

TITLE

Enhancing the Initial Acceleration Performance of Elite Rugby Backs. Part II: Insights From Multiple Longitudinal Individual-Specific Case-Study Interventions

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VERSIONS

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1 **ENHANCING THE INITIAL ACCELERATION PERFORMANCE OF ELITE**
2 **RUGBY BACKS. PART II: INSIGHTS FROM MULTIPLE LONGITUDINAL**
3 **INDIVIDUAL-SPECIFIC CASE STUDY INTERVENTIONS**
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6 **Purpose:** This study implemented 18-week individual-specific sprint acceleration training
7 interventions in elite male rugby backs based on their pre-determined individual technical
8 needs, and evaluated the effectiveness of these interventions. **Methods:** Individual-specific
9 interventions were prescribed to five elite rugby backs over an 18-week period. Interventions
10 were informed by the relationships between individual technique strategies and initial
11 acceleration performance, and their strength-based capabilities. Individual-specific changes in
12 technique and initial acceleration performance were measured at multiple time points across
13 the intervention period, and compared to three control participants who underwent their
14 normal sprint training. **Results:** Of the technique variables intentionally targeted during the
15 intervention period, moderate to very large ($|d| = 0.93$ to 3.99) meaningful changes were
16 observed in the participants who received an individual-specific intervention, but not in three
17 control participants. Resultant changes to the intervention participants' *whole-body kinematic*
18 *strategies* were broadly consistent with the intended changes. Moderate to very large ($|d| =$
19 1.11 to 2.82) improvements in initial acceleration performance were observed in participants
20 receiving individual-specific technical interventions, but not in the control participants or the
21 participant who received an individual-specific strength intervention. **Conclusions:**
22 Individual-specific technical interventions were more effective in manipulating aspects of
23 acceleration technique and performance, compared with the traditional 'one-size-fits-all'
24 approach adopted by the control participants. This study provides a novel, evidence-based
25 approach for applied practitioners working to individualize sprint-based practices to enhance
26 acceleration performance.

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28 Keywords/phrases: sprinting, constraints, training, motor control, biomechanics
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48 INTRODUCTION

49 Individualization is an important training principle for coaches^{1,2}. However, the majority of
50 scientific research investigating training interventions for sprint acceleration in team sport
51 players has primarily reported group-based data, focusing on the mean effects of the same
52 training program undertaken by all individuals within a group (see Nicholson et al.³ for a
53 review and meta-analysis). This reporting of group means is problematic since differences in
54 the constraints between individuals will likely alter their system behavior⁴, and thus the same
55 response to an intervention may not be elicited across all individuals^{5,6}. Therefore,
56 interventions should be considered on an individual-specific basis to capitalize on each
57 individual's capacity to adapt to a given training program.

58 In Part I of this investigation⁷, within-individual relationships between spatiotemporal
59 variables (step length (SL), step rate (SR), contact time (CT), flight time (FT), and SL/SR and
60 CT/FT ratios) and initial acceleration performance (normalized average horizontal external
61 power and 5 m time) across 12 sprint efforts (three sprints conducted on four separate
62 occasions) were determined in a group of 19 elite rugby backs. Meaningful relationships were
63 observed between spatiotemporal variables and initial acceleration performance in 17 of the
64 participants. Using this information and adopting a method to characterize initial acceleration
65 strategies using a whole-body kinematics approach⁸, a desirable change in *whole-body*
66 *kinematic strategy* (the combination of the SL/SR and CT/FT ratios) was identified for each
67 individual. This information was suggested as beneficial to helping practitioners subsequently
68 individualize sprint training for rugby backs by focusing on the spatiotemporal variables they
69 'rely' on⁹ for higher initial acceleration performance, i.e., the variables most closely related to
70 their performance. However, it remains unclear how interventions targeting the variables
71 athletes are individually 'reliant' on affects initial acceleration technique and performance.

72 Most studies which have investigated changes in aspects of sprint technique and performance
73 in team sport players have done so using just pre and post measures either side of relatively
74 short intervention periods (e.g., 6-11 weeks^{10,11,12}). While these studies still provide useful
75 information, longer intervention periods including intermediate measurement points can
76 provide a more comprehensive understanding of the effects of an intervention, and have been
77 identified as necessary to strengthen the practical application of sport science research.¹³
78 Longitudinally assessing changes in initial acceleration spatiotemporal variables and
79 performance of elite rugby union backs following individual-specific interventions would
80 also be of value to practitioners working in the sport. This multiple case study approach is
81 valuable because randomized controlled trial designs are not typically feasible in professional
82 sporting environments, and individuals can have a different intervention modality (e.g.,
83 technical instruction or resistance training) depending on their identified needs. The aim of
84 this study was therefore to determine the efficacy of longitudinal individual-specific training
85 interventions focused upon the variable(s) which elite rugby backs have been shown to be
86 'reliant' upon for better sprint performance.

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88 METHODS

89 *Overview*

90 In Part I⁷, the normalized spatiotemporal variables (step length, step rate, contact time, flight
91 time and SL/SR and CT/FT ratios) and performance (5 m time) of 19 elite¹⁴ male rugby backs
92 were collected during initial acceleration (i.e., the first four steps) from 12 sprint trials during
93 pre-season (hereafter referred to as the *baseline period*). From these data, technical needs

94 were determined as a desired change in *whole-body kinematic strategy*⁸ which was identified
95 for each individual based on spatiotemporal variables they were individually reliant on for
96 better initial acceleration performance. Linear and angular kinematic aspects of technique and
97 strength-based qualities were also obtained during this baseline period.

98
99 The above baseline information obtained in Part I⁷ was proposed as beneficial for
100 practitioners wishing to design personalized sprint acceleration intervention. This study (Part
101 II) details multiple individual-specific case study interventions which were subsequently
102 conducted. Thirteen of the participants whose individual technical needs were identified
103 during the baseline period (mean \pm SD: age 25 ± 3 years; stature 1.81 ± 0.03 m; leg length
104 1.00 ± 0.05 m; body mass 93.2 ± 4.3 kg) were selected based on their availability to be
105 studied over 18-weeks of training. All had a minimum of three years' professional rugby
106 experience and a minimum of five and two years of strength and sprint training experience,
107 respectively. Three participants were selected to undertake individual-specific strength-based
108 interventions. These were selected due deficits in strength-related qualities which were
109 identified during baseline and were known to be associated with the *whole-body kinematic*
110 *strategies*⁸ of elite rugby backs during sprint acceleration (see *Determining the focus for*
111 *individual-specific interventions* for how this was determined). The remaining participants
112 had no notable strength deficits and were randomly assigned to either control (n = 5) or
113 individual-specific technique-based (n = 5) interventions (see *Determining the focus for*
114 *individual-specific interventions* for how each individual's technique-based intervention was
115 determined).

116
117 Although there were two broad categories of intervention (strength-based; technique-based),
118 all interventions were individual-specific. All direct comparisons were therefore made within
119 individuals rather than between group. The control group were included to provide context
120 based on rugby backs completing the same 18-weeks of training aside from having additional
121 sprint-specific strength training (strength-based individuals) or a technical focus during their
122 sprint training session (technique-based individuals). As would be expected in a professional
123 rugby environment over 18 weeks within season, injury and/or changes to training schedules
124 meant that three control and five intervention (technique-based, n = 4; strength-based, n = 1)
125 participants fully completed the 18-week study. Study protocols were approved by the
126 institutional review board, in the spirit of the Helsinki Declaration.

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129 *Determining the focus for individual-specific interventions*

130 Prior to the 18-week intervention, the four technique-based intervention participants (T1-T4
131 [participants 4, 6, 16 and 17 from Part I⁷]), partook in an acute 'exploratory' session to self-
132 generate holistic cues or analogies as technical prompts for their individualized technical
133 interventions. During this exploratory session, the coach explained the findings from, and
134 implications of, the information collected during baseline to each participant, along with the
135 concept of using holistic cues or analogies as technical prompts to direct attention^{15,16}.
136 Participants practiced 10 m sprint efforts by themselves for 10 minutes, during which they
137 were asked to focus on targeting the specific variable(s) they were primarily and secondarily
138 found to individually 'rely' on for better initial acceleration performance during baseline.
139 Participants were asked to reflect on how this technical change felt (physically) and to
140 verbalize this feeling through a holistic cue or analogy as a self-generated technical prompt

141 (Table 1). Participants then completed six 10 m sprints alternating between no focus of
142 attention and focusing upon their technical prompts. Normalized spatiotemporal variables
143 were collected during each of these sprints to assess any acute changes in participants'
144 technical features to enable comparison of these against the intended changes.

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TABLE 1 NEAR HERE

149 The participant who followed an individual-specific strength-based intervention, (S1
150 [participant 15 from Part I⁷]) was 'reliant' on higher step rate for better sprinting performance
151 during baseline (Part I⁷), and this was underpinned primarily by shorter contact times. Such a
152 technical strategy has been associated with higher hip extensor torque assessment scores and
153 shorter contact times in repeated jumps in elite rugby backs⁸. The strength-based scores
154 participant S1 achieved during baseline for hip torque, repeated contact time and therefore
155 their torque/contact time ratio were all poor (25th%, see Table 4 in Part I⁷). Therefore, given
156 their technical 'reliance' during sprinting, participant S1's strength-based program was
157 designed to address the hip extensor and vertical stiffness strength deficiencies to facilitate a
158 technical strategy that would result in shorter contact times and higher step rates during initial
159 acceleration.

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161

162 *18-week intervention*

163 The control group (C1-C3 [participants 5, 8 and 13 from Part I⁷]) underwent their usual
164 training regime over the 18-week period (the full speed and strength-based training sessions
165 during baseline and each phase of the 18-week intervention are in online supplementary files
166 1A-C). The participants (T1-T4) following individual-specific technique-based interventions,
167 completed the same training as the control participants. However, when completing sprint
168 efforts during speed training sessions and in warm-ups for rugby training and matches, they
169 focused on the individual technical prompts which they generated during the prior
170 exploratory session (see Table 1). The participants did not focus on these technical prompts
171 during matches or in the main component of rugby training sessions. Control and technical
172 intervention participants followed the same strength-based training across the intervention
173 period.

174

175 The remaining participant (S1) completed the same sprint training as all other participants
176 (without any technical focus), but also received an individualized strength program. This
177 strength program incorporated specific isometric-based training and a higher volume of
178 plyometric training to enhance muscle-tendon stiffness qualities and stretch-shortening cycle
179 performance^{17,18,19}. The program also used exercises in which a greater extensor demand was
180 placed on the hip²⁰ and loading protocols recommended for maximum strength
181 development²¹ to enhance hip extensor maximum strength ability. Kinematic variables at
182 touchdown and toe-off were also analyzed for this participant post intervention so that
183 within-participant changes in these variables could also be compared to baseline. For the full
184 procedures used to obtain all sprint and strength-based measures, and their reliability, see
185 Wild et al. (2022)⁸.

186

187 The intervention timeline including the type and number of training sessions undertaken
188 during each phase is detailed in Figure 1. The full content of these training sessions is
189 provided as supplementary materials (1A-C). The number of sprints reported (Figure 1)
190 included those which took place during speed training sessions and warm-ups prior to
191 training and matches, as well as those completed during training and matches. On average per
192 training phase, this resulted in participants performing sprint accelerations on approximately
193 five separate occasions per week across speed training sessions (mean \pm SD sprints per phase
194 = 1.5 ± 0.7) and warm-ups prior to rugby training or matches (mean \pm SD sprints per phase =
195 3.3 ± 0.5). During training and matches a sprint was identified from GPS (Catapult Sports, 10
196 Hz) data when 80% of a player's maximum velocity was exceeded, since this has previously
197 been identified as an appropriate relative threshold to monitor sprinting in a team sport
198 setting²². This methodology is also common practice in professional rugby union clubs to
199 provide a relevant and objective applied measure, but it is acknowledged that it is not
200 possible to separate sprinting from just 'high-speed running' using this approach.

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203
204 ***FIGURE 1 NEAR HERE***
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208 The individualized technical prompts were used by the technical intervention participants
209 (T1-T4) in all phases aside from Phase 5 (Figure 1). During Phases 1 and 3 of the
210 intervention, contrasting technical training was undertaken (participants alternated between
211 sprinting with no focus and sprinting by focusing on their technical prompts, similar to the
212 "old way/new way" proposed by Lyndon²³). During Phases 2 and 4, participants always
213 focused on their technical prompts when sprinting. During Phase 5, and during any data
214 collection sessions throughout the intervention, the technical intervention participants were
215 simply instructed to cover the sprint distance as quickly as possible. Control participants and
216 the strength intervention participant always focused on covering sprint distances as quickly as
217 possible without a technical focus or feedback in any phase of the intervention.

218 219 220 *Statistical analyses* 221

222 *Acute effectiveness of technical prompts generated for individual who completed technique-* 223 *based interventions*

224 To assess if the technical prompts resulted in acute technical changes during the exploratory
225 session help prior to the 18-week intervention for participants T1-T4, effect size differences
226 (Cohen's *d*) between variables obtained during sprints completed with and without a
227 technical focus were determined. Differences were deemed meaningful when effect sizes
228 were larger than 0.20 (smallest worthwhile difference²⁴) and when absolute differences (%)
229 were greater than intra-individual CVs obtained for the selected variable during the
230 exploratory session. The magnitude of acute changes in *whole-body kinematic strategies*
231 during the exploratory session were measured by the Euclidean distance between the spatial
232 locations of their centroid cartesian coordinates.

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234

235 *Assessment of within-individual changes over the 18-week intervention period*

236 To assess changes for all eight participants within the 18-week intervention, the same
237 variables collected during baseline (normalized spatiotemporal variables, SL/SR and CT/FT
238 ratios, 5 m time) were also collected during three sprints on three separate occasions (Phases
239 2-4, weeks 7, 10 and 13; red weeks in Figure 1). For full details on the procedures used to
240 obtain these measures see Wild et al.⁸ and Part I⁷. These were also collected on a further three
241 to four occasions during the final four weeks of the intervention (Phase 5, weeks 15-18; green
242 weeks in Figure 1) to enable a comparison of the post intervention results against baseline
243 values.

244
245 Effect size differences (Cohen's d) were used to determine the magnitude of the pairwise
246 differences in mean \pm SD 5 m time, normalized spatiotemporal variables and SL/SR and
247 CT/FT ratios within each individual between all testing occasions. A sequential estimation
248 technique was used to determine the minimum number of sprint trials needed to establish a
249 stable mean for each kinematic variable and participant from the baseline period. This
250 ensured confidence in any changes observed between baseline and Phase 5 testing (see
251 supplementary material 2). Paired samples t -tests or Wilcoxon signed-rank (nonparametric
252 data) were used to determine whether changes in the mean \pm SD normalized spatiotemporal
253 variables, SL/SR and CT/FT ratios and 5 m time between baseline testing (12 sprint trials)
254 and the testing in Phase 5 (10 to 12 sprint trials) within each participant were also statistically
255 significant. Changes were deemed meaningful when all three of the following criteria were
256 met: 1) effect sizes > 0.20 (smallest worthwhile difference²⁴); 2) the absolute differences (%)
257 were greater than intra-individual CVs obtained for the selected variable²⁵; 3) differences
258 were statistically significant ($p \leq 0.05$). The linear and angular sprint kinematics and strength-
259 based variables obtained for participant S1 during the final phase (Phase 5, Figure 1) were
260 compared against the same measures obtained during baseline, with meaningful changes
261 determined when the first two criteria outlined above were met.

262
263 Magnitudes of the changes in the *whole-body kinematic strategy* between baseline and Phase
264 5 for all eight participants were determined using the Euclidean distance between the spatial
265 locations of their centroid cartesian coordinates. The direction change in *whole-body*
266 *kinematic strategy* was also quantified based on the vector from the baseline centroid to the
267 Phase 5 centroid (see Figure 2). These were expressed as compass bearings (north = 0°)
268 rounded to the nearest half-wind (22.5°).

269
270 To determine whether a participant's *whole-body kinematic strategy* was from different
271 distributions between baseline and Phase 5, thus reflecting a change in individual strategy
272 from one cluster to another rather than a within-cluster shift in strategy, a two-dimensional
273 Kolmogorov-Smirnov test was employed²⁶. A statistic in the range [0,1] was calculated by
274 scaling the statistic by the quantity:

275
276
$$\sqrt{\frac{n1n2}{n1 + n2}}$$

277
278 where $n1$ is the sample size of the pre data set and $n2$ is the sample size of the post data set.
279 The closer the statistic is to 1, the more different the distributions of the *whole-body*
280 *kinematic strategies* are. Statistical significance was determined using a permutation test in

281 which the observed data were resampled multiple times using an open-source package in R to
282 obtain a p -value for the test²⁷.

283

284

285 RESULTS

286 *Exploratory session for technique intervention participants*

287 Moderate to extremely large differences ($|d| = 1.08$ to 5.75) were observed when comparing
288 all variables between no focus and technical focus (prompt) conditions during the pre-
289 intervention exploratory session for the technical intervention participants (Figure 3). The
290 direction of the changes in *whole-body kinematic strategies* were closely aligned with those
291 technical variables that individuals primarily and secondarily ‘relied’ on for better initial
292 acceleration performance (Table 1) during the baseline period (to the nearest half-wind for
293 T1, and within one, two or three half-winds of the intended direction shift for T2, T3 and T4,
294 respectively; Figure 3). Initial acceleration performance was acutely negatively affected by
295 large to extremely large magnitudes during the sprints undertaken with the technical focus
296 provided (Figure 3).

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298

299 ***FIGURE 3 NEAR HERE***

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302 *Pre and post changes following intervention*

303 Pre (baseline testing) to post (Phase 5, Figure 1) changes in *whole-body kinematic strategies*
304 of all participants are shown in Figure 2. The change of whole-body centroids for the
305 intervention participants were the same (S1) or within one (T3), two (T1 and T2) or three
306 (T4) half-winds of the intended direction. The Euclidean distance between pre and post
307 whole-body kinematic centroids of participants given a technical or strength intervention
308 were greater than all control participants (C1-C3). T1 and S1 both exhibited statistically
309 significant different distributions of their pre and post *whole-body kinematic strategies*
310 (Figure 2), meaning a change in strategy from one cluster to another.

311

312 Initial acceleration performance of participants who received a technical intervention was
313 significantly enhanced from pre to post intervention (Figure 4; supplementary material 3A-
314 C). The magnitude of improvement in 5 m times ($d = 1.11$ to 2.82) were moderate to very
315 large. For strength (S1) and control participants, initial acceleration performance remained
316 unchanged (supplementary materials 3D-G). For control participants, there were no changes
317 in SL/SR and CT/FT ratios or normalized spatiotemporal variables, although the magnitude
318 of change in CT/FT ratio for participant C3 (supplementary 3E) exceeded their within-
319 individual CV. For participants who received an intervention, statistically significant
320 differences were evident and exceeded within-individual CV for at least two variables each (d
321 = 1.11 to 3.99).

322

323 For participant S1 very to extremely large ($d = 3.13$ to 9.15) meaningful differences (Figure
324 5) in all but one strength-based measure (squat jump P_{\max}) were observed between the
325 baseline period and Phase 5. For S1’s sprint kinematics, the proximal endpoints of their shank

326 and thigh at touchdown were rotated more forwards during the testing in Phase 5, while the
327 proximal end of their foot segment was less forwards rotated at toe-off. The largest pre to
328 post change of a technical feature was touchdown distance (extremely large magnitude),
329 where the foot was more posterior relative to the CM at touchdown.
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332 ***FIGURE 2 NEAR HERE***

333 ***FIGURE 4 NEAR HERE***

334 ***FIGURE 5 NEAR HERE***
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340 DISCUSSION

341
342 We evaluated the efficacy of longitudinal individual-specific training interventions focused
343 upon the variable(s) which elite rugby backs can be ‘reliant’ upon for better sprint
344 performance. In all participants who received an intervention, the changes in *whole-body*
345 *kinematic strategies* were greater than controls by more than a factor of two. The changes in
346 *whole-body kinematic strategies* for both the strength-based and technique-based intervention
347 participants were also broadly consistent with the intended changes (to within three half-
348 winds based on the developed method), confirming the effectiveness of these two approaches
349 to individual-specific intervention design. Significant improvements in initial acceleration
350 performance were evident for the participants who received technical interventions, whereas
351 no meaningful changes in initial acceleration performance were observed in the participant
352 who followed a strength-based intervention or in the three control participants. These
353 findings confirm that the carefully-prescribed individual-specific interventions were effective
354 at eliciting larger technical changes and, in the case of the four participants who received
355 technical intervention, greater enhancements in initial acceleration performance compared to
356 the typical ‘one-size-fits-all’ initial acceleration training approach which the control
357 participants underwent.

358 For participants T1-T4, the consistency of technically focused repetitions completed during
359 the first 14 weeks of the intervention period appeared to be sufficient to direct their
360 movement tendencies in the general direction of the technical focus during Phase 5 of the
361 intervention period. One possible explanation for this is the phenomenon known as ‘use-
362 dependent learning’ which describes how motor behavior is shaped in the direction of
363 previous motor actions^{28,29}. In the current study, the ‘previous motor actions’ of T1-T4
364 resulted from their individual technical prompts. However, the change in magnitude of the
365 variables that participants T1-T4 were primarily and secondarily reliant on for better
366 acceleration performance peaked in sessions prior to the testing in Phase 5 (see Figure 4 and
367 supplementary material 3A-C). This sequence was also the same for the magnitude of change
368 in 5 m sprint time in all but one (T1) whose best acceleration performance was in the testing
369 in Phase 5. As Phase 5 of the intervention did not emphasize technical prompts during
370 sprints, it is possible that the use-dependent aftereffects from their previous motor actions
371 started to subside when the participants stopped applying a technical focus during training.
372 Further research is needed to understand how technical features and acceleration performance
373 are retained across different durations following technical focused interventions.

374 For S1, no focus was applied to the sprint training undertaken in any phase. The strength
375 intervention targeted the variables they were primarily (higher SR) and secondarily (shorter
376 CT) ‘reliant’ on for better initial acceleration performance. Very large changes were observed
377 in these variables in the desired direction (supplementary material 3D) which were
378 underpinned by meaningful changes in a range of linear and angular kinematic aspects of
379 S1’s technique. These changes were evident alongside very large increases in the strength
380 capacities targeted in their intervention (Figure 5). The changes in participant S1’s strength
381 capacities may, in part, have shaped their touchdown kinematics, self-organising³⁰ to produce
382 a smaller touchdown distance by orienting their lower limb segments more horizontally post
383 intervention (Figure 5). Since a smaller touchdown distance will result in less distance for the
384 CM to travel forwards before rapid leg extension becomes more valuable for horizontal
385 translation³¹, the change in S1’s linear and angular kinematics may explain how shorter
386 contact times and, in turn, higher step rates were achieved.

387

388 Despite the observed technical changes, a meaningful difference in S1’s initial acceleration
389 performance was not found. Although the initial acceleration performances of team sport
390 players have been shown to be enhanced by strength-based interventions (see Nicholson et
391 al.³ for a review), combined methods including technical-based training with sprint *and*
392 strength-based training are considered best practice in the field³² for developing speed. More
393 research is therefore required to understand the efficacy of combined technical and strength
394 intervention targeting the specific sprint variables which individuals are ‘reliant’ on for better
395 initial acceleration performance.

396

397

398 PRACTICAL APPLICATIONS

399

400 Our study has identified the effectiveness of individual-specific strength-based and
401 technique-based interventions for altering initial sprint acceleration technique in a desired
402 direction, when compared against a traditional ‘one-size-fits-all’ approach. Furthermore,
403 individual-specific technique-based intervention also led to improvements in initial
404 acceleration performance in all four participants over the 18-week intervention period.
405 Individualizing the initial acceleration interventions of athletes should be an attractive
406 prospect for coaches working with elite rugby backs or with athletes from other sports where
407 initial acceleration is important. The steps needed to adopt the approach used in this study to
408 individualize the sprint technique interventions of these athletes should follow the robust and
409 rigorous protocols here and in Part I⁷, but they are straightforward: 1) Determine the within-
410 individual relationships between the spatiotemporal variables, SL/SR and CT/FT ratios and
411 initial acceleration performance of each individual during a baseline period to identify which
412 variable(s) they are ‘reliant’ on for higher initial acceleration performance and how this is
413 underpinned by a change in spatial location of their *whole-body kinematic strategies*; 2)
414 Work with the athlete(s) to identify the focus of attention which results in a shift in their
415 *whole-body kinematic strategy* towards the direction of the intended technical change; 3) Use
416 opportunities within the training week (e.g., at the end of warm-ups prior to sport training and
417 matches and/or during ‘stand-alone’ speed training sessions) for players to focus on their
418 technical prompts during sprint efforts; and 4) After a defined period of time, measure
419 changes in their initial acceleration technique and performance to determine the effectiveness
420 of the intervention applied and to establish whether their individual needs have changed.

421

422 One important benefit here is that an individualized approach to technique-based sprint
423 training can be applied to a large group during the same sprint training session. For instance,

424 provided each individual (or sub-group where relevant) has their own technical prompt to
425 follow, it is not necessary for the team sport players to undertake different sprinting tasks to
426 one another within the speed training session and sprinting volume and frequency can remain
427 the same across the group. The multiple case study design adopted provides rich insights into
428 individual responses and changes in system behaviors of elite athletes. However, caution is
429 needed in interpreting the findings, particularly for the participant undergoing the strength
430 intervention, as single participant investigations may have limited generalizability and
431 subjective data interpretation. However, the inclusion of control participants who underwent
432 the same general training program provides valuable context to the individual responses
433 observed in all intervention participants studied. Ultimately, the current framework developed
434 provides a unique approach for coaches and other practitioners to integrate individualized
435 sprint acceleration-based interventions into their field-based training environment, thus
436 offering a valuable service to the athletes they work with and their employers.

437

438

439 **CONCLUSION**

440

441 Meaningful and statistically significant enhancements were observed in the initial
442 acceleration performance of participants who were given novel individual-specific technical
443 interventions, in contrast to the lack of meaningful changes in initial acceleration
444 performance of controls who underwent a generic, group-based sprint training protocol. An
445 individual-specific strength-based intervention for a single participant led to favorable
446 changes in their strength capacities, and intended changes in their sprint technique
447 kinematics, but this did not result in better initial acceleration performance. Although the
448 findings from the approach used during this research cannot be generalized to all individuals,
449 collectively, the current findings emphasize the importance of considering individual
450 characteristics when prescribing technical or physical interventions to enhance initial
451 acceleration performance. This is the first study to investigate how initial acceleration
452 performance and technique change following individual-specific interventions, based on
453 individual needs from prior analyses. The unique approach used bridges the gap between
454 research and applied practice, using evidence-based individual-specific interventions to
455 provide a novel and robust method for practitioners working with elite rugby union backs, or
456 other athletes competing in sports where initial acceleration performance is important, to
457 individualize their sprint-based training practices.

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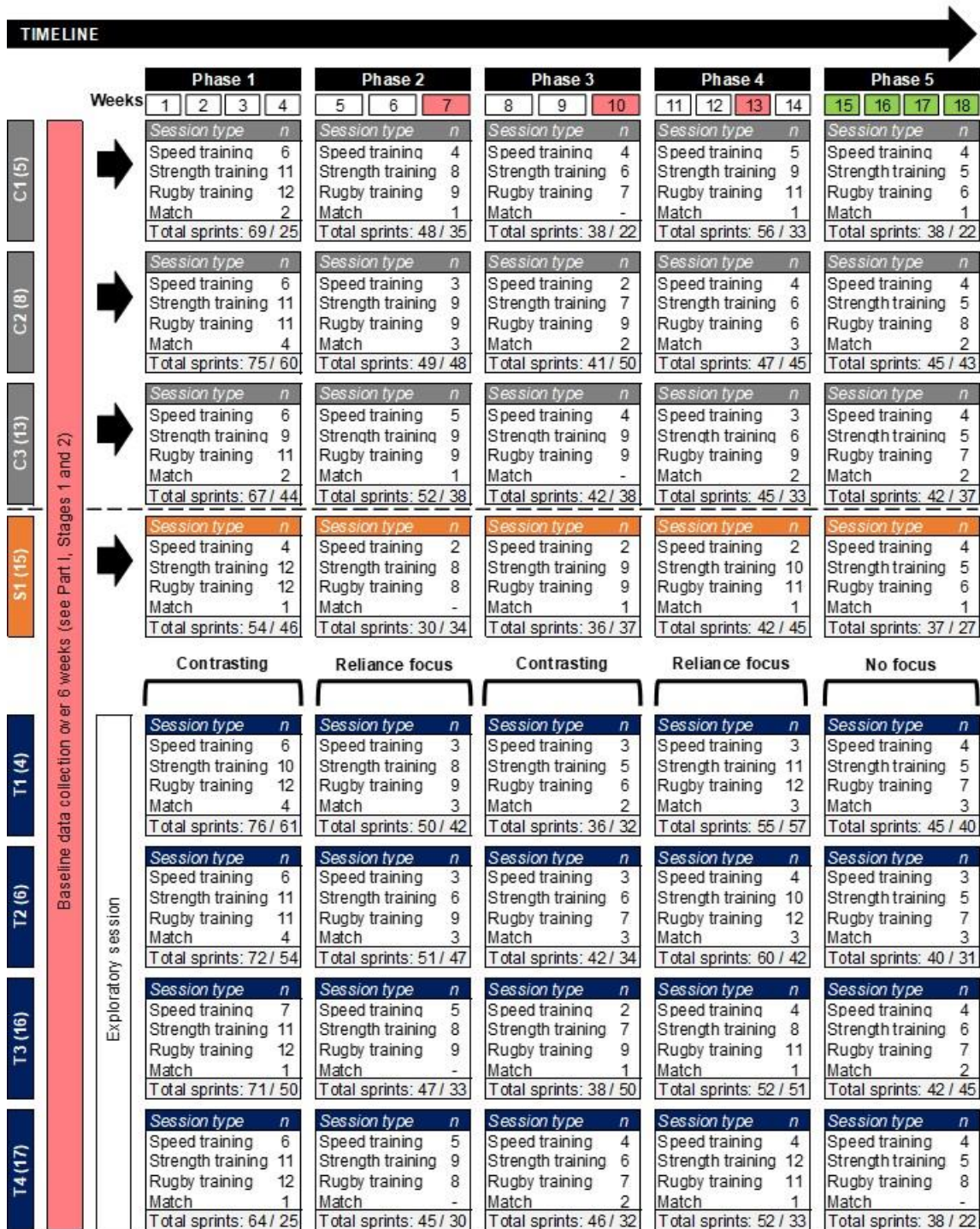
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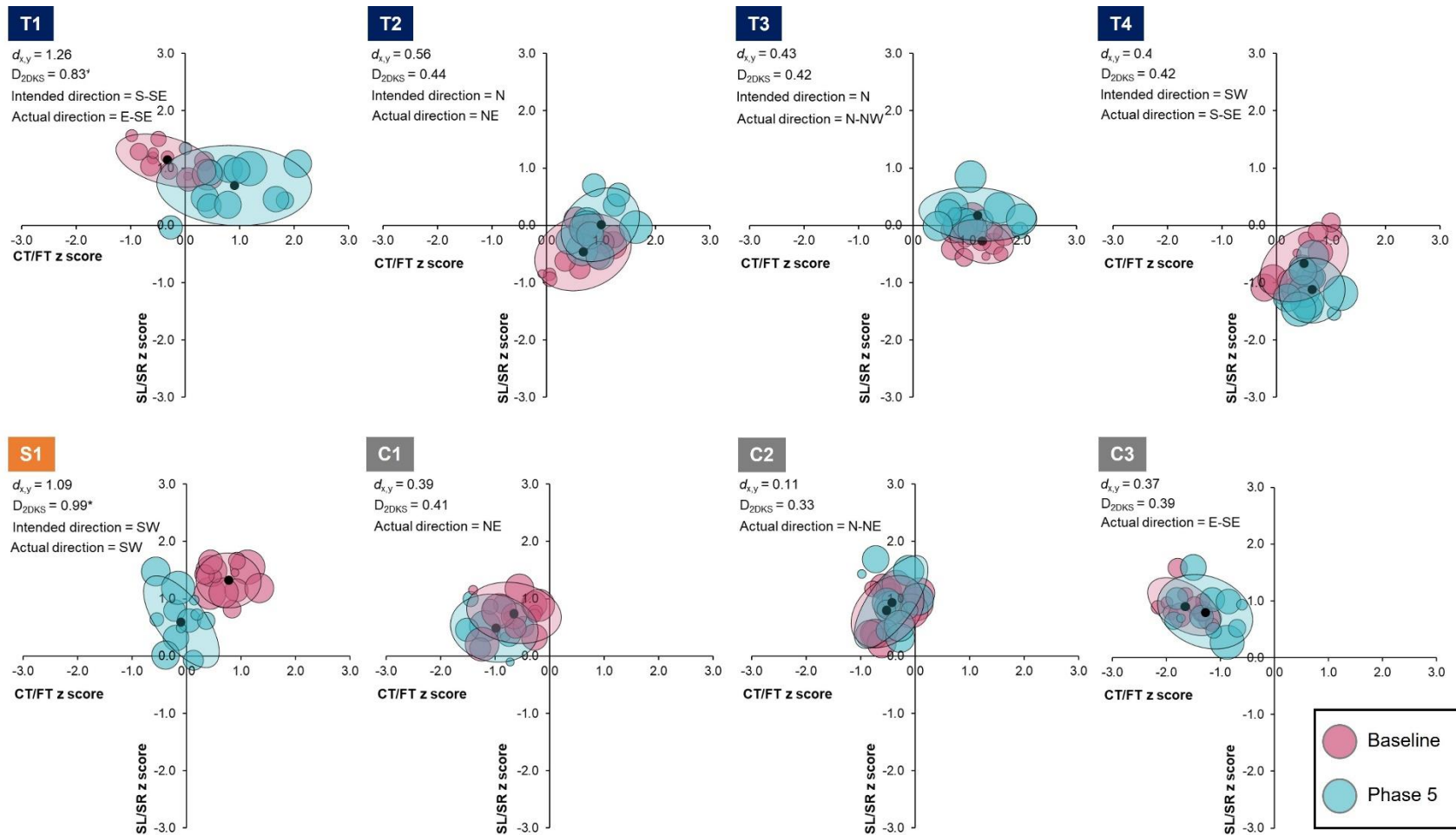
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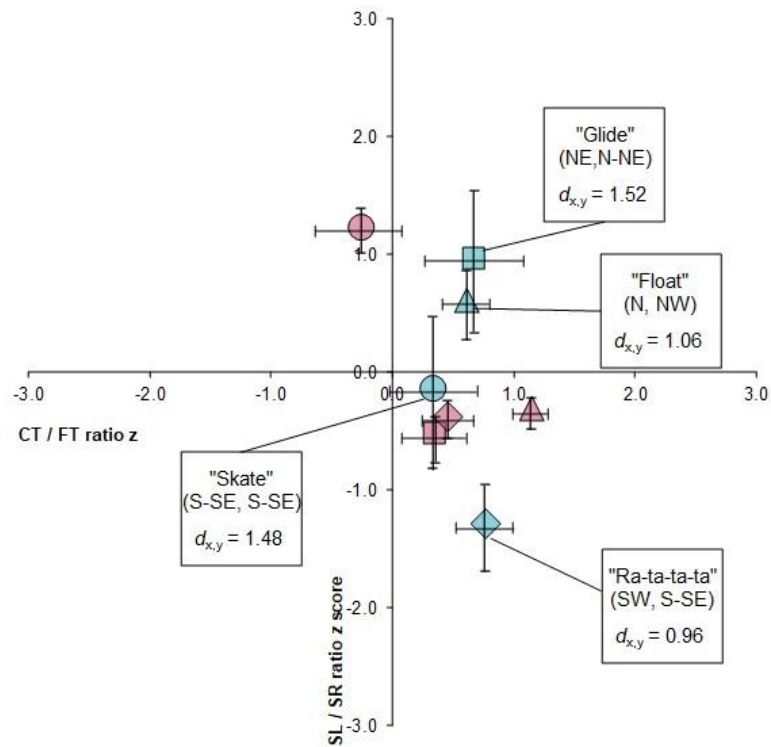


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585 **Figure 1.** Intervention timeline and the type and number of sessions completed by participants. The total
 586 number of sprints shown for each participant include those completed during speed sessions and warm-ups
 587 before rugby training and matches (left side of the forward slash) and those completed during rugby training and
 588 matches, considered when participant’s velocity was above 80% of their maximum velocity capability, derived
 589 from GPS outputs (right side of the forward slash). Individuals (C1-3) above the dashed line formed the control
 590 participants. Participants underneath the dashed line underwent strength (S1) and technical (T1-4) based
 591 interventions. The numbers in brackets for each individual back are the participants numbers from the baseline
 592 period⁷. Shaded weeks represent the weeks in which sprint testing occasions took place during the intervention
 593 (weeks 7, 10 and 13) and green the final testing period (weeks 15-18).



594 **Figure 2.** Change in *whole-body kinematic strategies* of participants between initial baseline and final testing phases (Phase 5). Each sprint is represented by a circle, the
 595 diameter of which is directly proportional to performance (the inverse of 5 m time, i.e. larger circles = higher performance (shorter times)), and the ellipses quantify the 90%
 596 confidence interval across all sprints within each phase. $d_{x,y}$ = Euclidean distance between the whole-body kinematic strategies; D_{2DKS} = two-dimensional Kolmogorov-
 597 Smirnov statistic to determine the extent to which whole-body kinematic strategies are from the same distribution. Asterisks indicate whether the differences in distribution
 598 are statistically significant ($p < 0.05$)



T1	Mean \pm SD		Effect sizes
	No focus ●	Prompt ●	
5 m time (s)	1.021 \pm 0.018	1.074 \pm 0.036	2.94
CT/FT	2.41 \pm 0.15	2.65 \pm 0.21	1.64
SL/SR	1.11 \pm 0.06	0.97 \pm 0.14	-2.31
SL	1.43 \pm 0.03	1.35 \pm 0.09	-2.67
SR	1.29 \pm 0.03	1.39 \pm 0.07	3.33
CT	0.549 \pm 0.006	0.523 \pm 0.013	-4.33
FT	0.228 \pm 0.007	0.197 \pm 0.020	-4.43

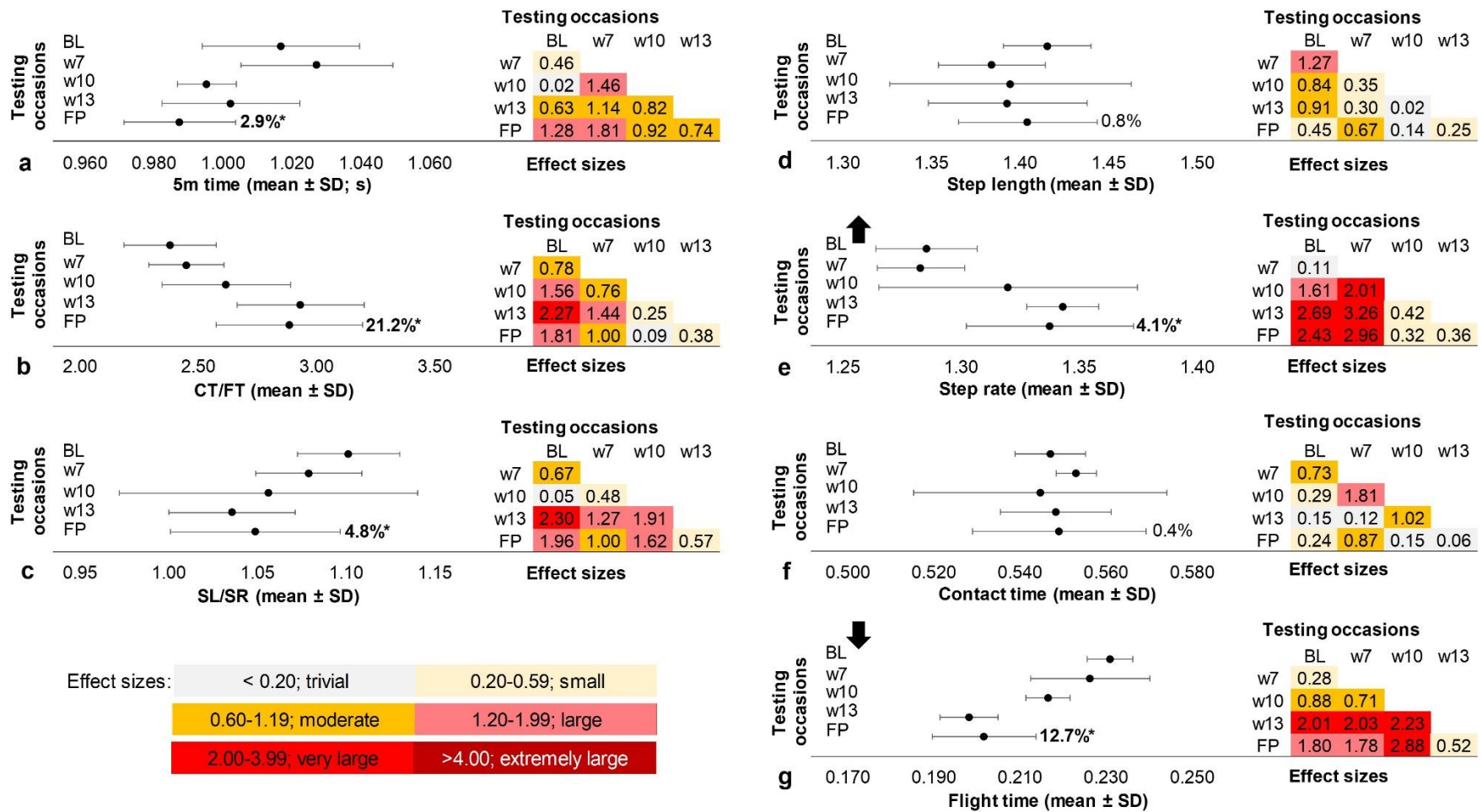
T3	Mean \pm SD		Effect sizes
	No focus ▲	Prompt ▲	
5 m time (s)	1.067 \pm 0.013	1.105 \pm 0.015	2.92
CT/FT	3.01 \pm 0.09	2.78 \pm 0.12	-2.56
SL/SR	0.93 \pm 0.04	1.04 \pm 0.09	2.75
SL	1.31 \pm 0.03	1.40 \pm 0.07	3.00
SR	1.41 \pm 0.02	1.33 \pm 0.05	-4.00
CT	0.532 \pm 0.007	0.552 \pm 0.016	2.86
FT	0.177 \pm 0.006	0.191 \pm 0.008	2.33

T2	Mean \pm SD		Effect sizes
	No focus ■	Prompt ■	
5 m time (s)	1.017 \pm 0.006	1.046 \pm 0.023	4.83
CT/FT	2.67 \pm 0.13	2.81 \pm 0.19	1.08
SL/SR	0.91 \pm 0.06	1.08 \pm 0.14	2.83
SL	1.30 \pm 0.04	1.41 \pm 0.08	2.75
SR	1.43 \pm 0.05	1.33 \pm 0.08	-2.00
CT	0.508 \pm 0.010	0.564 \pm 0.012	5.60
FT	0.191 \pm 0.005	0.201 \pm 0.014	2.00

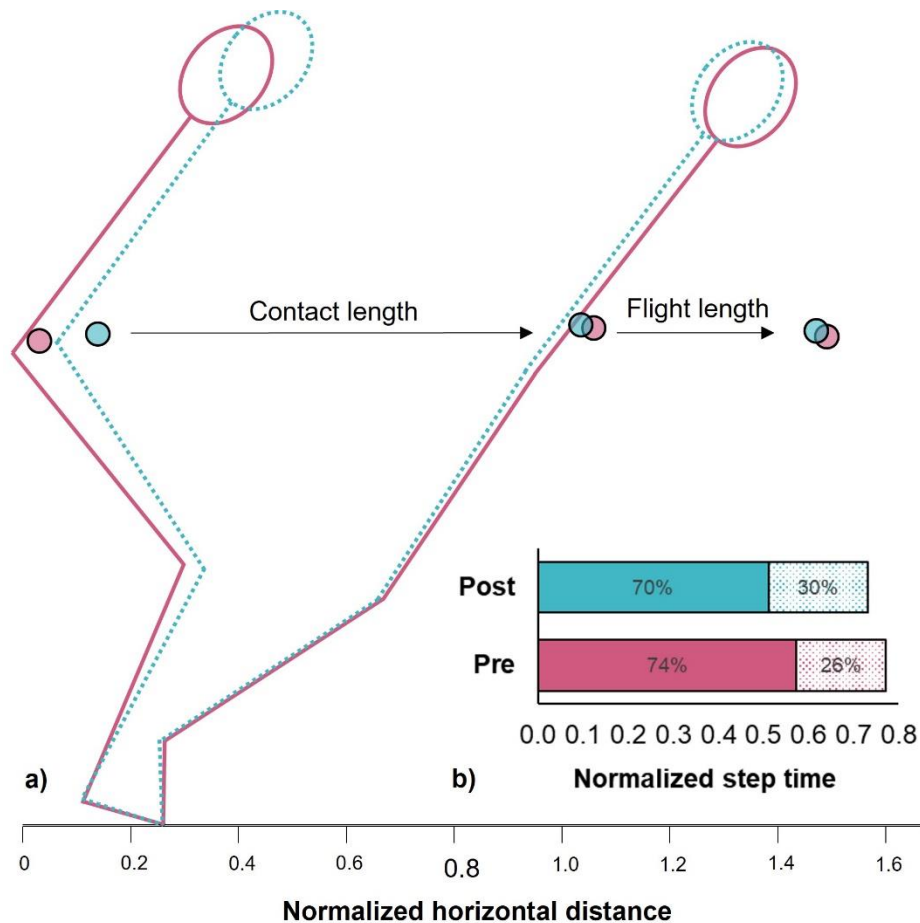
T4	Mean \pm SD		Effect sizes
	No focus ◆	Prompt ◆	
5 m time (s)	1.061 \pm 0.014	1.098 \pm 0.029	2.64
CT/FT	2.72 \pm 0.12	2.85 \pm 0.15	1.08
SL/SR	0.92 \pm 0.05	0.82 \pm 0.11	-2.00
SL	1.30 \pm 0.04	1.21 \pm 0.08	-2.25
SR	1.41 \pm 0.03	1.48 \pm 0.06	2.33
CT	0.520 \pm 0.010	0.499 \pm 0.018	-2.10
FT	0.532 \pm 0.007	0.502 \pm 0.009	-4.29

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Figure 3. Differences in *whole-body kinematic strategies* spatial locations and the magnitude of normalized spatiotemporal variables, SL/SR and CT/FT ratios and initial acceleration performance for participants under no focus and technical focus (prompt) conditions during an acute exploratory session prior to the 18-week intervention. Self-generated technical prompts are shown in the speech marks for each participant, with the direction changes in strategy indicated in brackets (intended, actual) as compass bearings calculated to the nearest half-wind (22.5°). Euclidean distance ($d_{x,y}$) depicts the magnitude of change in participant *whole-body kinematic strategies*.



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 614 **Figure 4.** 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T1** (technical intervention; mean ± SD). Between testing occasion
 615 effect sizes (absolute) are shown. Black arrows indicate the direction of the intended changes in magnitude of the variables which were most underpinning the intended
 616 change in spatial location of the participant's *whole-body kinematic strategy*. The absolute percentage change between initial baseline testing (session number 1) and the final
 617 testing phase (session 5) is shown. If this value is bold, the magnitude of the change is greater than the smallest worthwhile difference,²⁴ and asterisks indicate whether the
 618 difference is statistically significant ($p \leq 0.05$), according to Paired samples *t*-tests or *Wilcoxon signed-rank (nonparametric data) tests. (SL = step length, SR = step rate, CT
 619 = contact time, FT = flight time; BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase).



Variables	Mean ± SD		Effect sizes
	Pre —	Post	
Foot TD (°)	164 ± 2	162 ± 2	-1.00
Shank TD (°)	67 ± 2	62 ± 3	-2.50
Thigh TD (°)	129 ± 2	123 ± 2	-3.00
Trunk TD (°)	53 ± 3	54 ± 3	0.33
Foot TO (°)	89 ± 1	92 ± 2	3.00
Shank TO (°)	33 ± 2	33 ± 3	0.00
Thigh TO (°)	56 ± 2	57 ± 3	0.50
Trunk TO (°)	52 ± 3	53 ± 3	0.33
Touchdown distance	0.242 ± 0.014	0.134 ± 0.019	-7.71
Toe-off distance	-0.769 ± 0.018	-0.760 ± 0.024	0.50
Contact length	1.011 ± 0.063	0.894 ± 0.071	-1.86
Flight length	0.436 ± 0.031	0.441 ± 0.041	0.16
Pmax (W/kg)	26.91 ± 1.36	27.99 ± 1.02	0.79
Hip torque (Nm/kg)	4.51 ± 0.11	4.95 ± 0.09	4.00
Repeated RSI	0.45 ± 0.02	0.64 ± 0.02	9.55
Repeated jump height (m)	0.14 ± 0.01	0.17 ± 0.01	3.13
Repeated CT (s)	0.312 ± 0.011	0.258 ± 0.014	-4.91
Torque / CT	14.46 ± 0.94	19.24 ± 0.91	5.09

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Figure 5. a) Scaled spatial model showing the mean stance leg and torso segmental orientations across all (four) steps for **participant S1** (strength intervention) at touchdown and toe-off during baseline (purple, pre) and final (turquoise, post) testing phases. The mean center of mass location at touchdown and toe-off positions is depicted as markers (circles), showing normalized linear kinematic variables. Note that horizontal and vertical scales are the same and all normalized linear kinematic variables are referenced to position of the toe of the stance leg; b) average of the mean normalized step times during baseline and final testing (Phase 5), divided into contact time (filled bars) and flight time (pattern filled bars). The proportion of time spent during the contact and flight phases relative to step time are shown as percentages; c) differences in mean ± SD values for segment and angular kinematics and strength qualities between baseline and final testing (Phase 5) for participant S1.

Table 1. Variables participants given a technical intervention were primarily and secondarily ‘reliant’ on for better initial acceleration performance along with the intended directional changes in spatial location of their *whole-body kinematic strategies* associated with better sprinting performance and the self-generated technical prompts to facilitate these changes.

Participant	Primary reliance ^a	Secondary reliance ^b	Intended Cartesian plane direction shift ^c	Technical prompt	Prompt context for intended direction shift in <i>whole-body kinematic strategy</i>
T1	↑Step rate	↓Flight time	S-SE	"Skate"	Participant explained the feeling of increasing their step rate primarily through a reduction in flight time as "fast skating". That is, it felt like they were skating over the ground with each step.
T2	↑CT/FT ratio	↑Step length	NE	"Glide"	Participant explained the feeling of increasing their step length while increasing CT/FT ratio as "gliding". The typical flat trajectory of a hang-glider was used to describe the feeling the participant had with a flatter center of mass trajectory in sprinting likely resulting from the combination of longer contact times and shorter flight times in a step (i.e., a higher contact/flight ratio).
T3	↑SL/SR	↑Step length	N	"Float"	Participant explained the feeling of increasing their step length as "floating."
T4	↑Step rate	↓Contact time	SW	"Ra-ta-ta-ta"	Participant explained the feeling of increasing their step rate primarily through a reduction in contact time audibly with a noise reflecting the sound of a machine gun.

^aVariable most related to initial acceleration performance (arrows represent whether an increase (up) or decrease (down) in the variable is associated with initial acceleration performance);

^bvariable second most related to initial acceleration performance;

^cthe Cartesian plane shift depicts the intended Cartesian plane spatial location change in the *whole-body kinematic strategy* of participants related to their initial acceleration performance (see explanation below, also Part I⁷)

S-SE = south southeast; NE = northeast; N = north; SW = southwest

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SUPPLEMENTARY MATERIAL 1

1A. Strength and speed training undertaken by participants T1-T4, S1 and C1-C3 during the baseline phase. A PDF copy of this with video demonstrations of the exercises in the speed training undertaken can be accessed here: <https://figshare.com/s/95455f88c1c823d5ad4e>

Week number		-5	-4	-3	Week number		-2	-1	0	Week number		-2	-1	0					
STRENGTH	Session 1	Exercise	Sets x reps			Exercise	Sets x reps			Session 1	Exercise	Sets x reps			Session 1	Exercise	Sets x reps		
		SA DB flat press	4 x 8	4 x 8	4 x 6	SA DB flat press	4 x 6	4 x 6	-		Switch (single)	2 x 5m	2 x 8m	2 x 10m		Switch (triple)	2 x 8m	2 x 10m	3 x 15m
		SA DB row	4 x 8	4 x 8	4 x 6	SA DB row	4 x 6	4 x 6	-		Switch (triple)	2 x 5m	2 x 5m	2 x 8m		Straight leg bound	3 x 10m	3 x 15m	2 x 20m
		BB javelin press	4 x 10	4 x 10	4 x 10	BB javelin press	4 x 10	4 x 8	-		Straight leg bound	2 x 8m	2 x 10m	2 x 10m		Jump conditioning 2	x 2 rounds (5 reps)	x 2 rounds (5 reps)	x 2 rounds (5 reps)
		Half kneeling cable row	4 x 10	4 x 10	4 x 10	Half kneeling cable row	4 x 10	4 x 8	-		Jump conditioning 1	x 2 rounds (6 reps)	x 2 rounds (6 reps)	x 2 rounds (6 reps)		Medball heave (upwards)	2 x 2 (8kg)	2 x 2 (10kg)	2 x 3 (10kg)
		Chin ups	3 x AP	3 x AP	3 x AP	Chin ups	3 x AP	3 x AP	-		Medball heave (upwards)	2 x 2 (5kg)	2 x 3 (5kg)	2 x 3 (8kg)		Resisted acceleration bound	2 x 10m	2 x 10m	2 x 10m
	Press ups	3 x AP	3 x AP	3 x AP	Press ups	3 x AP	3 x AP	-	Resisted acceleration bound	2 x 5m	2 x 10m	2 x 10m	Resisted sprint	2 x 10m (40kg)	2 x 10m (60kg)	-			
	Session 2	Bulgarian split squat ISOs hold ^a	3 x 5	3 x 5	3 x 5	Squat jump (20kg)	4 x 4	4 x 4	4 x 4	SPEED	Resisted sprint	-	-	1 x 10m (40kg)	Sprint (2-point start)	3 x 30m	4 x 20m	3 x 30m	
		Supine SL hip ext. ISOs ^b	3 x 5	3 x 5	3 x 5	Back squat	3 x 5	3 x 5	3 x 5		Sprint (2-point start)	2 x 10m	3 x 30m	2 x 10m	Sprint (2-point start)	-	-	2 x 15m	
		Seated SL calf raise	2 x 10	2 x 10	2 x 10	DB walking lunge	3 x 5	3 x 5	3 x 5		Sprint (2-point start)	-	-	2 x 15m	Session 2	Dribble (shin)	2 x 20m	2 x 20m	2 x 20m
		Squat jump (20kg)	2 x 4	3 x 4	3 x 4	Romanian deadlift	3 x 5	3 x 5	3 x 5		Dribble (knee)	2 x 10m	2 x 10m	2 x 10m		Hop conditioning 2	x 2 rounds (4 reps)	x 2 rounds (4 reps)	x 2 rounds (4 reps)
		Back squat	3 x 5	3 x 5	3 x 5	Incline bench press	3 x 4	4 x 3	4 x 3		Hop conditioning 1	x 2 rounds (4 reps)	x 2 rounds (4 reps)	x 2 rounds (4 reps)		Pogo (maximal)	2 x 5m	2 x 8m	2 x 10m
Romanian deadlift		3 x 5	3 x 5	3 x 5	Weighted chin up	3 x 5	4 x 5	4 x 5	Pogo (rhythmic)		2 x 10m	3 x 10m	3 x 10m	Dribble (knee)		2 x 15m	2 x 20m	2 x 20m	
Rollouts	3 x 8	3 x 8	3 x 10	Prone DB row	3 x 8	4 x 8	4 x 8	Sprint (upright, rolling start)	-		2 x 10m	2 x 10m	Sprint (2-point start)	1 x 10m		1 x 10m	1 x 20m		
				DB reverse fly	3 x 10	4 x 10	4 x 10	Sprint (2-point start)	-		-	1 x 15m	Sprint (2-point start)	1 x 20m		1 x 20m	2 x 40m		
Session 3				Weighted press ups	4 x 15	4 x 20	4 x 25	Sprint (2-point start)	-		-	1 x 15m	Sprint (upright, rolling start)	2 x 15m	2 x 20m	-			
				Nordic curl (band assisted)	3 x 5	3 x 5	3 x 5	Sprint (2-point start)	3 x 30m		2 x 10m	3 x 20m							
	Session 4	Incline bench press	4 x 5	4 x 5	4 x 5	Strength key: SA = single arm; SL = single leg; DB = dumbbell; BB = barbell; ISOs = isometrics; AP = as many reps as possible		Speed key: m = metres; red shaded contents = testing sessions during which acceleration technique and performance data were obtained from participants; exercises underlined are linked to video demonstrations			Speed notes: rest between sets for drills and jumping exercises typically involved a slow walk back between each set. For throw-based exercises rest between sets was typically ~90s. For sprint-based activities 60s of rest for every 10m travelled in the effort was employed between sets (e.g., a 20 m sprint would result in a 120s rest). The exception to this was during testing where 4-5 minutes of rest were taken between sprints. On testing occasions, sprint efforts were completed before all other activities. Warm-up sets have not been included in the programme detailed. Participants had followed a home-based speed programme including sprinting over distances progressing from 5 m to 20 m over 3 weeks prior to the start of the baseline period								
		Weighted chin up	4 x 6	4 x 6	4 x 6	Strength notes: generally, participants selected a load whereby 1-3 reps were left in reserve for each set. Rest between sets were typically 60-150s, with the lower and higher ends of this rest continuum applied to exercises when intensity was lower and higher respectively. ^a Participants held for 5 s in the bottom position for each rep. ^b Completed in the set up position for the hip torque test, participants attempted to 'push' the immovable bar upwards, gradually increasing their effort (similar to Balshaw et al., 2016) to ~80% of their maximum and held this intensity for 3s before resting for 5s in each in rep. Shaded rows depict supersets, whereby participants alternated between exercises with small rest (~15-45s) between each exercise and longer rest (~90-150s) between sets. Warm-up sets have not been included in the programme detailed. Participants had followed a home-based (predominantly bodyweight) strength programme for 3 weeks prior to the start of the baseline period													
		Prone DB row	4 x 8	4 x 8	4 x 8														
		Close-grip press up	4 x 20	4 x 20	4 x 20														
Incline DB fly		3 x 10	3 x 10	3 x 10															
BB curl		3 x 12	3 x 12	3 x 12															
Nordic curl (band assisted)	3 x 5	3 x 5	3 x 5																

1B. Strength training undertaken by participants T1-T4, S1 and C1-C3 during the intervention phase.

		Phase 1				Phase 2			Phase 3			Phase 4				Phase 5					
Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
Exercise		Sets x reps				Sets x reps			Sets x reps			Sets x reps				Sets x reps					
Session 1	Squat jump	3 x 3 (20kg)	3 x 3 (20kg)	3 x 3 (30kg)	3 x 3 (30kg)	3 x 4 (30kg)	3 x 4 (30kg)	-	Power clean	3 x 4	4 x 4	-	Power clean (hang position)	4 x 4	3 x 3	-	4 x 3	4 x 4	4 x 3	-	3 x 3
	Hurdle rebound jump	3 x 6	3 x 6	-	3 x 6-8	3 x 6-8	3 x 6-8	-	Hurdle rebound jump	3 x 6	3 x 6	3 x 3	Back squat	-	3 x 4	3 x 5	4 x 3	3 x 4	5 x 3	3 x 3	-
	Back squat	3 x 3	4 x 3	3 x 3	-	3 x 5	4 x 3	1 x 3	Back squat	4 x 5	4 x 4	3 x 3	SL DB calf raise	2 x 10	2 x 10	-	2 x 10	2 x 10	2 x 10	2 x 10	-
	DB walking lunge	3 x 7	3 x 7	3 x 7	3 x 7	3 x 6	3 x 7	-	DB Bulgarian split squat	3 x 5	3 x 6	3 x 7	Step up w/hip flexion	3 x 5	3 x 5	3 x 6	3 x 6	3 x 7	3 x 6	-	3 x 5
	Romanian deadlift	3 x 5	3 x 5	3 x 5	3 x 5	3 x 6	3 x 5	2 x 5	Romanian deadlift	3 x 6	3 x 6	-	Romanian deadlift	-	3 x 6	-	3 x 6	3 x 5	-	3 x 6	3 x 7
Session 2	Bench press	4 x 4	4 x 3	4 x 3	-	3 x 5	4 x 3	1 x 3	Bench press	3 x 5	4 x 5	5 x 5	Bench press	-	4 x 4	5 x 3	2 x 3	-	4 x 4	3 x 3	2 x 3
	Seated DB press	4 x 8	4 x 8	4 x 8	4 x 8	4 x 6	4 x 6	3 x 6	Seated DB press	4 x 10	4 x 8	3 x 6	Weighted chin up	5 x 5	5 x 5	5 x 5	-	5 x 5	5 x 5	-	5 x 5
	Incline DB fly	4 x 10	4 x 10	4 x 8	4 x 8	4 x 8	3 x 8	3 x 8	Incline DB fly	-	4 x 10	4 x 8	Seated DB press	-	4 x 8	4 x 6	-	4 x 8	4 x 6	4 x 4	-
	Weighted chin ups	4 x 10	4 x 10	4 x 10	4 x 10	3 x 8	3 x 8	3 x 8	Weighted chin ups	-	3 x 5	4 x 5	Seated cable row	4 x 12	4 x 10	4 x 8	4 x 6	4 x 10	4 x 8	4 x 6	4 x 4
	Nordic curl (band assisted)	3 x 5	3 x 5	3 x 5	3 x 5	3 x 4	3 x 4	3 x 4	Nordic curl (band assisted)	3 x 5	-	3 x 5	Nordic curl (band assisted)	-	3 x 5	-	3 x 5	3 x 5	-	3 x 5	-
Session 1	Skipping routine ^a	2 x 15s/15s	3 x 15s/15s	3 x 15s/15s	-	4 x 15s/15s	3 x 20s/20s	4 x 20s/20s	Skipping routine ^a	3 x 25s/25s	3 x 30s/30s	-	Skipping routine ^b	3 x 20s/20s	3 x 25s/25s	-	3 x 30s/30s	3 x 30s/30s	3 x 30s/30s	-	2 x 30s/30s
	Hurdle rebound jump	3 x 6	3 x 6	3 x 8	3 x 8	3 x 8	3 x 8	-	SL low hurdle rebound jump	3 x 4	3 x 5	3 x 6	SL low hurdle rebound jump	-	3 x 6	-	3 x 8	3 x 6	2 x 4	3 x 8	3 x 5
	Hip thrust	3 x 8	3 x 6	3 x 5	4 x 5	3 x 3	4 x 3	2 x 3	SL hip thrust	3 x 6	3 x 5	4 x 5	Single leg hip thrust	3 x 4	3 x 4	-	3 x 3	4 x 3	3 x 3	3 x 3	-
	Seated SL ankle ISOs ^c	2 x 3s/5s	3 x 3s/5s	3 x 3s/5s	-	3 x 3s/5s	3 x 3s/5s	3 x 1s/10s	Seated SL ankle ISOs ^c	2 x 1s/10s	2 x 1s/10s	3 x 1s/10s	Standing SL ankle ISOs ^d	2 x 1s/10s	2 x 1s/10s	3 x 1s/10s	-	2 x 1s/10s	-	3 x 1s/10s	2 x 1s/10s
	Romanian deadlift	3 x 5	3 x 5	3 x 5	3 x 5	3 x 6	3 x 5	2 x 5	Romanian deadlift	3 x 6	3 x 6	-	Romanian deadlift	-	3 x 6	-	3 x 6	3 x 5	-	3 x 6	3 x 7
Session 2	Participant S1 carried out the same session 2 programme as completed by participants T1-4 and C1-C3, apart from the nordic curl exercise which was replaced as follows:																				
	Supine SL hip ext. ISOs ^e	2 x 3s/5s	3 x 3s/5s	3 x 3s/5s	-	3 x 3s/5s	3 x 3s/5s	3 x 1s/10s	Supine SL hip ext. ISOs ^e	2 x 1s/10s	2 x 1s/10s	3 x 1s/10s	Supine SL hip ext. ISOs ^e	2 x 1s/10s	2 x 1s/10s	3 x 1s/10s	-	2 x 1s/10s	-	3 x 1s/10s	2 x 1s/10s
3	On a separate occasion in the week, participant S1 also repeated the Seated / Standing SL ankle ISOs and Hurdle rebound jump / SL low hurdle rebound jump exercises as detailed in session 1																				

Key: SA = single arm; SL = single leg; DB = dumbbell; ISOs = isometrics; blue shaded boxes represent the training completed by participants T1-T4 and C1-C3, whereas orange shaded boxes represent the training completed by participants S1; red shaded week numbers = weeks during which acceleration technique and performance data were obtained from participants

Notes: Generally, participants selected a load whereby 1-3 reps were left in reserve for each set. Rest between sets were typically 90s-150s, with the lower and higher ends of this rest continuum applied to exercises when intensity was lower and higher respectively. ^aParticipant skipped (using a skipping rope) with consecutive bilateral foot contacts (time specified to the left and right of a forward slash depicts duration of skipping and resting respectively in each set). ^bParticipant skipped (using a skipping rope) with 2 unilateral foot contacts on the left side followed by 2 unilateral contacts on the right side and alternated in this fashion for a specified duration (left of a forward slash) before resting for a specified duration (right of the forward slash) in each set. ^cParticipant used a seated calf raise machine (knee angle ~90°; ankle angle ~0°) which was weighted such that it was not possible to move the load. The participant 'pushed' against the immovable load for a specified time (to the left of the forward slash) and then rested for a specified time (to the right of the forward slash) in each repetition and rested for ~2-3 minutes between each set. ^dParticipant was in a standing position in a custom squat cage, positioned under an immovable bar which rested across their upper trapezius muscles (with legs straight and ankle joints at ~0°). In each rep, the participant raised one foot off the ground (hip flexed to ~90°) and then attempted to lift the bar upwards by trying to plantarflex the ankle in contact with the ground. They 'pushed' against the immovable load for a specified time (to the left of the forward slash) and then rested for a specified time (to the right of the forward slash) in each repetition and rested for ~2-3 minutes between each set. ^eParticipant completed in the set up position for the hip torque test, attempting to 'push' the immovable bar upwards for a specified time (to the left of the forward slash) and then rested for a specified time (to the right of the forward slash) in each repetition and rested for ~2-3 minutes between each set. For weeks 1-5 in isometric exercises performed by participant S1, the participant gradually increased their effort (similar to Balshaw et al., 2016) to ~100% of their maximum and held this intensity when 'pushing' during each rep. For remaining weeks the participant was required to 'push' as fast and as hard as possible from the outset of 'pushing' (similar to Lum et al., 2021) and for the duration specified in each rep. Shaded rows depict supersets, whereby participants alternated between exercises with small rest (~30-45s) between each exercise and longer rest (~90-150s) between sets. Warm-up sets have not been included in the programme detailed.

1C. Speed training undertaken by participants T1-T4, S1 and C1-C3 during the intervention phase. A PDF copy of this with video demonstrations of the exercises undertaken can be accessed here: <https://figshare.com/s/95455f88c1c823d5ad4e>

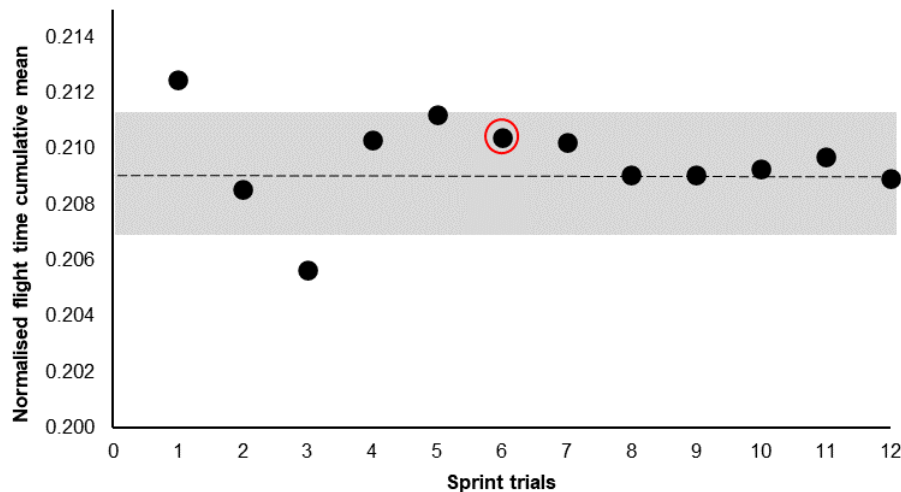
	Phase 1				Phase 2		Phase 3			Phase 4				Phase 5							
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
	Exercise	Sets x reps				Sets x reps			Sets x reps			Sets x reps				Sets x reps					
Session 1	<u>Switch (triple-stick OH)</u>	3 x 10m	3 x 10m	3 x 15m	3 x 15m	2 x 10m	2 x 10m	2 x 10m	<u>Switch (triple-medball OH)</u>	2 x 10m	2 x 10m	2 x 10m	<u>Str. leg bound (medball OH)</u>	2 x 20m	2 x 20m	2 x 20m	-	2 x 20m	2 x 20m	2 x 20m	-
	<u>Acceleration bound</u>	2 x 10m	2 x 10m	-	-	-	1 x 20m	3 x 20m	<u>Bounding</u>	-	2 x 30m	-	<u>Speed bound</u>	2 x 30m	2 x 30m	-	3 x 30m	3 x 30m	-	3 x 30m	-
	<u>Resisted sprint</u>	-	2 x 10m (40kg)	2 x 10m (50kg)	-	2 x 10m (50kg)	2 x 10m (50kg)	-	<u>Resisted sprint</u>	1 x 10m (60kg)	2 x 10m (60kg)	1 x 10m (60kg)	<u>Resisted sprint</u>	2 x 10m (60kg)	2 x 10m (60kg)	-	2 x 10m (60kg)	-	2 x 10m (60kg)	-	2 x 10m (60kg)
	<u>Sprint (2-point start)</u>	3 x 10m	2 x 10m	1 x 10m	2 x 10m	2 x 10m	1 x 20m	3 x 30m	<u>Sprint (2-point start)</u>	2 x 20m	2 x 20m	3 x 30m	<u>Sprint (2-point start)</u>	2 x 10m	2 x 20m	3 x 30m	1 x 10m	3 x 30m	2 x 40m	3 x 30m	3 x 30m
	<u>Sprint (2-point start)</u>	3 x 20m	2 x 20m	3 x 30m	2 x 20m	4 x 30m	2 x 30m	-	<u>Sprint (2-point start)</u>	2 x 30m	2 x 30m	1 x 40m	<u>Sprint (2-point start)</u>	3 x 20m	2 x 30m	-	3 x 40m	-	-	1 x 40m	-
	<u>Sprint (2-point start)</u>	-	2 x 30m	1 x 40m	2 x 30m	-	3 x 40m	-	<u>Sprint (2-point start)</u>	2 x 40m	2 x 40m	-	<u>Sprint (2-point start)</u>	1 x 40m	2 x 40m	-	1 x 20m	-	-	-	-
Session 2	<u>A-skip</u>	2 x 15m	2 x 20m	2 x 20m	-	2 x 10m	2 x 15m	-	<u>Dribble (speed ascending)</u>	3 x 30m	-	-	<u>Dribble (speed ascending)</u>	3 x 30m	-	3 x 30m	-	-	3 x 30m	-	-
	<u>Dribble (ascending)</u>	2 x 30m	2 x 30m	2 x 30m	-	2 x 30m	2 x 30m	-	<u>Wicket run</u>	2 x 40m	-	-	<u>Wicket run</u>	2 x 40m	-	2 x 40m	-	-	2 x 40m	-	-
	<u>Sprint (2-point start)</u>	1 x 10m	1 x 20m	1 x 10m	-	2 x 20m	2 x 10m	-	<u>Sprint (2-point start)</u>	1 x 10m	-	-	<u>Sprint (2-point start)</u>	1 x 10m	-	1 x 10m	-	-	1 x 10m	-	-
	<u>Sprint (2-point start)</u>	2 x 20m	2 x 20m	1 x 20m	-	2 x 20m	3 x 20m	-	<u>Sprint (upright, rolling start)</u>	2 x 20m	-	-	<u>Sprint (upright, rolling start)</u>	2 x 20m	-	2 x 20m	-	-	3 x 30m	-	-
	<u>Sprint (sprint-float-sprint)</u>	3 x 10-10-10m	2 x 20-10-10m	4 x 10-10-10m	-	2 x 20-10-10m	-	-	<u>Sprint (sprint-float-sprint)</u>	2 x 20-10-20m	-	-	<u>Sprint (sprint-float-sprint)</u>	2 x 20-10-20m	-	2 x 20-10-20m	-	-	1 x 20-10-20m	-	-

Key: m = metres; red shaded contents = testing sessions during which acceleration technique and performance data were obtained from participants; exercises underlined are linked to video demonstrations

Notes: rest between sets for drills and jumping exercises typically involved a slow walk back between each set. For sprint-based activities 60s of rest for every 10m travelled in the effort was employed between sets (e.g., a 20 m sprint would result in a 120s rest). The exception to this was during testing where 4-5 minutes of rest were taken between sprints. On testing occasions, sprint efforts were completed before all other activities. Warm-up sets have not been included in the programme detailed.

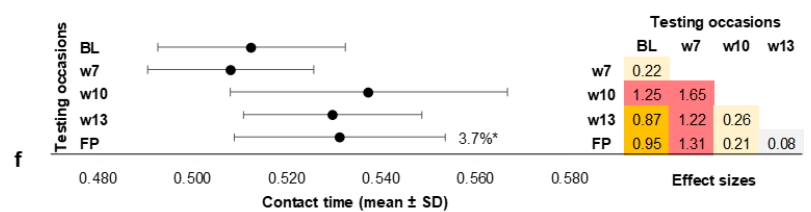
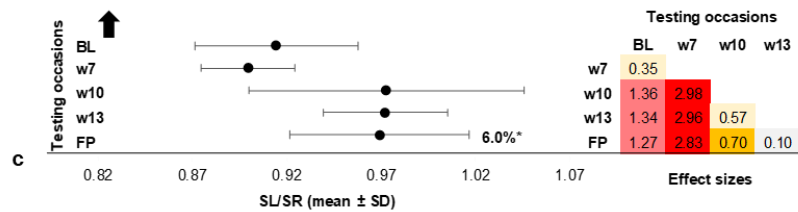
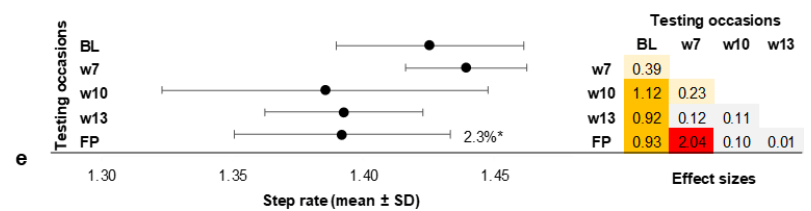
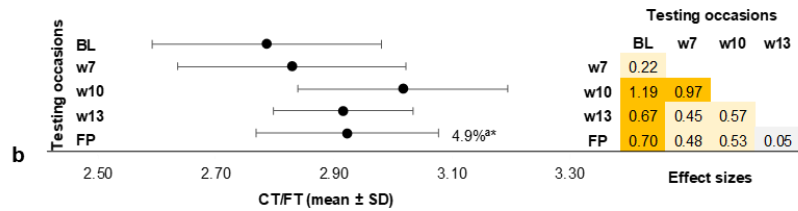
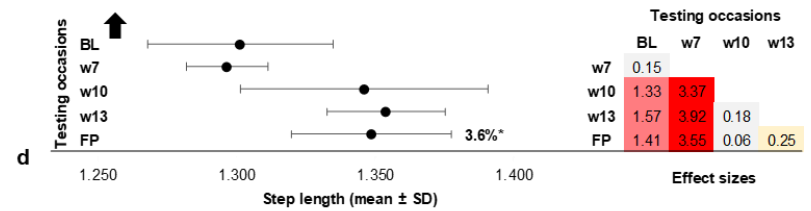
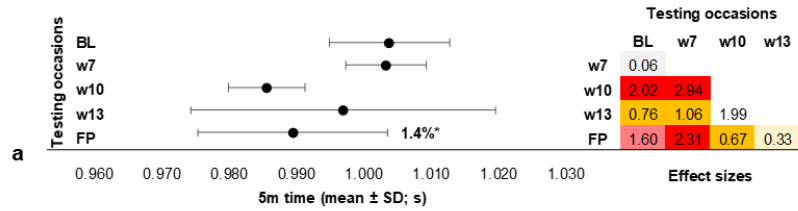
SUPPLEMENTARY MATERIAL 2

The sequential estimation technique used involved calculating the cumulative mean of each variable, adding one trial at a time (Clarkson et al., 1980; Preatoni et al., 2013). Stability was assumed to have been reached for each variable when the cumulative mean remained constant within an acceptance bandwidth of ± 0.25 SD of the mean, which has commonly been used previously (Chen et al., 2019; Hamill & McNiven, 1990; Preatoni et al., 2010; Rodano & Squadroni, 2002). The minimum number of trials necessary to establish stable means for kinematic variables and participants ranged between 4 and 10. An example of this approach is shown below.



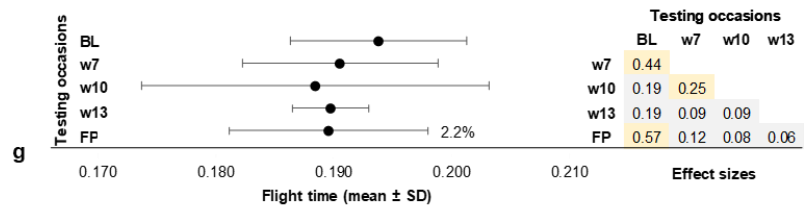
2A. An example of the sequential estimation technique used to identify the minimum number of trials necessary to establish a stable mean for the variables of interest. This figure shows that a minimum of six trials were needed to identify the stable mean for the normalized flight time of a participant.

SUPPLEMENTARY MATERIAL 3 – ADDITIONAL FIGURES FOR THE PARTICIPANTS THAT WERE STUDIED IN PART II, BUT FOR WHOM THE FIGURES WEREN'T INCLUDED IN THE MANUSCRIPT

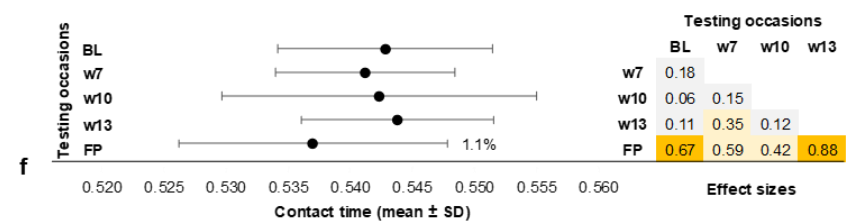
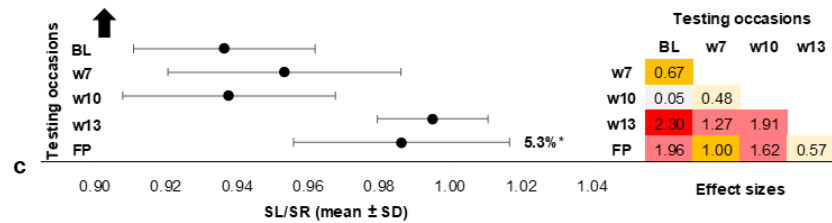
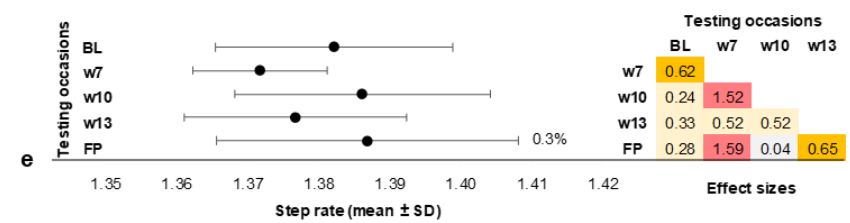
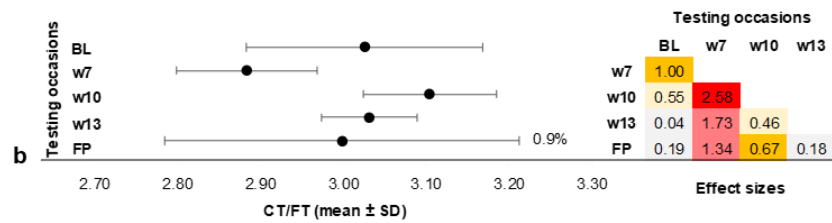
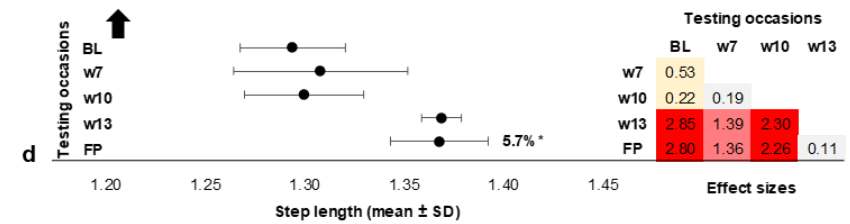
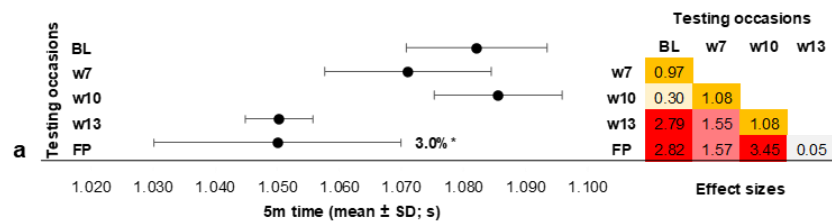


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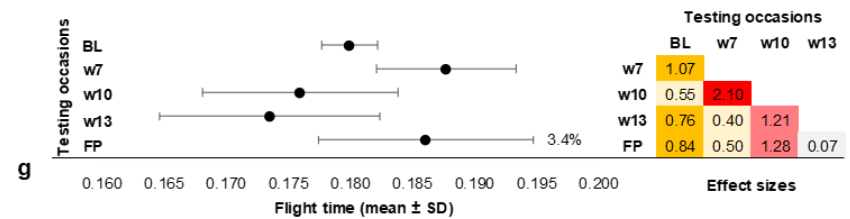
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0.60-1.19; moderate	1.20-1.99; large
2.00-3.99; very large	>4.00; extremely large



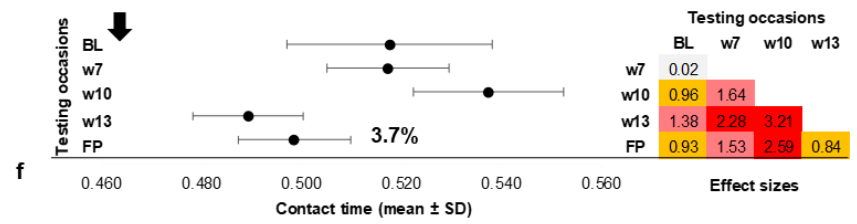
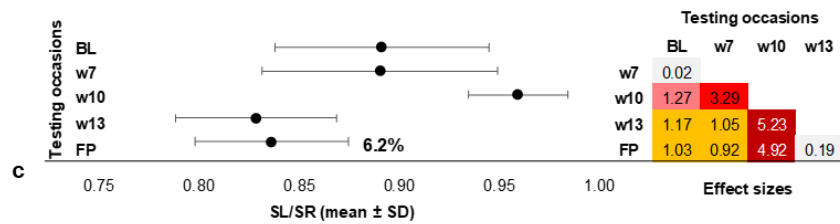
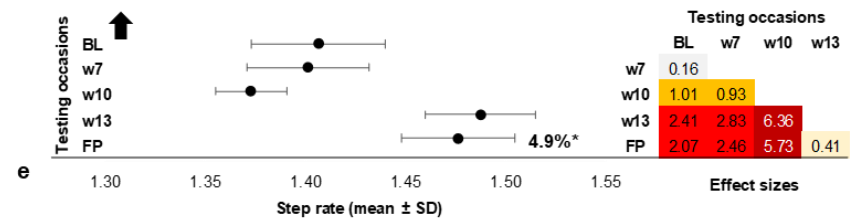
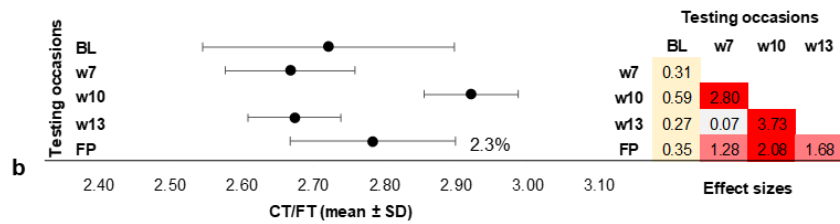
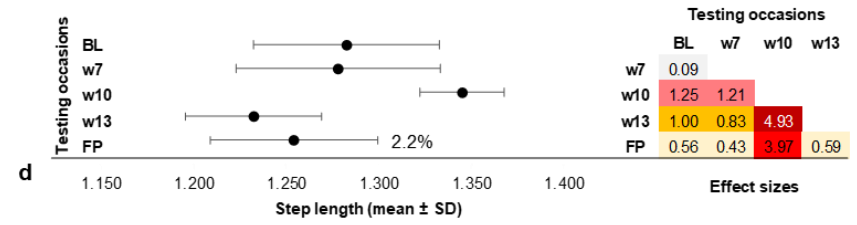
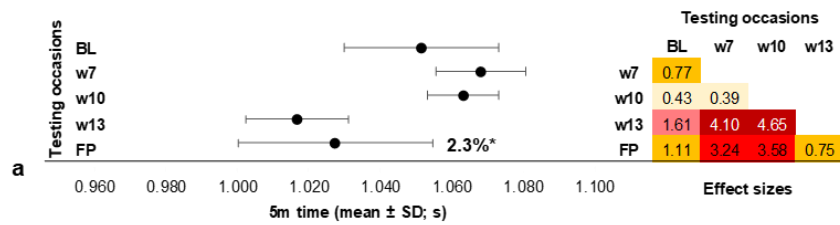
3A. 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T2** (technical intervention; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.



Effect sizes:	< 0.20; trivial	0.20-0.59; small
	0.60-1.19; moderate	1.20-1.99; large
	2.00-3.99; very large	>4.00; extremely large

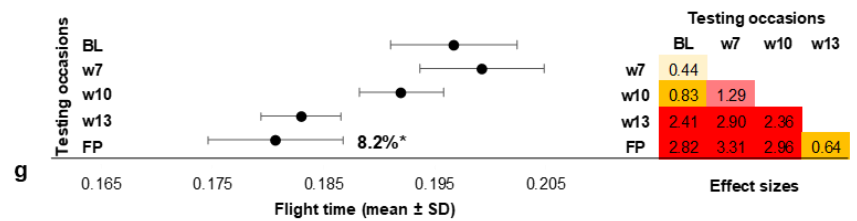


3B. 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T3** (technical intervention; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.

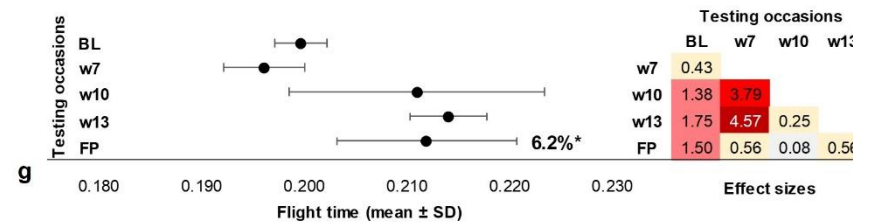
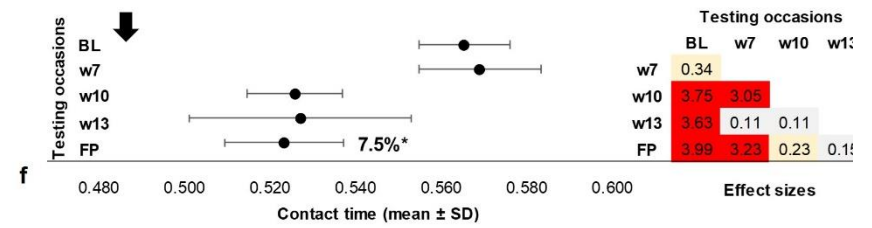
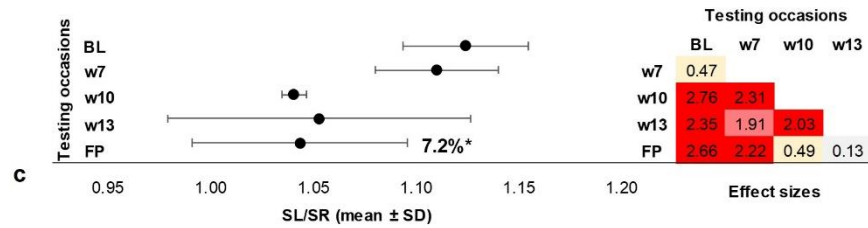
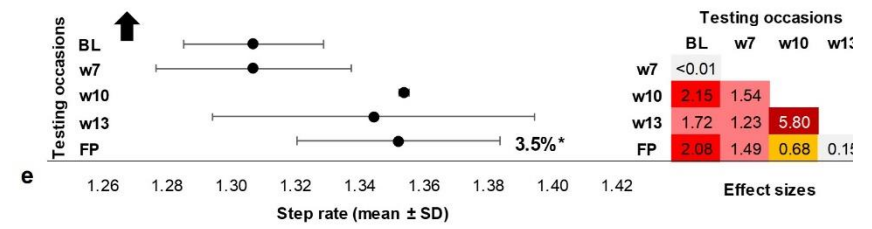
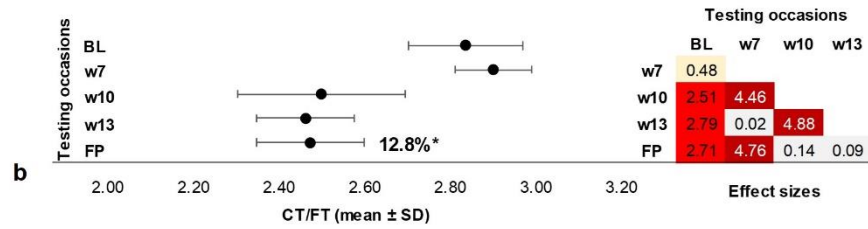
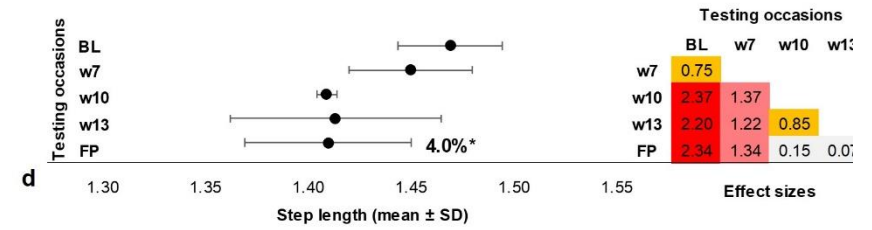
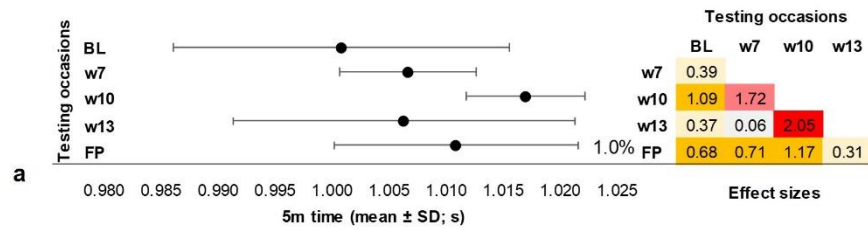


Effect sizes:

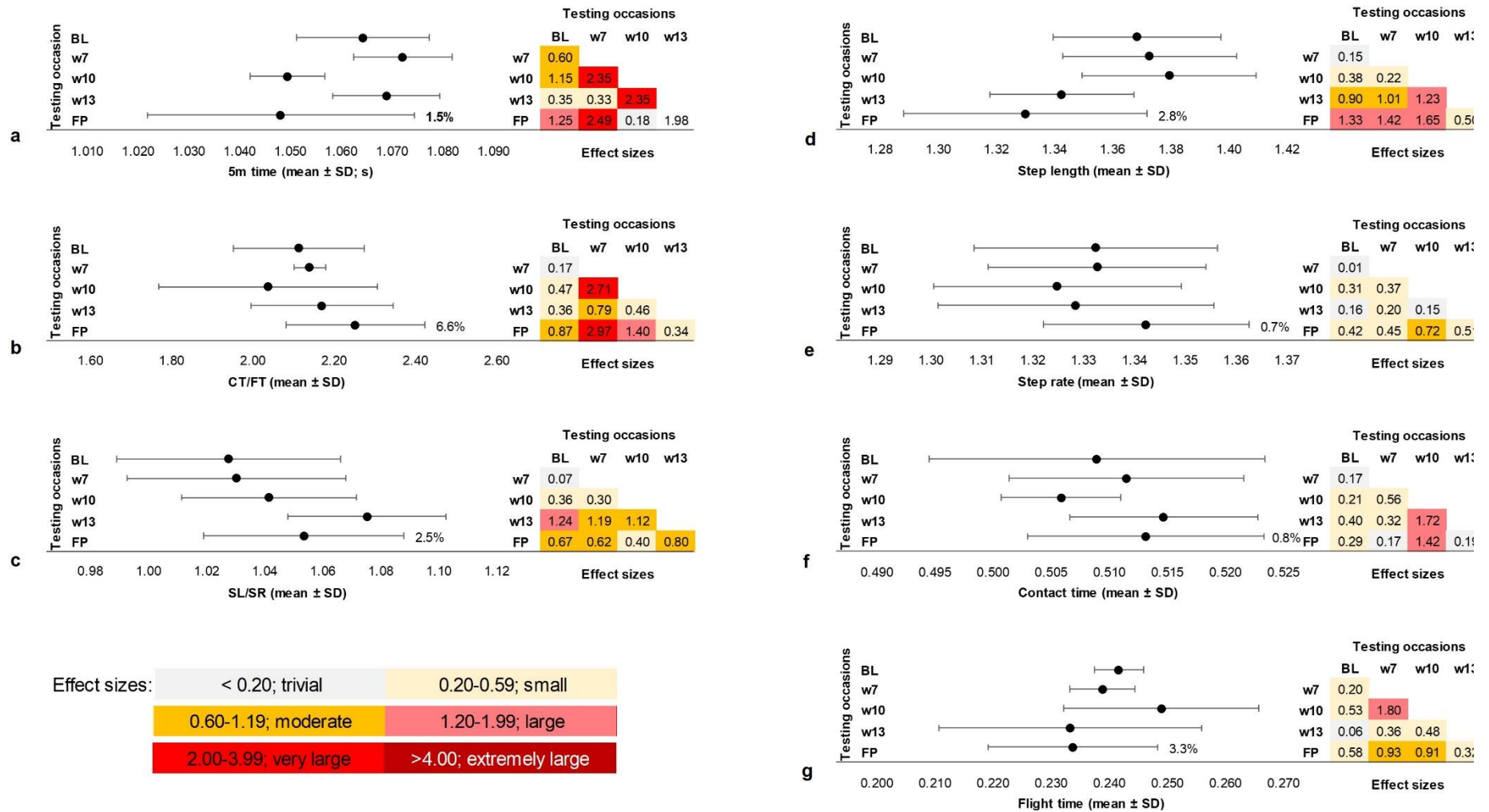
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0.60-1.19; moderate	1.20-1.99; large
2.00-3.99; very large	>4.00; extremely large



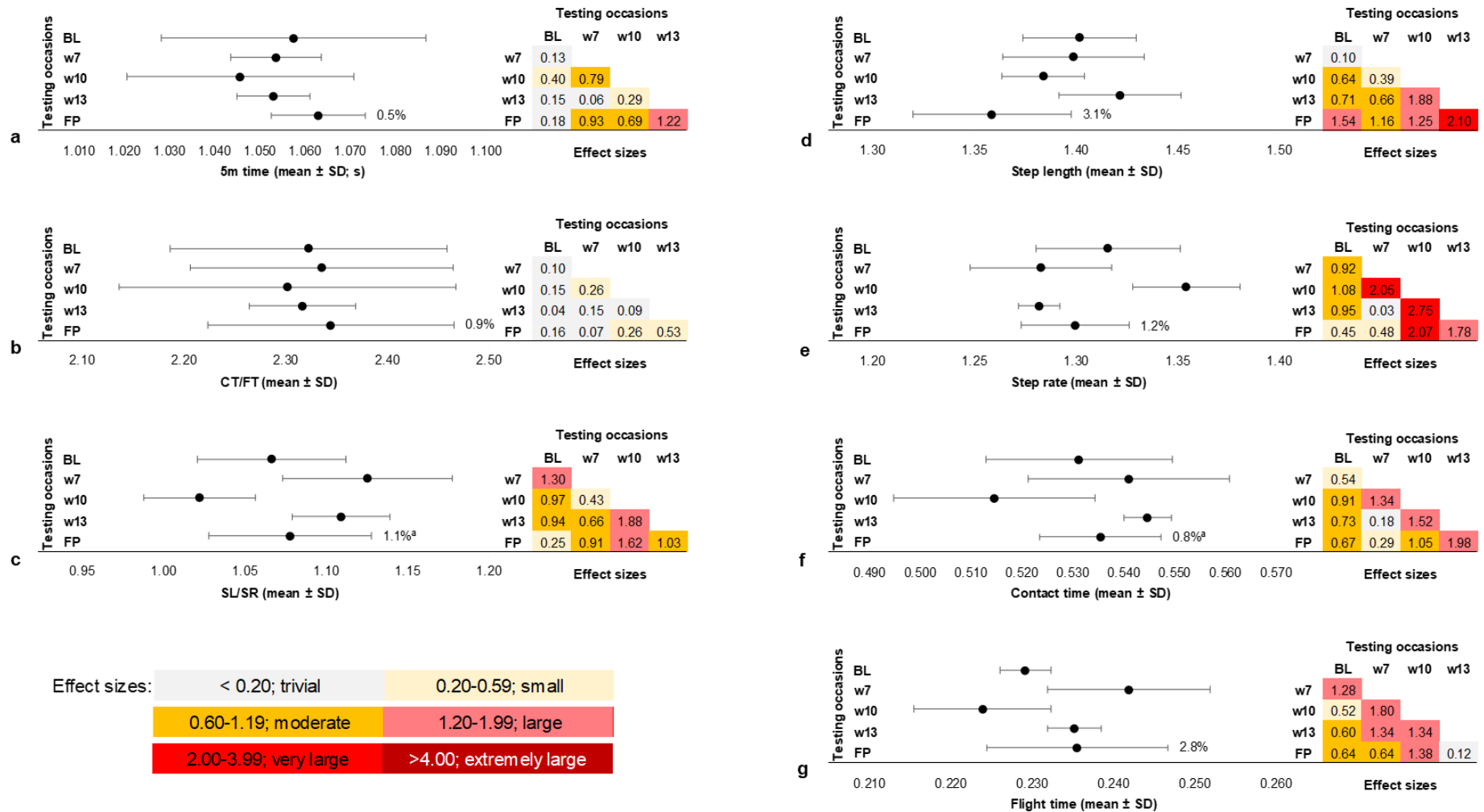
3C. 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T4** (technical intervention; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.



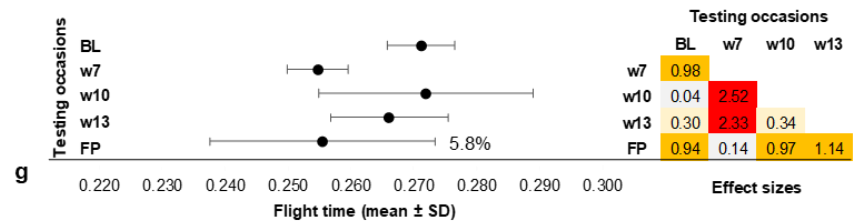
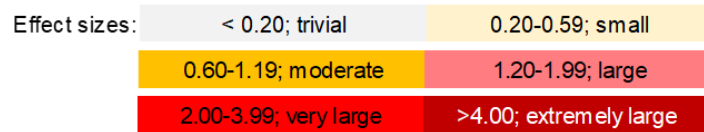
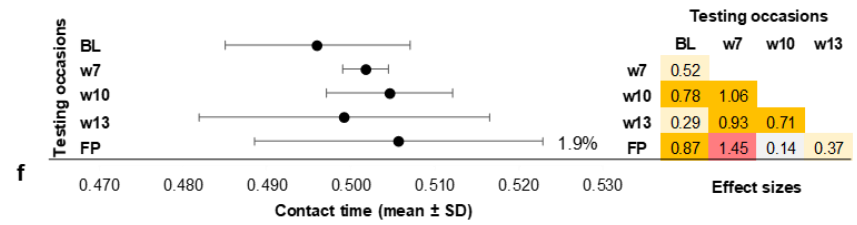
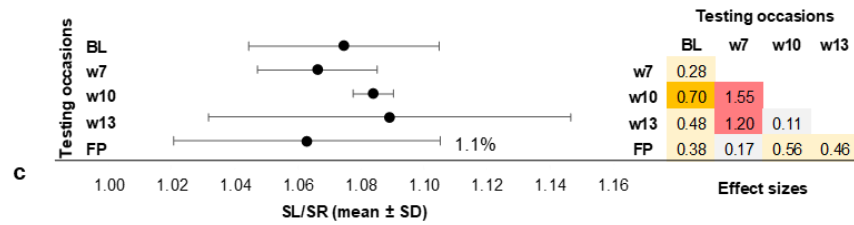
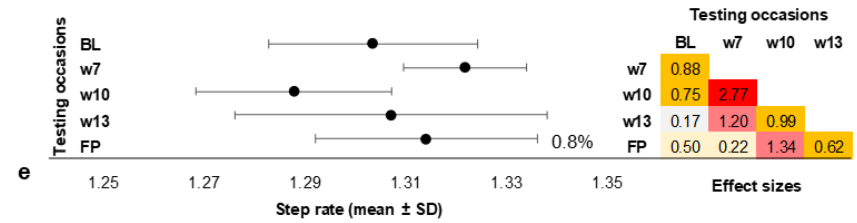
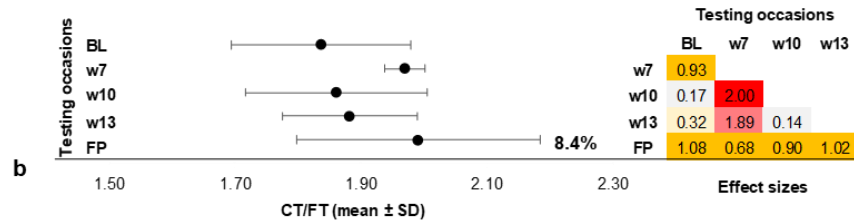
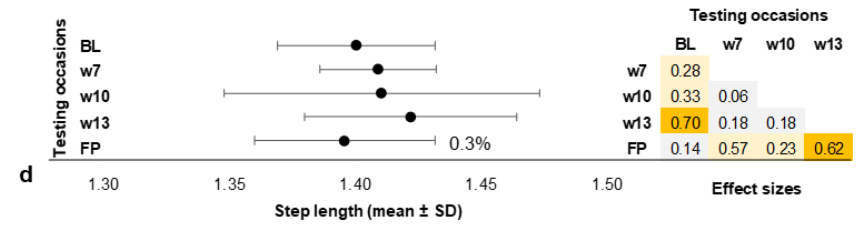
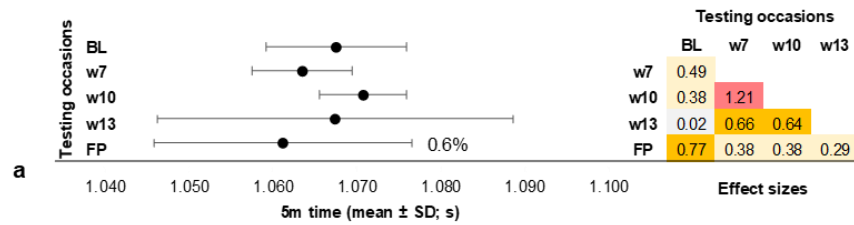
3D. Mean \pm SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant S1** (strength intervention; mean \pm SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.



3E. Mean ± SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant C1** (control; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.



3F. Mean ± SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant C2** (control; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.



3G. Mean \pm SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant C3** (control; mean \pm SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See Figure 4 caption for full explanation.