ENHANCING THE INITIAL ACCELERATION PERFORMANCE OF ELITE RUGBY BACKS. PART II: INSIGHTS FROM MULTIPLE LONGITUDINAL INDIVIDUAL-SPECIFIC CASE STUDY INTERVENTIONS

Purpose: This study implemented 18-week individual-specific sprint acceleration training interventions in elite male rugby backs based on their pre-determined individual technical needs, and evaluated the effectiveness of these interventions. **Methods:** Individual-specific interventions were prescribed to five elite rugby backs over an 18-week period. Interventions were informed by the relationships between individual technique strategies and initial acceleration performance, and their strength-based capabilities. Individual-specific changes in technique and initial acceleration performance were measured at multiple time points across the intervention period, and compared to three control participants who underwent their normal sprint training. **Results:** Of the technique variables intentionally targeted during the intervention period, moderate to very large ($|d| = 0.93$ to 3.99) meaningful changes were observed in the participants who received an individual-specific intervention, but not in three control participants. Resultant changes to the intervention participants' *whole-body kinematic strategies* were broadly consistent with the intended changes. Moderate to very large ($|d| =$ 1.11 to 2.82) improvements in initial acceleration performance were observed in participants receiving individual-specific technical interventions, but not in the control participants or the participant who received an individual-specific strength intervention. **Conclusions:** Individual-specific technical interventions were more effective in manipulating aspects of acceleration technique and performance, compared with the traditional 'one-size-fits-all' approach adopted by the control participants. This study provides a novel, evidence-based approach for applied practitioners working to individualize sprint-based practices to enhance acceleration performance.

Keywords/phrases: sprinting, constraints, training, motor control, biomechanics

INTRODUCTION

Individualization is an important training principle for coaches[1,2]. However, the majority of scientific research investigating training interventions for sprint acceleration in team sport players has primarily reported group-based data, focusing on the mean effects of the same training program undertaken by all individuals within a group (see Nicholson et al.[3] for a review and meta-analysis). This reporting of group means is problematic since differences in the constraints between individuals will likely alter their system behavior[4], and thus the same response to an intervention may not be elicited across all individuals[5,6]. Therefore, interventions should be considered on an individual-specific basis to capitalize on each individual's capacity to adapt to a given training program.

In Part I of this investigation[7], within-individual relationships between spatiotemporal variables (step length (SL), step rate (SR), contact time (CT), flight time (FT), and SL/SR and CT/FT ratios) and initial acceleration performance (normalized average horizontal external power and 5 m time) across 12 sprint efforts (three sprints conducted on four separate occasions) were determined in a group of 19 elite rugby backs. Meaningful relationships were observed between spatiotemporal variables and initial acceleration performance in 17 of the participants. Using this information and adopting a method to characterize initial acceleration strategies using a whole-body kinematics approach[8], a desirable change in *whole-body kinematic strategy* (the combination of the SL/SR and CT/FT ratios) was identified for each individual. This information was suggested as beneficial to helping practitioners subsequently individualize sprint training for rugby backs by focusing on the spatiotemporal variables they 'rely' on[9] for higher initial acceleration performance, i.e., the variables most closely related to their performance. However, it remains unclear how interventions targeting the variables athletes are individually 'reliant' on affects initial acceleration technique and performance.

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

METHODS

Overview

In Part I[7], the normalized spatiotemporal variables (step length, step rate, contact time, flight time and SL/SR and CT/FT ratios) and performance (5 m time) of 19 elite[14] male rugby backs were collected during initial acceleration (i.e., the first four steps) from 12 sprint trials during pre-season (hereafter referred to as the *baseline period*). From these data, technical needs were determined as a desired change in *whole-body kinematic strategy*[8] which was identified for each individual based on spatiotemporal variables they were individually reliant on for better initial acceleration performance. Linear and angular kinematic aspects of technique and strength-based qualities were also obtained during this baseline period.

The above baseline information obtained in Part I[7] was proposed as beneficial for practitioners wishing to design personalized sprint acceleration intervention. This study (Part II) details multiple individual-specific case study interventions which were subsequently conducted. Thirteen of the participants whose individual technical needs were identified during the baseline period (mean ± SD: age 25 ± 3 years; stature 1.81 ± 0.03 m; leg length 1.00 ± 0.05 m; body mass 93.2 ± 4.3 kg) were selected based on their availability to be studied over 18-weeks of training. All had a minimum of three years' professional rugby experience and a minimum of five and two years of strength and sprint training experience, respectively. Three participants were selected to undertake individual-specific strength-based interventions. These were selected due deficits in strength-related qualities which were identified during baseline and were known to be associated with the *whole-body kinematic strategies*[8] of elite rugby backs during sprint acceleration (see *Determining the focus for individual-specific interventions* for how this was determined). The remaining participants had no notable strength deficits and were randomly assigned to either control (n = 5) or individual-specific technique-based (n = 5) interventions (see *Determining the focus for individual-specific interventions* for how each individual's technique-based intervention was determined).

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

Determining the focus for individual-specific interventions

Prior to the 18-week intervention, the four technique-based intervention participants (T1-T4 [participants 4, 6, 16 and 17 from Part I[7]]), partook in an acute 'exploratory' session to self-generate holistic cues or analogies as technical prompts for their individualized technical interventions. During this exploratory session, the coach explained the findings from, and implications of, the information collected during baseline to each participant, along with the concept of using holistic cues or analogies as technical prompts to direct attention[15,16]. Participants practiced 10 m sprint efforts by themselves for 10 minutes, during which they were asked to focus on targeting the specific variable(s) they were primarily and secondarily found to individually 'rely' on for better initial acceleration performance during baseline. Participants were asked to reflect on how this technical change felt (physically) and to verbalize this feeling through a holistic cue or analogy as a self-generated technical prompt

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

TABLE 1 NEAR HERE

The participant who followed an individual-specific strength-based intervention, (S1 [participant 15 from Part I[7]]) was 'reliant' on higher step rate for better sprinting performance during baseline (Part I[7]), and this was underpinned primarily by shorter contact times. Such a technical strategy has been associated with higher hip extensor torque assessment scores and shorter contact times in repeated jumps in elite rugby backs[8]. The strength-based scores participant S1 achieved during baseline for hip torque, repeated contact time and therefore their torque/contact time ratio were all poor (25th%, see Table 4 in Part I[7]). Therefore, given their technical 'reliance' during sprinting, participant S1's strength-based program was designed to address the hip extensor and vertical stiffness strength deficiencies to facilitate a technical strategy that would result in shorter contact times and higher step rates during initial acceleration.

18-week intervention

The control group (C1-C3 [participants 5, 8 and 13 from Part I[7]]) underwent their usual training regime over the 18-week period (the full speed and strength-based training sessions during baseline and each phase of the 18-week intervention are in online supplementary files 1A-C). The participants (T1-T4) following individual-specific technique-based interventions, completed the same training as the control participants. However, when completing sprint efforts during speed training sessions and in warm-ups for rugby training and matches, they focused on the individual technical prompts which they generated during the prior exploratory session (see Table 1). The participants did not focus on these technical prompts during matches or in the main component of rugby training sessions. Control and technical intervention participants followed the same strength-based training across the intervention period.

The remaining participant (S1) completed the same sprint training as all other participants (without any technical focus), but also received an individualized strength program. This strength program incorporated specific isometric-based training and a higher volume of plyometric training to enhance muscle-tendon stiffness qualities and stretch-shortening cycle performance[17,18,19]. The program also used exercises in which a greater extensor demand was placed on the hip[20] and loading protocols recommended for maximum strength development[21] to enhance hip extensor maximum strength ability. Kinematic variables at touchdown and toe-off were also analyzed for this participant post intervention so that within-participant changes in these variables could also be compared to baseline. For the full procedures used to obtain all sprint and strength-based measures, and their reliability, see Wild et al. (2022)[8].

The intervention timeline including the type and number of training sessions undertaken during each phase is detailed in Figure 1. The full content of these training sessions is provided as supplementary materials (1A-C). The number of sprints reported (Figure 1) included those which took place during speed training sessions and warm-ups prior to training and matches, as well as those completed during training and matches. On average per training phase, this resulted in participants performing sprint accelerations on approximately five separate occasions per week across speed training sessions (mean ± SD sprints per phase = 1.5 ± 0.7) and warm-ups prior to rugby training or matches (mean ± SD sprints per phase = 3.3 ± 0.5). During training and matches a sprint was identified from GPS (Catapult Sports, 10 Hz) data when 80% of a player's maximum velocity was exceeded, since this has previously been identified as an appropriate relative threshold to monitor sprinting in a team sport setting[22]. This methodology is also common practice in professional rugby union clubs to provide a relevant and objective applied measure, but it is acknowledged that it is not possible to separate sprinting from just 'high-speed running' using this approach.

FIGURE 1 NEAR HERE

The individualized technical prompts were used by the technical intervention participants (T1-T4) in all phases aside from Phase 5 (Figure 1). During Phases 1 and 3 of the intervention, contrasting technical training was undertaken (participants alternated between sprinting with no focus and sprinting by focusing on their technical prompts, similar to the "old way/new way" proposed by Lyndon[23]). During Phases 2 and 4, participants always focused on their technical prompts when sprinting. During Phase 5, and during any data collection sessions throughout the intervention, the technical intervention participants were simply instructed to cover the sprint distance as quickly as possible. Control participants and the strength intervention participant always focused on covering sprint distances as quickly as possible without a technical focus or feedback in any phase of the intervention.

Statistical analyses

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

To assess if the technical prompts resulted in acute technical changes during the exploratory session help prior to the 18-week intervention for participants T1-T4, effect size differences (Cohen's *d*) between variables obtained during sprints completed with and without a technical focus were determined. Differences were deemed meaningful when effect sizes were larger than 0.20 (smallest worthwhile difference[24]) and when absolute differences (%) were greater than intra-individual CVs obtained for the selected variable during the exploratory session. The magnitude of acute changes in *whole-body kinematic strategies* during the exploratory session were measured by the Euclidean distance between the spatial locations of their centroid cartesian coordinates.

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

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

Effect size differences (Cohen's *d*) were used to determine the magnitude of the pairwise differences in mean ± SD 5 m time, normalized spatiotemporal variables and SL/SR and CT/FT ratios within each individual between all testing occasions. A sequential estimation technique was used to determine the minimum number of sprint trials needed to establish a stable mean for each kinematic variable and participant from the baseline period. This ensured confidence in any changes observed between baseline and Phase 5 testing (see supplementary material 2). Paired samples *t*-tests or Wilcoxon signed-rank (nonparametric data) were used to determine whether changes in the mean ± SD normalized spatiotemporal variables, SL/SR and CT/FT ratios and 5 m time between baseline testing (12 sprint trials) and the testing in Phase 5 (10 to 12 sprint trials) within each participant were also statistically significant. Changes were deemed meaningful when all three of the following criteria were met: 1) effect sizes > 0.20 (smallest worthwhile difference[24]); 2) the absolute differences (%) were greater than intra-individual CVs obtained for the selected variable[25]; 3) differences were statistically significant ($p \leq 0.05$). The linear and angular sprint kinematics and strength-based variables obtained for participant S1 during the final phase (Phase 5, Figure 1) were compared against the same measures obtained during baseline, with meaningful changes determined when the first two criteria outlined above were met.

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

To determine whether a participant's *whole-body kinematic strategy* was from different distributions between baseline and Phase 5, thus reflecting a change in individual strategy from one cluster to another rather than a within-cluster shift in strategy, a two-dimensional Kolmogorov-Smirnov test was employed[26]. A statistic in the range [0,1] was calculated by scaling the statistic by the quantity:

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

where $n1$ is the sample size of the pre data set and $n2$ is the sample size of the post data set. The closer the statistic is to 1, the more different the distributions of the *whole-body kinematic strategies* are. Statistical significance was determined using a permutation test in which the observed data were resampled multiple times using an open-source package in R to obtain a p-value for the test[27].

RESULTS

Exploratory session for technique intervention participants

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

FIGURE 3 NEAR HERE

Pre and post changes following intervention

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

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

For participant S1 very to extremely large (d = 3.13 to 9.15) meaningful differences (Figure 5) in all but one strength-based measure (squat jump P_{max}) were observed between the baseline period and Phase 5. For S1's sprint kinematics, the proximal endpoints of their shank and thigh at touchdown were rotated more forwards during the testing in Phase 5, while the proximal end of their foot segment was less forwards rotated at toe-off. The largest pre to post change of a technical feature was touchdown distance (extremely large magnitude), where the foot was more posterior relative to the CM at touchdown.

FIGURE 2 NEAR HERE

FIGURE 4 NEAR HERE

FIGURE 5 NEAR HERE

DISCUSSION

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

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

For S1, no focus was applied to the sprint training undertaken in any phase. The strength intervention targeted the variables they were primarily (higher SR) and secondarily (shorter CT) ‘reliant’ on for better initial acceleration performance. Very large changes were observed in these variables in the desired direction (supplementary material 3D) which were underpinned by meaningful changes in a range of linear and angular kinematic aspects of S1’s technique. These changes were evident alongside very large increases in the strength capacities targeted in their intervention (Figure 5). The changes in participant S1’s strength capacities may, in part, have shaped their touchdown kinematics, self-organising[30] to produce a smaller touchdown distance by orienting their lower limb segments more horizontally post intervention (Figure 5). Since a smaller touchdown distance will result in less distance for the CM to travel forwards before rapid leg extension becomes more valuable for horizontal translation[31], the change in S1’s linear and angular kinematics may explain how shorter contact times and, in turn, higher step rates were achieved.

Despite the observed technical changes, a meaningful difference in S1’s initial acceleration performance was not found. Although the initial acceleration performances of team sport players have been shown to be enhanced by strength-based interventions (see Nicholson et al.[3] for a review), combined methods including technical-based training with sprint *and* strength-based training are considered best practice in the field[32] for developing speed. More research is therefore required to understand the efficacy of combined technical and strength intervention targeting the specific sprint variables which individuals are ‘reliant’ on for better initial acceleration performance.

PRACTICAL APPLICATIONS

Our study has identified the effectiveness of individual-specific strength-based and technique-based interventions for altering initial sprint acceleration technique in a desired direction, when compared against a traditional ‘one-size-fits-all’ approach. Furthermore, individual-specific technique-based intervention also led to improvements in initial acceleration performance in all four participants over the 18-week intervention period. Individualizing the initial acceleration interventions of athletes should be an attractive prospect for coaches working with elite rugby backs or with athletes from other sports where initial acceleration is important. The steps needed to adopt the approach used in this study to individualize the sprint technique interventions of these athletes should follow the robust and rigorous protocols here and in Part I[7], but they are straightforward: 1) Determine the within-individual relationships between the spatiotemporal variables, SL/SR and CT/FT ratios and initial acceleration performance of each individual during a baseline period to identify which variable(s) they are ‘reliant’ on for higher initial acceleration performance and how this is underpinned by a change in spatial location of their *whole-body kinematic strategies;* 2) Work with the athlete(s) to identify the focus of attention which results in a shift in their *whole-body kinematic strategy* towards the direction of the intended technical change; 3) Use opportunities within the training week (e.g., at the end of warm-ups prior to sport training and matches and/or during ‘stand-alone’ speed training sessions) for players to focus on their technical prompts during sprint efforts; and 4) After a defined period of time, measure changes in their initial acceleration technique and performance to determine the effectiveness of the intervention applied and to establish whether their individual needs have changed.

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

CONCLUSION

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

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FIGURES

C1 (5)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	4	4	5	4
Strength training	11	8	6	9	5
Rugby training	12	9	7	11	6
Match	2	1	-	1	1
Total sprints	69 / 25	48 / 35	38 / 22	56 / 33	38 / 22

C2 (8)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	3	2	4	4
Strength training	11	9	7	6	5
Rugby training	11	9	9	6	8
Match	4	3	2	3	2
Total sprints	75 / 60	49 / 48	41 / 50	47 / 45	45 / 43

C3 (13)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	5	4	3	4
Strength training	9	9	9	6	5
Rugby training	11	9	9	9	7
Match	2	1	-	2	2
Total sprints	67 / 44	52 / 38	42 / 38	45 / 33	42 / 37

S1 (15)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	4	2	2	2	4
Strength training	12	8	9	10	5
Rugby training	12	8	9	11	6
Match	1	-	1	1	1
Total sprints	54 / 46	30 / 34	36 / 37	42 / 45	37 / 27

T1 (4)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	3	3	3	4
Strength training	10	8	5	11	5
Rugby training	12	9	6	12	7
Match	4	3	2	3	3
Total sprints	76 / 61	50 / 42	36 / 32	55 / 57	45 / 40

T2 (6)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	3	3	4	3
Strength training	11	6	6	10	5
Rugby training	11	9	7	12	7
Match	4	3	3	3	3
Total sprints	72 / 54	51 / 47	42 / 34	60 / 42	40 / 31

T3 (16)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	7	5	2	4	4
Strength training	11	8	7	8	6
Rugby training	12	9	9	11	7
Match	1	-	1	1	2
Total sprints	71 / 50	47 / 33	38 / 50	52 / 51	42 / 45

T4 (17)

Session type	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Speed training	6	5	4	4	4
Strength training	11	9	6	12	5
Rugby training	12	8	7	11	8
Match	1	-	2	1	-
Total sprints	64 / 25	45 / 30	46 / 32	52 / 33	38 / 22

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

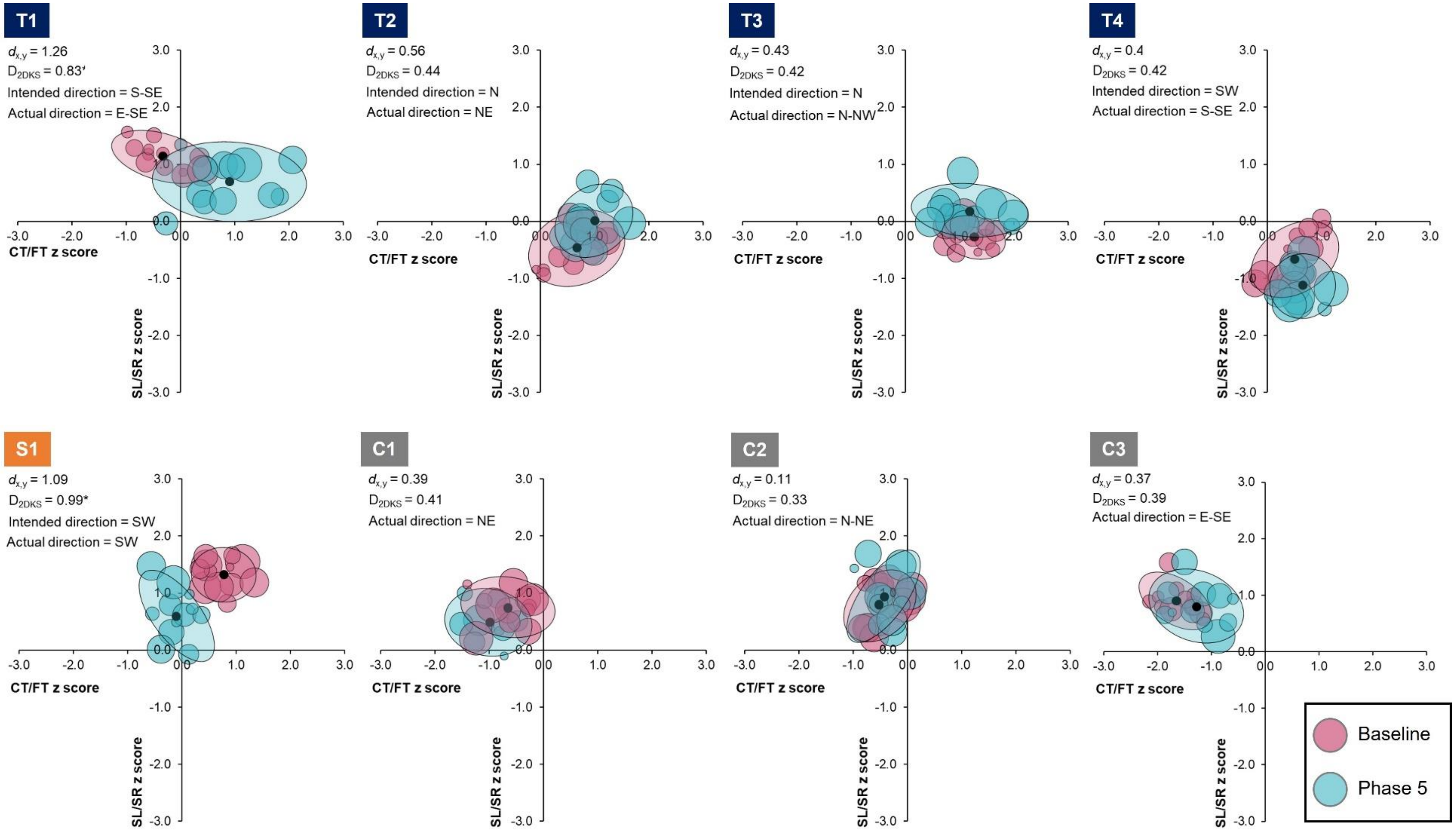
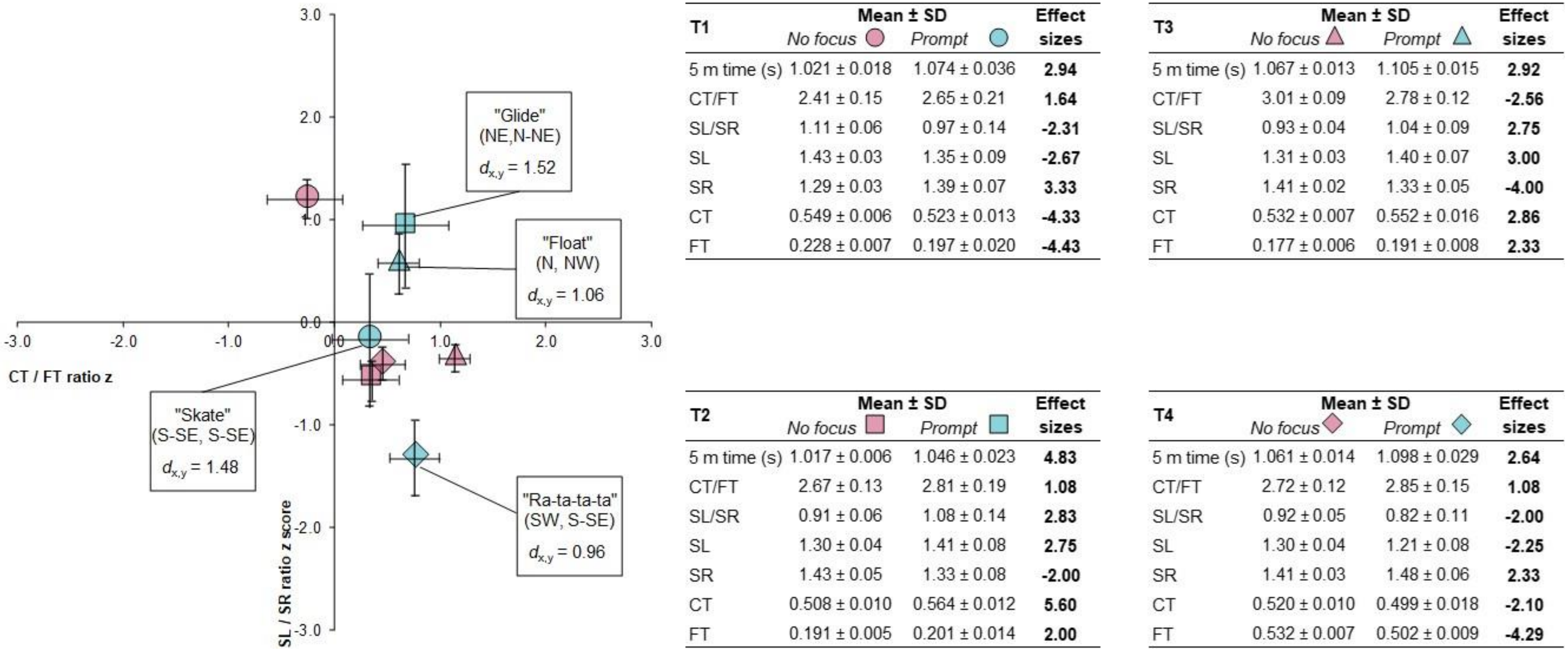


Figure 2. Change in *whole-body kinematic strategies* of participants between initial baseline and final testing phases (Phase 5). Each sprint is represented by a circle, the diameter of which is directly proportional to performance (the inverse of 5 m time, i.e. larger circles = higher performance (shorter times)), and the ellipses quantify the 90% confidence interval across all sprints within each phase. dx,y = Euclidean distance between the whole-body kinematic strategies; D2DKS = two-dimensional Kolmogorov-Smirnov statistic to determine the extent to which whole-body kinematic strategies are from the same distribution. Asterisks indicate whether the differences in distribution are statistically significant ($p < 0.05$)



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

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

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

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

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*.

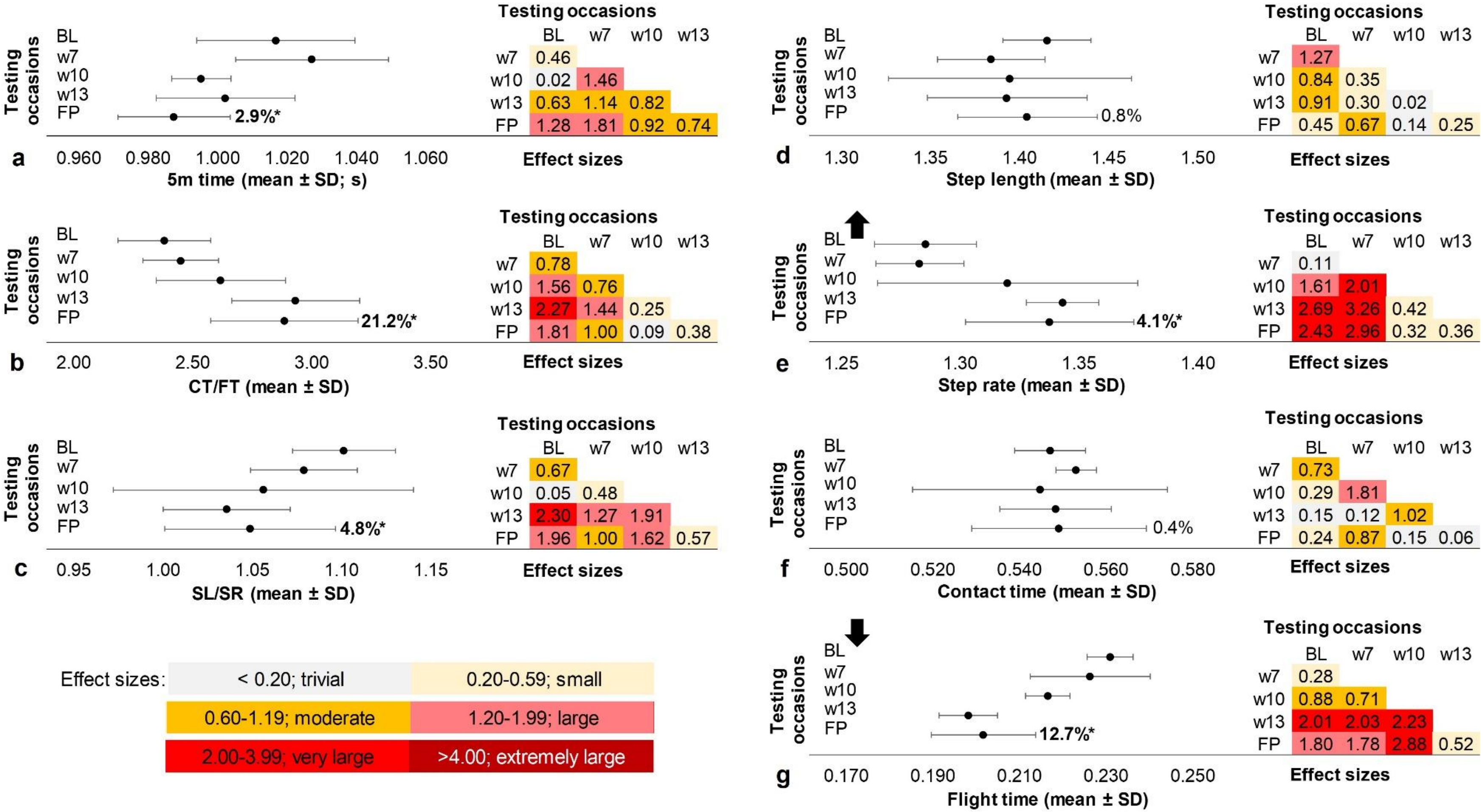
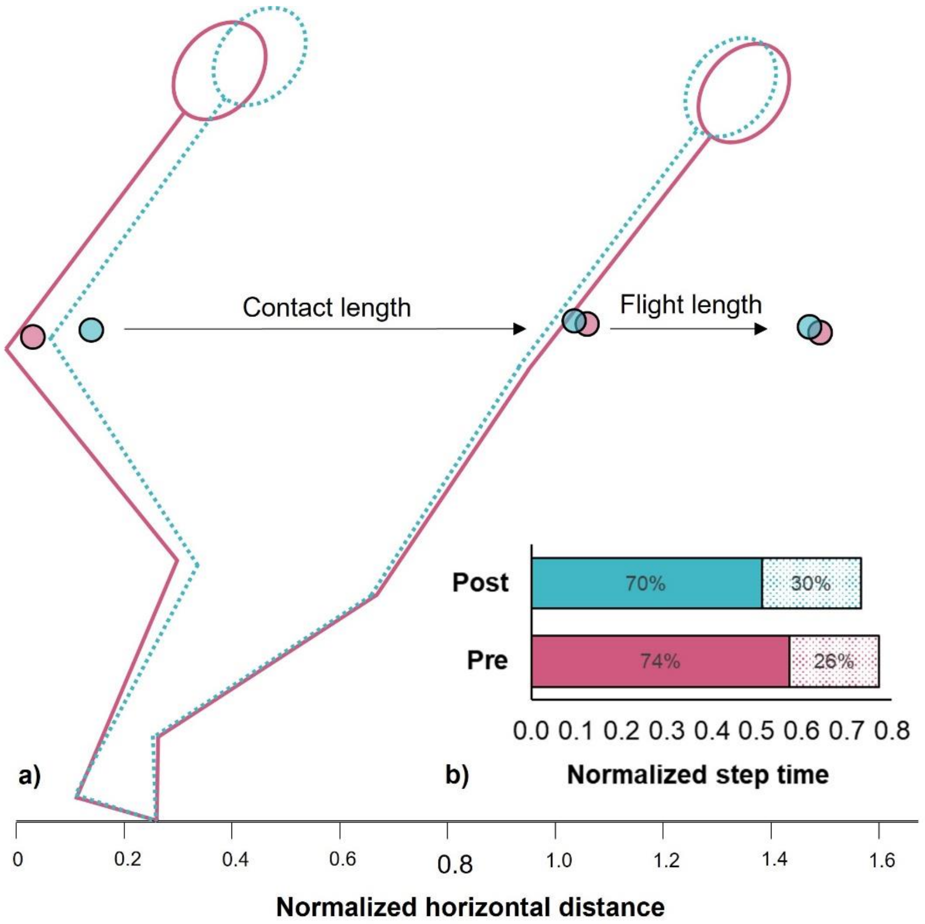


Figure 4. 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T1** (technical intervention; mean ± SD). Between testing occasion effect sizes (absolute) are shown. Black arrows indicate the direction of the intended changes in magnitude of the variables which were most underpinning the intended 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 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 difference is statistically significant ($p \leq 0.05$), according to Paired samples *t*-tests or ^{a}Wilcoxon signed-rank (nonparametric data) tests. (SL = step length, SR = step rate, CT = contact time, FT = flight time; BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase).



c)

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 legth	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**

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.

TABLES

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 *whole-body kinematic strategy***
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.

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

[b] variable second most related to initial acceleration performance;

[c] the 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 I[7])

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

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		-2	-1	0
		Exercise	**Sets x reps**			**Exercise**	**Sets x reps**		
STRENGTH	Session 1	SA DB flat press	4 x 8	4 x 8	4 x 6	SA DB flat press	4 x 6	4 x 6	-
		SA DB row	4 x 8	4 x 8	4 x 6	SA DB row	4 x 6	4 x 6	-
		BB javelin press	4 x 10	4 x 10	4 x 10	BB javelin press	4 x 10	4 x 8	-
		Half kneeling cable row	4 x 10	4 x 10	4 x 10	Half kneeling cable row	4 x 10	4 x 8	-
		Chin ups	3 x AP	3 x AP	3 x AP	Chin ups	3 x AP	3 x AP	-
		Press ups	3 x AP	3 x AP	3 x AP	Press ups	3 x AP	3 x AP	-
	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
		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
		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
						Romanian deadlift	3 x 5	3 x 5	3 x 5
	Session 3	Squat jump (20kg)	2 x 4	3 x 4	3 x 4	Incline bench press	3 x 4	4 x 3	4 x 3
		Back squat	3 x 5	3 x 5	3 x 5	Weighted chin up	3 x 5	4 x 5	4 x 5
		Romanian deadlift	3 x 5	3 x 5	3 x 5	Prone DB row	3 x 8	4 x 8	4 x 8
		Rollouts	3 x 8	3 x 8	3 x 10	DB reverse fly	3 x 10	4 x 10	4 x 10
						Weighted press ups	4 x 15	4 x 20	4 x 25
						Nordic curl (band assisted)	3 x 5	3 x 5	3 x 5
	Session 4	Incline bench press	4 x 5	4 x 5	4 x 5				
		Weighted chin up	4 x 6	4 x 6	4 x 6				
		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				

		Week number	-5	-4	-3		-2	-1	0
		Exercise	**Sets x reps**			**Exercise**	**Sets x reps**		
SPEED	Session 1	Switch (single)	2 x 5m	2 x 8m	2 x 10m	Switch (triple)	2 x 8m	2 x 10m	3 x 15m
		Switch (triple)	2 x 5m	2 x 5m	2 x 8m	Straight leg bound	3 x 10m	3 x 15m	2 x 20m
		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)
		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)
		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
		Resisted acceleration bound	2 x 5m	2 x 10m	2 x 10m	Resisted sprint	2 x 10m (40kg)	2 x 10m (60kg)	-
		Resisted sprint	-	-	1 x 10m (40kg)	Sprint (2-point start)	🟥 3 x 30m	4 x 20m	🟥 3 x 30m
		Sprint (2-point start)	2 x 10m	🟥 3 x 30m	2 x 10m				
		Sprint (2-point start)	-	-	2 x 15m				
	Session 2	Dribble (shin)	2 x 20m	2 x 20m	2 x 20m	Hop conditioning 2	x 2 rounds (4 reps)	x 2 rounds (4 reps)	x 2 rounds (4 reps)
		Dribble (knee)	2 x 10m	2 x 10m	2 x 10m	Pogo (maximal)	2 x 5m	2 x 8m	2 x 10m
		Hop conditioning 1	x 2 rounds (4 reps)	x 2 rounds (4 reps)	x 2 rounds (4 reps)	Dribble (knee)	2 x 15m	2 x 20m	2 x 20m
		Pogo (rhythmic)	2 x 10m	3 x 10m	3 x 10m	Sprint (2-point start)	1 x 10m	1 x 10m	1 x 20m
		Sprint (upright, rolling start)	-	2 x 10m	2 x 10m	Sprint (2-point start)	1 x 20m	1 x 20m	2 x 40m
		Sprint (2-point start)	-	-	1 x 15m	Sprint (upright, rolling start)	2 x 15m	2 x 20m	-
		Sprint (2-point start)	🟥 3 x 30m	2 x 10m	3 x 20m				

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

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

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

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			Exercise	Sets x reps			Exercise	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	-
	Exercise	Sets x reps				Sets x reps			Exercise	Sets x reps			Exercise	Sets x reps				Sets x reps			
Session 1	Skipping routine[a]	2 x 15s/15s	3 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 5 3s/5s	3 x 5 3s/5s	3 x 5 3s/5s	-	3 x 3 3s/5s	3 x 3 3s/5s	3 x 5 1s/10s	Seated SL ankle ISOs[c]	2 x 8 1s/10s	2 x 10 1s/10s	3 x 10 1s/10s	Standing SL ankle ISOs[d]	2 x 8 1s/10s	2 x 8 1s/10s	3 x 10 1s/10s	-	2 x 10 1s/10s	-	3 x 10 1s/10s	2 x 10 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 5 3s/5s	3 x 5 3s/5s	3 x 5 3s/5s	-	3 x 3 3s/5s	3 x 3 3s/5s	3 x 5 1s/10s	Supine SL hip ext. ISOs[e]	2 x 8 1s/10s	2 x 10 1s/10s	3 x 10 1s/10s	Supine SL hip ext. ISOs[e]	2 x 8 1s/10s	2 x 8 1s/10s	3 x 10 1s/10s	-	2 x 10 1s/10s	-	3 x 10 1s/10s	2 x 10 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. [a]Participant 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). [b]Participant 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. [c]Participant 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. [d]Participant 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. [e]Participant 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

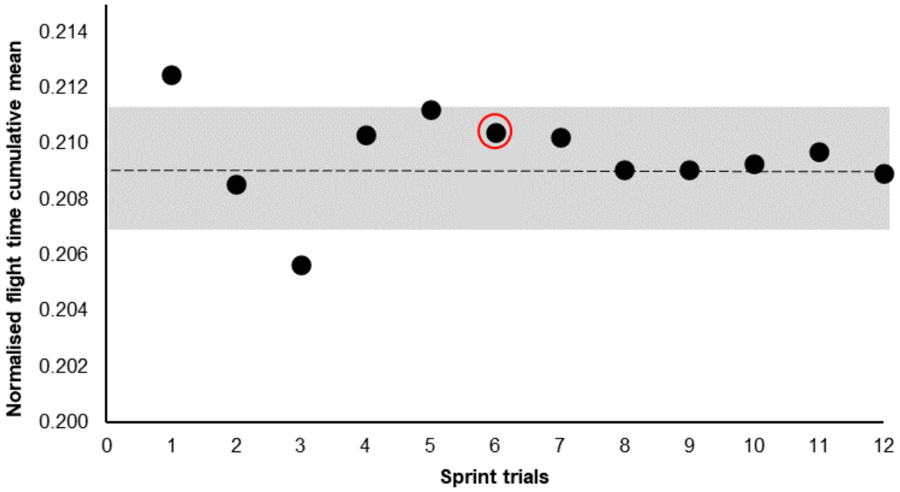
	Phase 1					Phase 2			Phase 3				Phase 4					Phase 5			
	Week	1	2	3	4	5	6	7		8	9	10		11	12	13	14	15	16	17	18
	Exercise	Sets x reps				Sets x reps			Exercise	Sets x reps			Exercise	Sets x reps				Sets x reps			
Session 1	Switch (triple, stick OH)	3 x 10m	3 x 10m	3 x 15m	3 x 15m	2 x 10m	2 x 10m	2 x 10m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

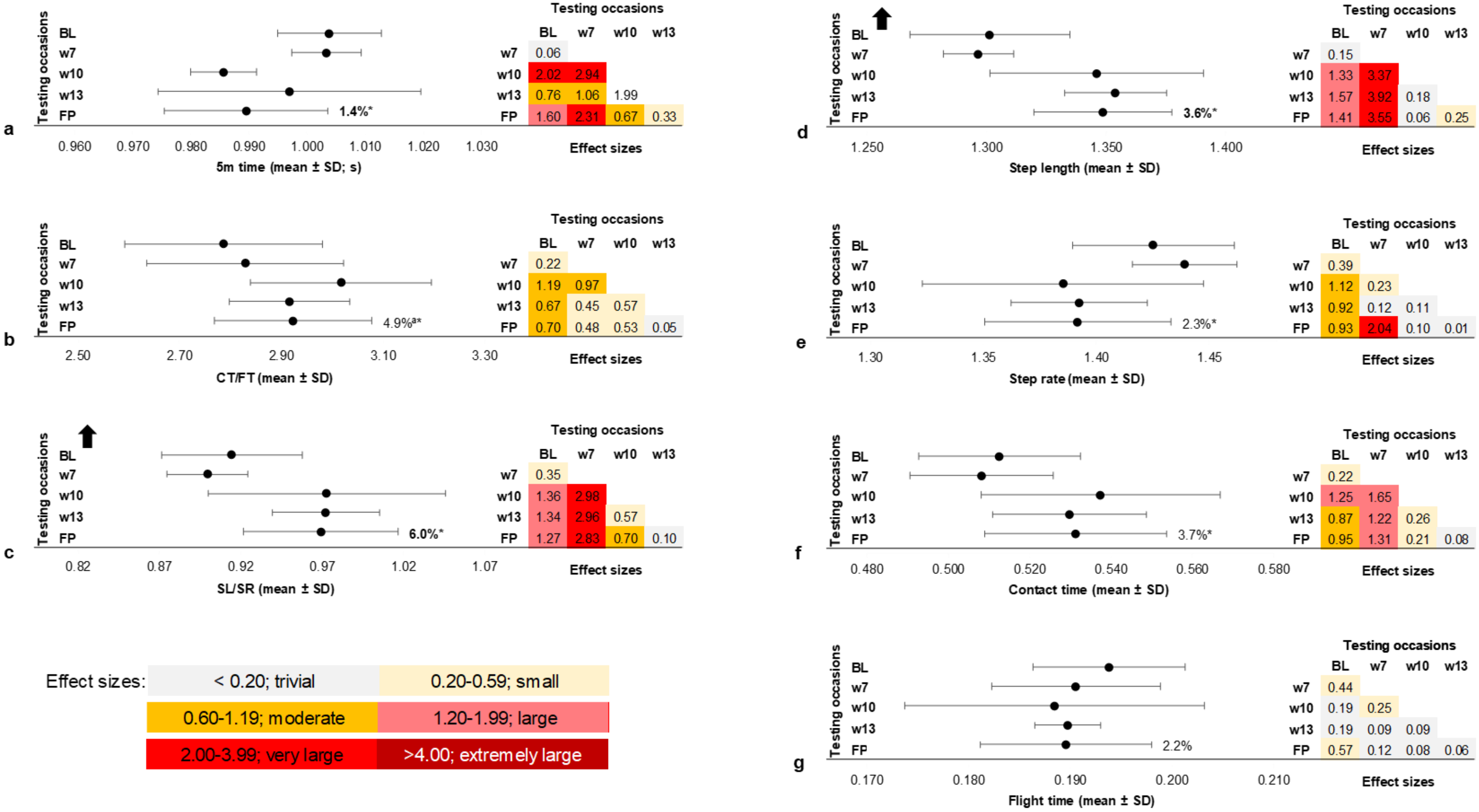
SUPPLEMENTARY MATERIAL 2

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 & Squadrone, 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



a

	BL	w7	w10	w13
w7	0.06			
w10	2.02	2.94		
w13	0.76	1.06	1.99	
FP	1.60	2.31	0.67	0.33

b

	BL	w7	w10	w13
w7	0.22			
w10	1.19	0.97		
w13	0.67	0.45	0.57	
FP	0.70	0.48	0.53	0.05

c

	BL	w7	w10	w13
w7	0.35			
w10	1.36	2.98		
w13	1.34	2.96	0.57	
FP	1.27	2.83	0.70	0.10

d

	BL	w7	w10	w13
w7	0.15			
w10	1.33	3.37		
w13	1.57	3.92	0.18	
FP	1.41	3.55	0.06	0.25

e

	BL	w7	w10	w13
w7	0.39			
w10	1.12	0.23		
w13	0.92	0.12	0.11	
FP	0.93	2.04	0.10	0.01

f

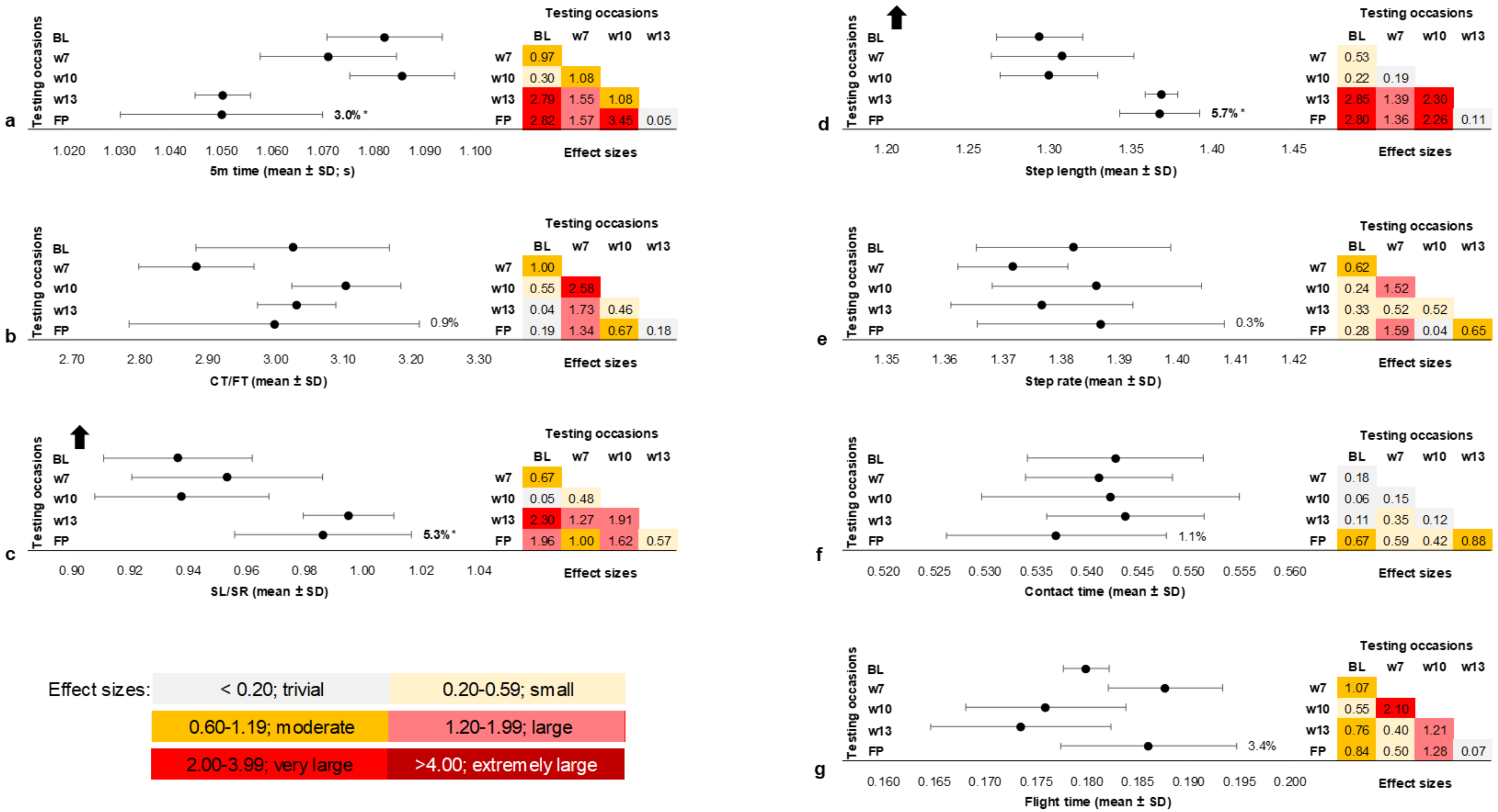
	BL	w7	w10	w13
w7	0.22			
w10	1.25	1.65		
w13	0.87	1.22	0.26	
FP	0.95	1.31	0.21	0.08

g

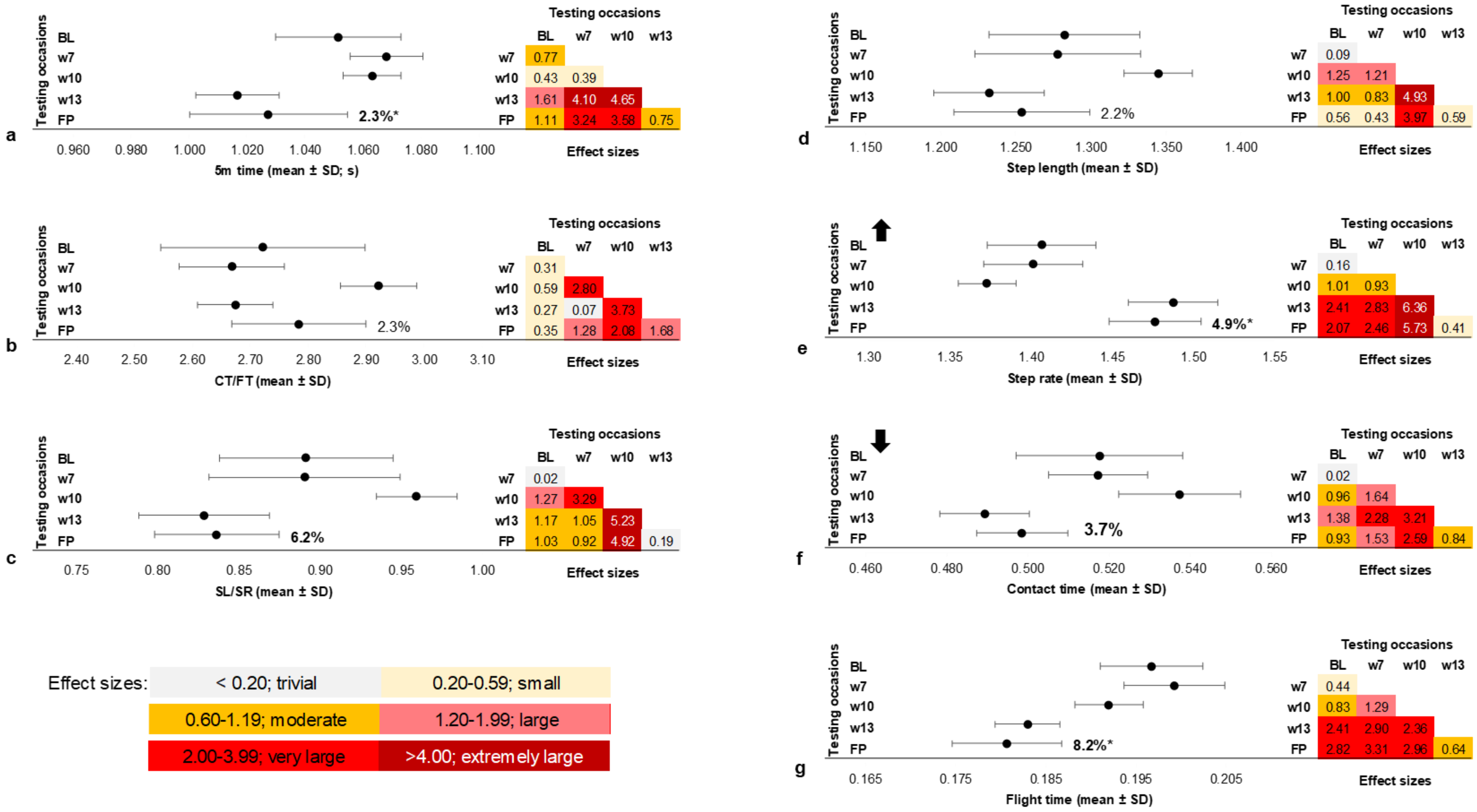
	BL	w7	w10	w13
w7	0.44			
w10	0.19	0.25		
w13	0.19	0.09	0.09	
FP	0.57	0.12	0.08	0.06

< 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

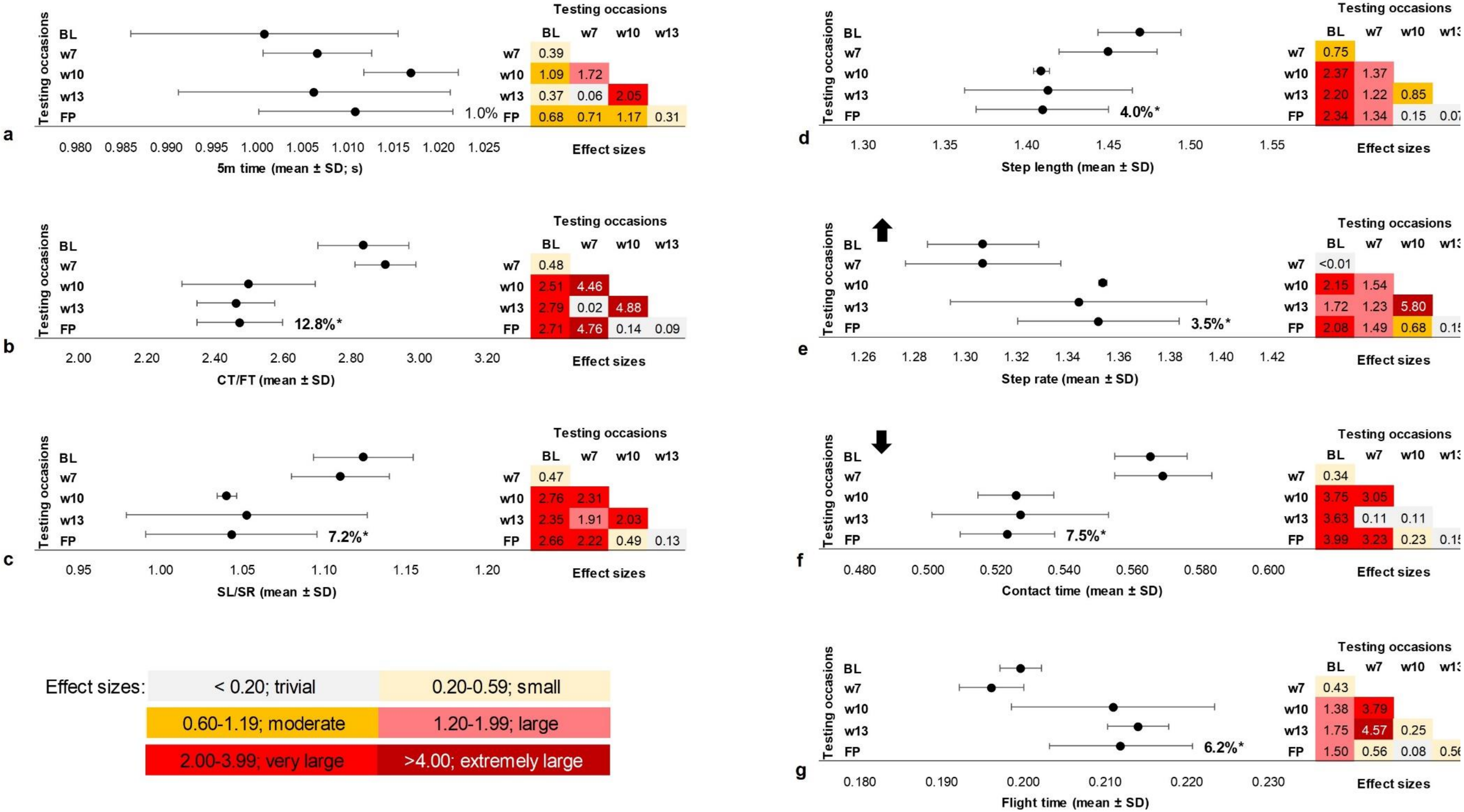
3A. 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant T2** (technical intervention; mean ± SD). Between testing occasion effect sizes (absolute) are shown (BL = baseline testing phase, w7 = week 7, w10 = week 10, w13 = week 13, FP = final testing phase). See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



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.



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.



a

	BL	w7	w10	w13
w7	0.39			
w10	1.09	1.72		
w13	0.37	0.06	2.05	
FP	0.68	0.71	1.17	0.31

b

	BL	w7	w10	w13
w7	0.48			
w10	2.51	4.46		
w13	2.79	0.02	4.88	
FP	2.71	4.76	0.14	0.09

c

	BL	w7	w10	w13
w7	0.47			
w10	2.76	2.31		
w13	2.35	1.91	2.03	
FP	2.66	2.22	0.49	0.13

d

	BL	w7	w10	w1
w7	0.75			
w10	2.37	1.37		
w13	2.20	1.22	0.85	
FP	2.34	1.34	0.15	0.0

e

	BL	w7	w10	w1
w7	<0.01			
w10	2.15	1.54		
w13	1.72	1.23	5.80	
FP	2.08	1.49	0.68	0.1

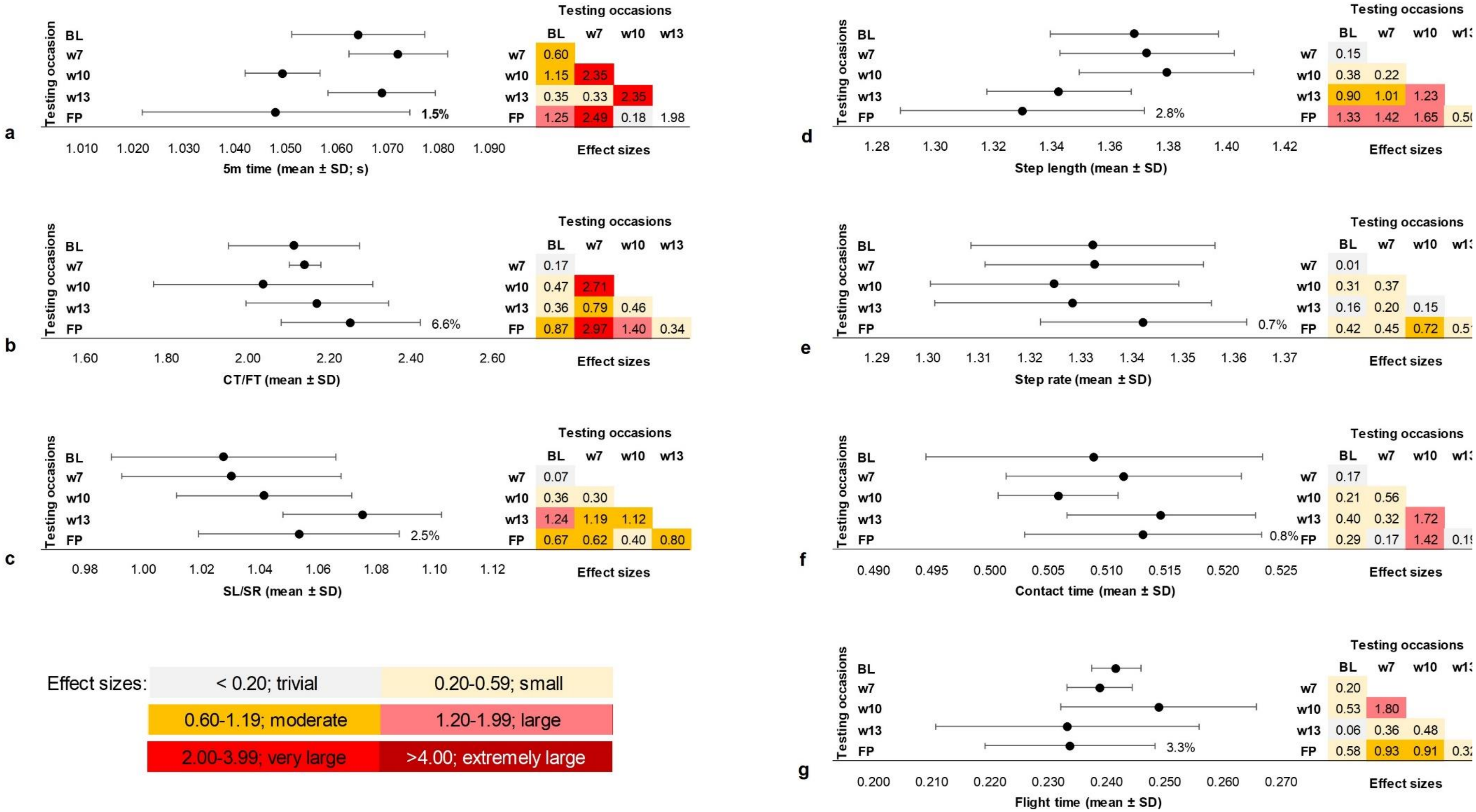
f

	BL	w7	w10	w1
w7	0.34			
w10	3.75	3.05		
w13	3.63	0.11	0.11	
FP	3.99	3.23	0.23	0.1

g

	BL	w7	w10	w1
w7	0.43			
w10	1.38	3.79		
w13	1.75	4.57	0.25	
FP	1.50	0.56	0.08	0.5

3D. Mean ± SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant S1** (strength 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.



a

	BL	w7	w10	w13
w7	0.60			
w10	1.15	2.35		
w13	0.35	0.33	2.35	
FP	1.25	2.49	0.18	1.98

b

	BL	w7	w10	w13
w7	0.17			
w10	0.47	2.71		
w13	0.36	0.79	0.46	
FP	0.87	2.97	1.40	0.34

c

	BL	w7	w10	w13
w7	0.07			
w10	0.36	0.30		
w13	1.24	1.19	1.12	
FP	0.67	0.62	0.40	0.80

d

	BL	w7	w10	w1
w7	0.15			
w10	0.38	0.22		
w13	0.90	1.01	1.23	
FP	1.33	1.42	1.65	0.5

e

	BL	w7	w10	w1
w7	0.01			
w10	0.31	0.37		
w13	0.16	0.20	0.15	
FP	0.42	0.45	0.72	0.5

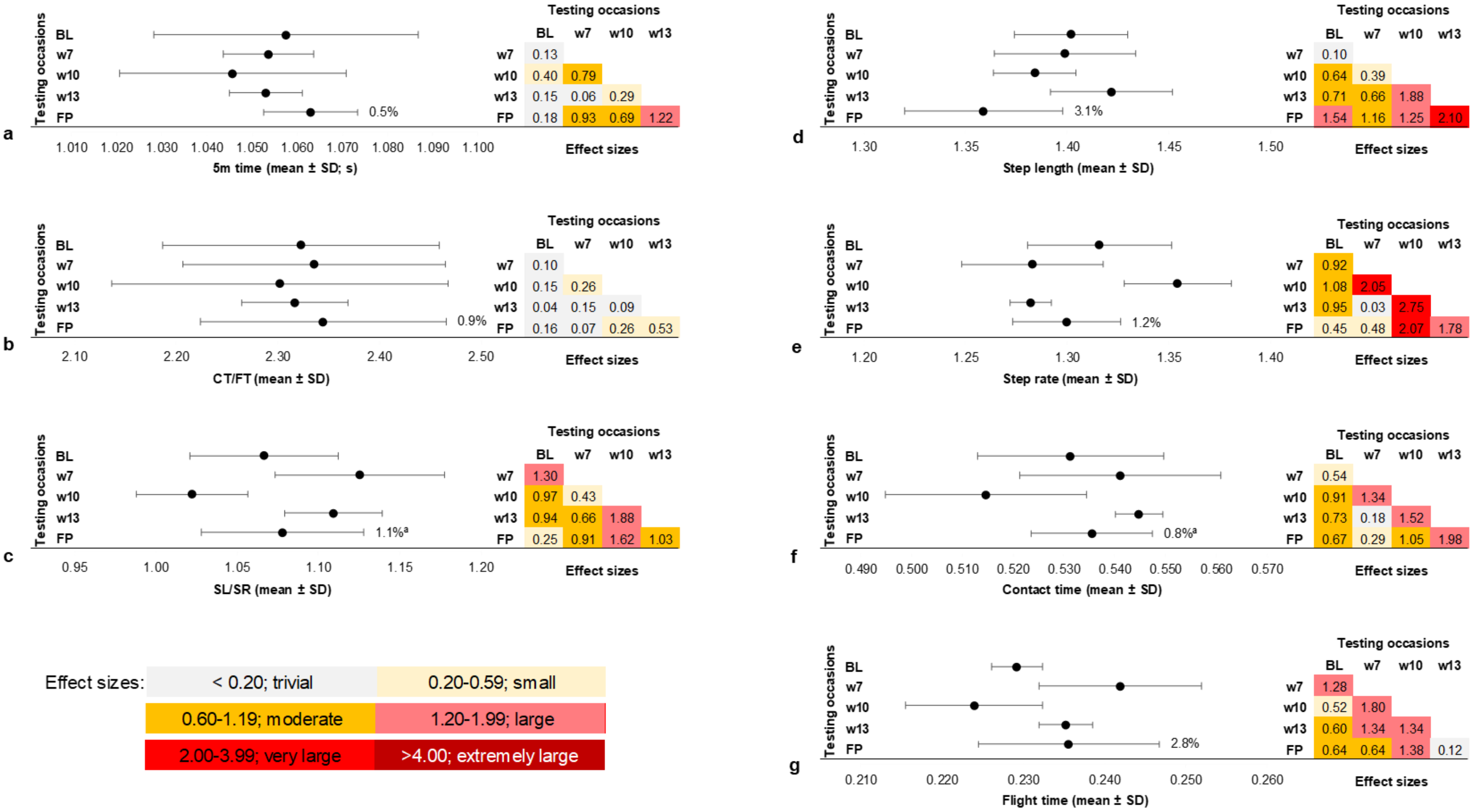
f

	BL	w7	w10	w1
w7	0.17			
w10	0.21	0.56		
w13	0.40	0.32	1.72	
FP	0.29	0.17	1.42	0.1

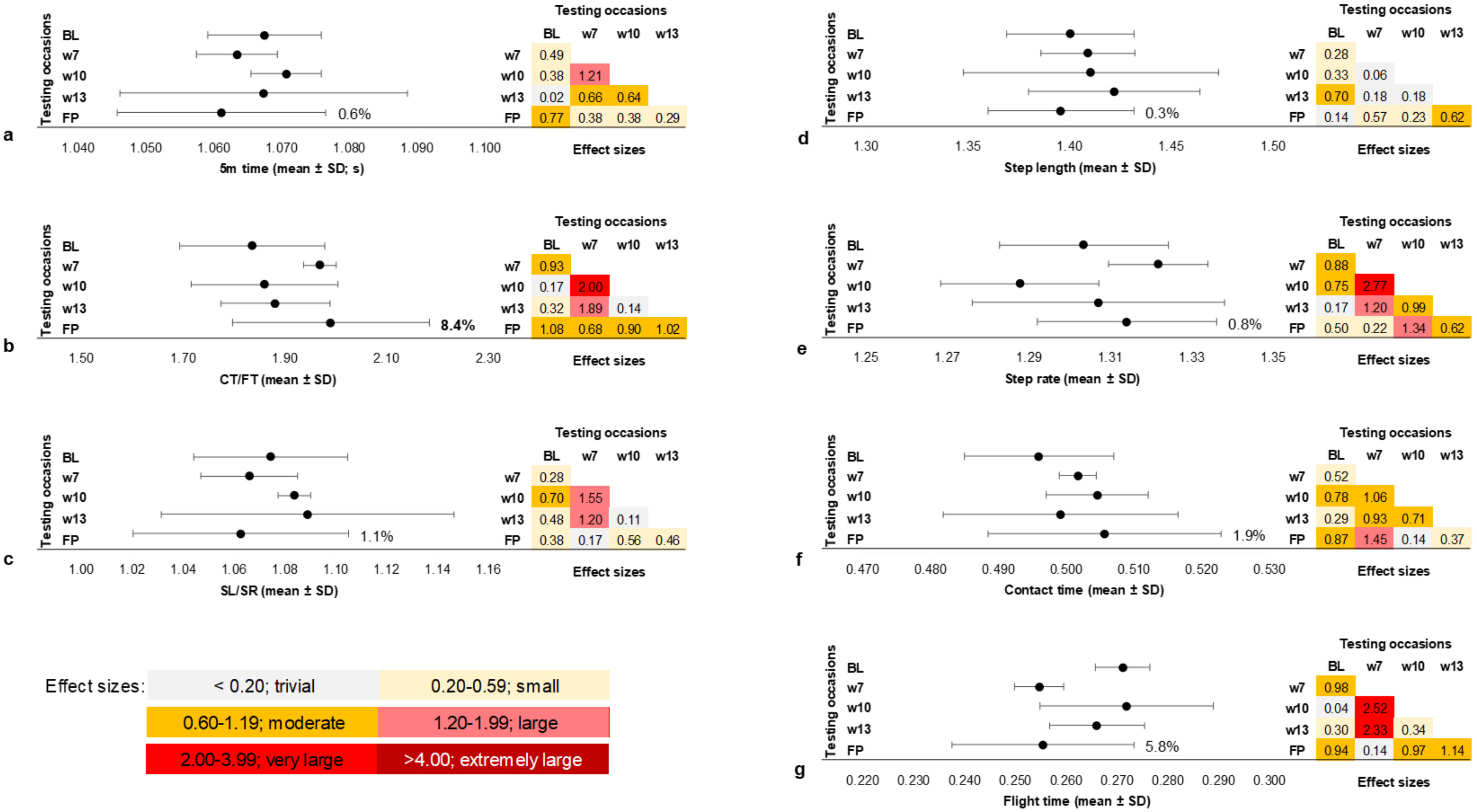
g

	BL	w7	w10	w1
w7	0.20			
w10	0.53	1.80		
w13	0.06	0.36	0.48	
FP	0.58	0.93	0.91	0.3

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 ± SD of 5 m time, normalized spatiotemporal variables and the SL/SR and CT/FT ratios for **participant C3** (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.