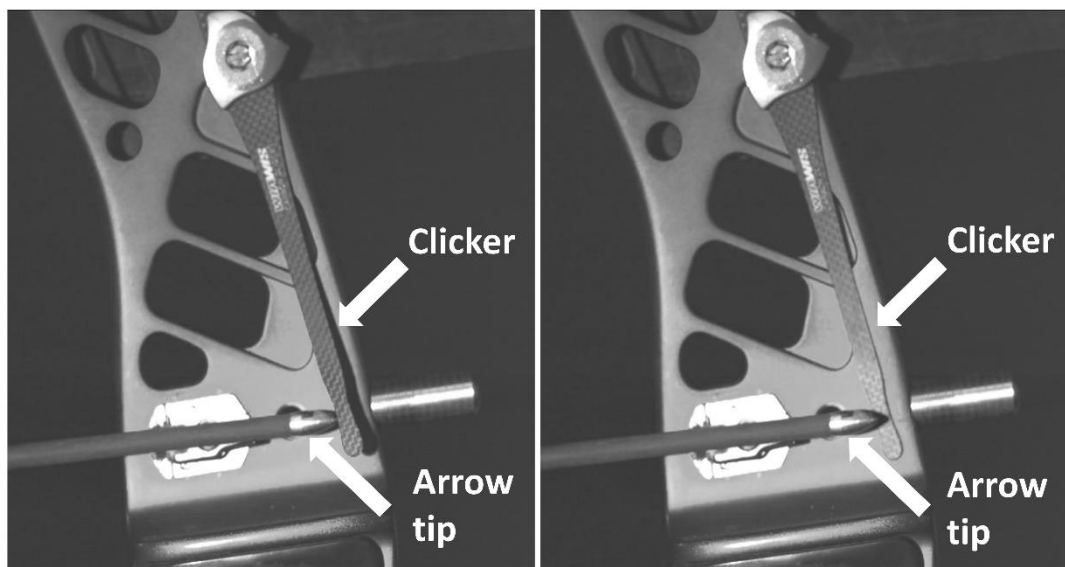


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# Figure 1



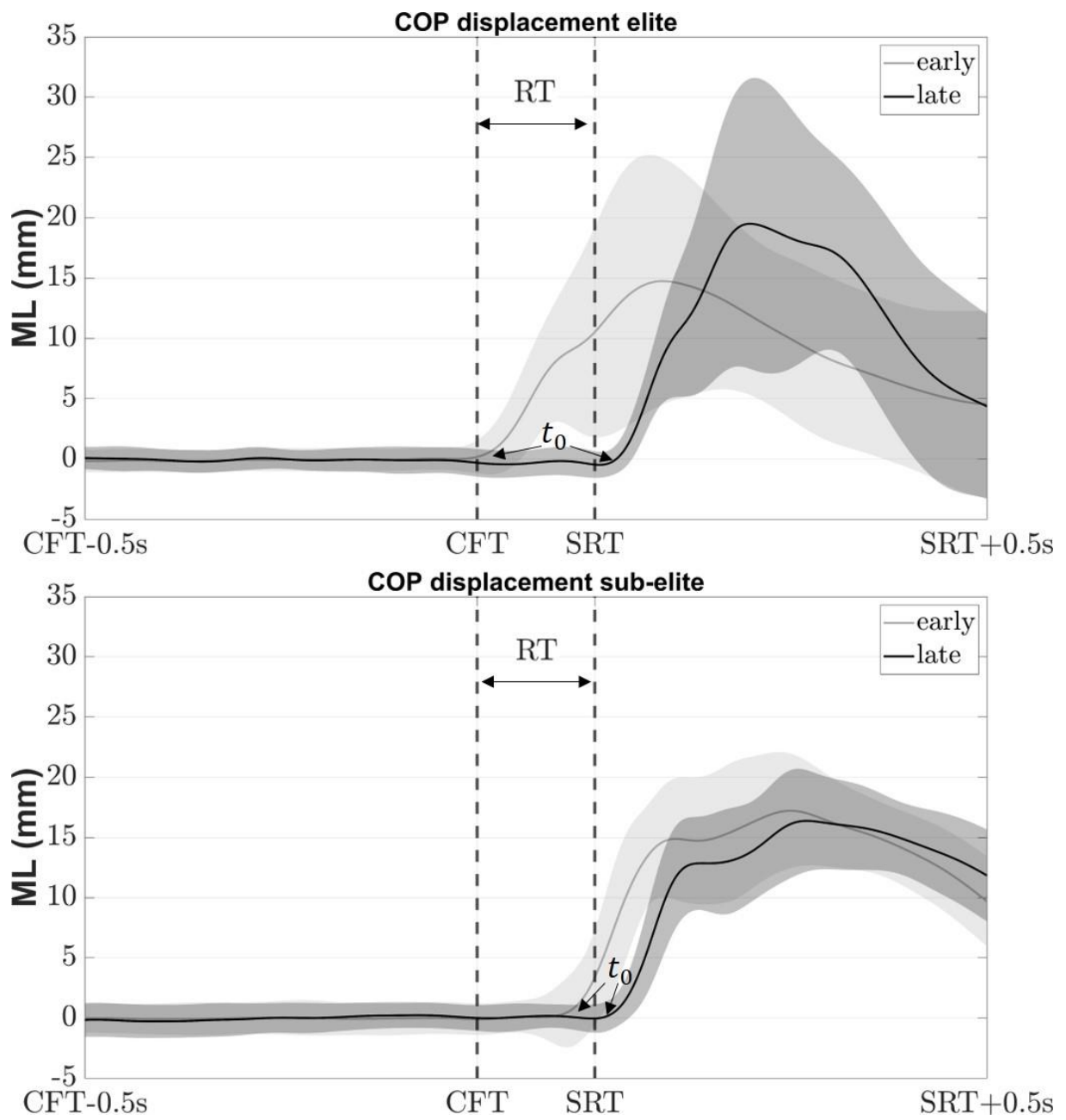
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526 **Figure 2**

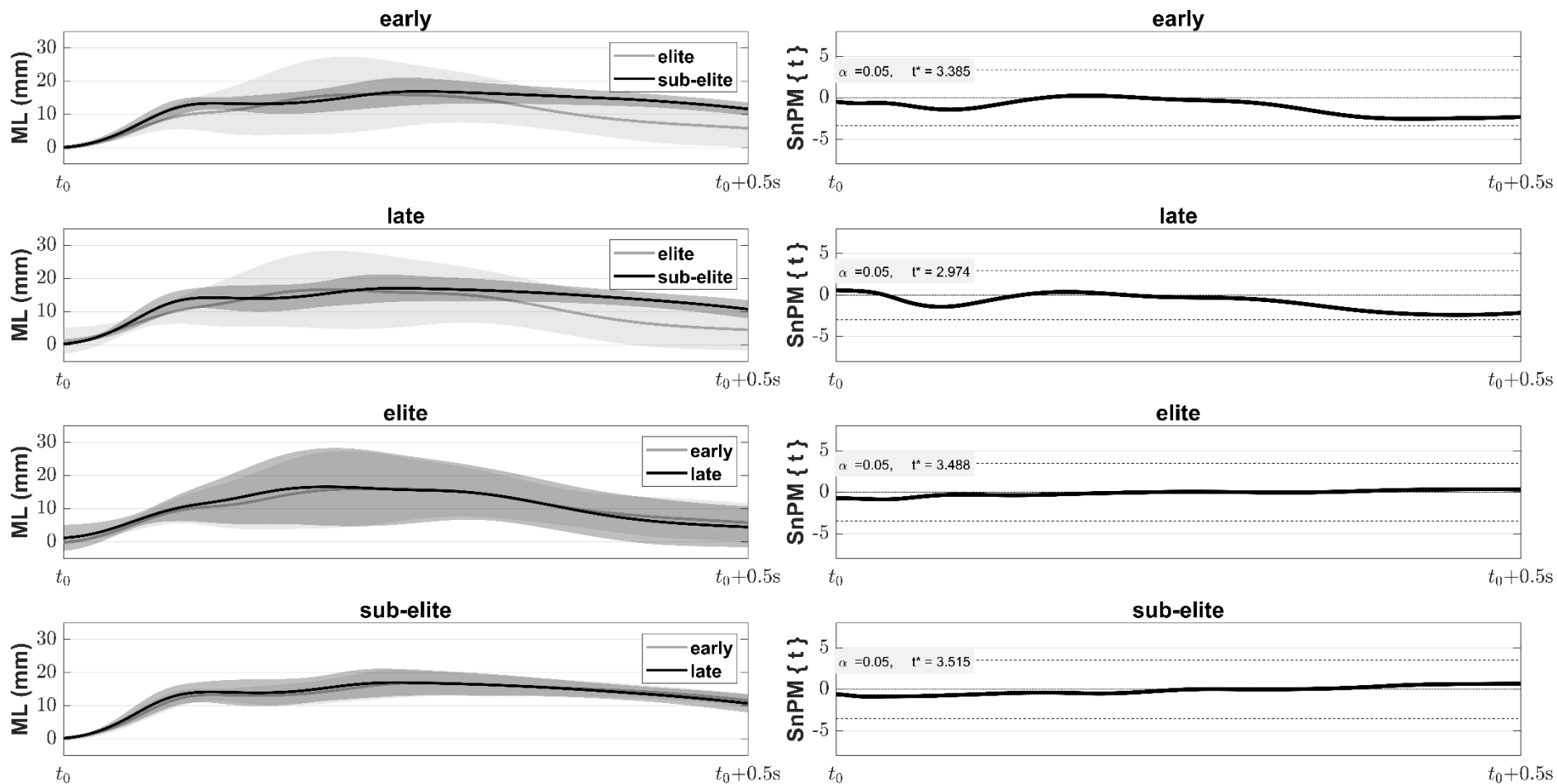


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# Figure 3



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## 532 **Figure Captions**

533 Figure 1. **A.** Reference frame, top view for a left-handed archer, with instrumentation used in the  
534 experiment (force plates, high-speed camera). The mediolateral axis is defined as the shooting axis.  
535 **B.** Snapshots from the high-speed camera. Left panel: right before clicker falling time, the arrow is  
536 almost at full draw behind the clicker. Right panel: at clicker falling time, the arrow is at full draw and  
537 the clicker falls, giving an auditory stimulus that archers are taught to react to. AP = anteroposterior.  
538 ML = mediolateral.

539  
540 Figure 2. Center of pressure (COP) timeseries in the mediolateral axis (shooting direction) for both  
541 groups. Mean (plain lines) and standard deviation (shaded area) of all trials are presented for one  
542 postural strategy (early – light grey – or late – dark grey). For clarity purposes, the timeseries are  
543 presented from 0.5 second prior to the clicker falling time to 0.5 seconds after the string release time.  
544 Data points between clicker falling time and string release time are normalized to the reaction time  
545 (duration between clicker falling time and string release time). *CFT*: clicker falling time; *SRT*: string  
546 release time; ML: mediolateral;  $t_0$ : onset of center of pressure displacement away from the target,  
547 *RT* = reaction time.

548  
549 Figure 3. Comparisons of the center of pressure mediolateral displacement with all trials aligned  
550 with  $t_0$  (onset of center of pressure displacement away from the target) between strategy (early/late  
551 – top panels) and expertise (elite/sub-elite – bottom panels). Left: timeseries mean and error cloud.  
552 Right: SPM timeseries. No temporal differences within strategy or expertise as there is no crossing over  
553 or under their respective  $p$  value threshold (dotted lines). ML = mediolateral.