Rakovic, E., Paulsen, G., Helland, C., Eriksrud, O., Haugen, T. (2018). The effect of individualised sprint training in elite female team sport athletes: A pilot study. *Journal of Sports Sciences, 36*, 2802-2808.

The effect of individualised sprint training in elite female team sport athletes: A pilot study

Individualised sprint training

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Keywords: physical training; physical performance; acceleration; horizontal power production, handball.

Abstract

This study aimed to evaluate whether an individualised sprint-training program was more effective in improving sprint performance in elite team-sport players compared to a generalised sprint-training program. Seventeen elite female handball players (23 ± 3 y, 177 ± 7 cm, 73 ± 6 kg) performed two weekly sprint training sessions over eight weeks in addition to their regular handball practice. An individualised training group (ITG, *n* = 9) performed a targeted sprint-training program based on their horizontal force-velocity profile from the pre-training test. Within ITG, players displaying the lowest, highest and mid-level force-velocity slope values relative to body mass were assigned to a resisted, an assisted or a mixed sprint-training program (resisted sprinting in the first half and assisted sprinting in the second half of the intervention period), respectively. A control group (CG, *n* = 8) performed a generalised sprint-training program. Both groups improved 30-m sprint performance by ~ 1% (small effect) and maximal velocity sprinting by ~ 2% (moderate effect). Trivial or small effect magnitudes were observed for mechanical outputs related to horizontal force- or power production. All between-group differences were trivial. In conclusion, individualised sprint-training was no more effective in improving sprint performance than a generalised sprint-training program.

Introduction

Accelerated sprinting is a fundamental part of the motor skill requirements in team sports to win duels, defend or create goal-scoring opportunities. Sprint performance becomes more resistant to training enhancement with increasing performance level, age and training status (Vescovi, Rupf, Brown, & Marques, 2011; Haugen, Tønnessen, & Seiler, 2012 and 2013; Tønnessen, Svendsen, Olsen, Guttormsen, & Haugen, 2015). However, previous studies have shown that professional players are generally faster than semi-professional and amateur players, and professional players have become faster over time, indicating that the importance of well-developed sprinting skills has increased in modern team sports (Haugen et al., 2012 and 2013; Haugen, Tønnessen, Hisdal, & Seiler, 2014). Previously published intervention studies have typically been performed on young and/or amateur players and limited to investigating whether certain training methods are more effective than others. Although the principle of specificity is clearly present, assisted or resisted sprint training have so far not provided superior effects on accelerated sprinting capability in team sport players compared to sprinting under normal conditions (Haugen et al., 2014; Petrakos, Morin, & Egan, 2016; Rumpf, Lockie, Cronin, & Jalilvand, 2016).

An increasing number of studies pay attention to underlying mechanical determinants for sprint performance, as such variables provide insights into individual biomechanical limitations (Morin et al., 2012; Buchheit et al., 2014; Rabita et al., 2015). Recently, a French research group presented a field method to calculate mechanical outputs and develop horizontal profiles of accelerated sprinting (Samozino et al., 2016; Morin & Samozino, 2016). Theoretical maximal velocity (V0), horizontal force (F0), horizontal power (P0) and force-velocity profile can be calculated from the modelling by derivation of the speed-time curve that leads to horizontal acceleration data. The promising aspect of this approach is an individualised diagnosing and development of training programs that target the major limiting factors (Morin & Samozino, 2016). It has recently been reported that an individualised training program based on vertical force-velocity profiling was more effective in improving jumping performance than traditional strength/power training common to all participants (Jiménez-Reyes, Samozino, Brughelli, & Morin, 2017[A]; Jiménez-Reyes et al., 2017[B]). A similar approach based on horizontal force-velocity profiling remains to be explored for sprint running performance purposes. This can be achieved by comparing the relative strengths and weaknesses in each player's profile to the rest of the team (Morin & Samozino, 2016). Accordingly, athletes with horizontal force deficits should be given more horizontal strength work (e.g., resisted sprint), while athletes with velocity deficits should prioritize maximal velocity sprinting (e.g., assisted sprinting).

Therefore, the aim of the current study was to evaluate whether an individualised training program based on horizontal force-velocity profiling was more effective on accelerated and maximal velocity sprinting performance in elite team sport players compared to a generalised sprint-training program. We hypothesised that individualised sprint training would provide better effects on accelerated and maximal velocity sprinting performance.

Methods

Design

In this randomised controlled trial, participants (n=21) were allocated pairwise according to their horizontal force-velocity profile (force-velocity slope relative to body mass) from pre-training tests and then randomly assigned to one of two treatment conditions. The randomisation process was performed by a co-author not directly involved in testing or the training intervention. The individualised training group (ITG, n=11) performed a targeted and individualised sprint-training program, while the control group (CG, n=10) performed a generalised sprint-training program that was the same for all the participants. Three subgroups within ITG were established. Here, the players displaying the lowest, highest and mid-level force-velocity slope values relative to body mass were assigned to a resisted (ITG_1 = 3), an assisted (overspeed) (ITG_2 = 4) and a mixed sprint-training program (ITG_3 = 4) (resisted sprinting in the first half and assisted sprinting in the second half of the intervention period), respectively (Figure 1). The intervention included sprint training twice a week for an 8-week period for both groups. Participants were required to complete at least 14 out of 16 intervention-training sessions (87.5%) and all pre- and post-training tests in order to be included. Both ITG and CG completed, on average, 93% of the total sprint training sessions. Session rating of perceived exertion (session RPE) and perceived recovery status (PRS) were registered throughout the intervention period based on previously published guidelines (Foster, 2001; Laurent et al., 2011).

Figure 1 about here

Participants

Twenty-one professional or semi-professional female handball players in the national upper league volunteered to participate and underwent the pre-training tests. Four players dropped out immediately prior to or during the intervention, including one (from CG) who sustained a hamstring injury during one of the sprint training sessions. Overall, 17 participants completed the study with the following sample sizes: ITG = 9 (age 23 ± 3 y, height 177 ± 7 cm, body mass 73 ± 6 kg) and CG = 8 (age 23 ± 3 y, height 176 ± 6 cm, body mass 72 ± 5 kg). Training characteristics for both groups are presented in Table 1.

Table 1 about here

Each participant had a minimum of 10 years of handball-specific training experience. Four of the participants played for the national team while eleven players participated in the Champions League tournament during the current season. During the intervention period, participants were requested to refrain from performing any other heavy and/or high intensity off-field physical training regimes in the form of maximum strength training, high-intensity interval running or plyometric training. Regular handball training sessions typically commenced with warm-up activities like running in different directions and specific warm-up for upper and lower extremities, followed by progressive passing drills and goalkeeper warm-up. The main part of the handball practices during this period consisted of tactical-oriented and match-preparing sessions with low to moderate intensity.

The study was reviewed by the Regional Ethics Committee and approved by the Norwegian Data Protection Authority. All subjects signed an informed consent form before the study and were made aware that they could withdraw at any point without providing an explanation. The study was conducted in accordance with the Declaration of Helsinki.

Testing procedures

The pre- and post-training tests were conducted in the same handball arena. All participants completed the tests in the same order and at the same time of day. Regarding nutrition, hydration, sleep and physical activity, participants were instructed to prepare as they would for a regular handball match, including no high-intensity training the last day prior to testing. They were also instructed to use identical footwear and kit for each of the tests. All participants were familiarised with sprint testing. Body mass was assessed half an hour prior to testing on each testing day. Participants then completed a 20 min standardised warm-up consisting of a general warm-up (jogging at ~60-75% of age-predicted maximal heart rate), ”local” muscle warm-up (lunges, hip lift, ballistic hamstring- and hip mobility in supine and prone), specific running drills (high knees skipping, butt-kicks, straight leg pulls) and finally 3-4 runs over 30-40 m with progressively increasing speed.

After the warm-up, participants completed two maximal 30-m sprints. Best 30-m time was included for analysis. Recovery time between trials was 3-4 min. All sprints were commenced from a standing split stance position with the toe of the front foot placed at the start line. After a ready signal was given by the test operator, athletes started on their own initiative. Musclelab (Ergotest AS, Porsgrunn, Norway) timing system was used for sprint performance assessments. An infrared contact mat covered the start line. Timing was initiated by the infrared contact at the time of front foot lift-off. Post-processing timing gates were placed at 5,10,15,20 and 30 m (120 cm above floor level), and the start of the longest photocell break was used as a trigger criterion (the torso will always produce a longer break than an arm). The present timing setup provided sufficient data points for mechanical output computations (Samozino et al., 2016; Morin & Samozino, 2016) performed by a purpose-built software integrated in the Musclelab system. Typical error (TE) and coefficient of variation (CV) were 0.03 s and 1.0% for 0-30 m sprint time, 0.08 $m \cdot s^{-1}$ and 1.4% for V0, 20 W and 2.6% for P0, 0.30 $W \cdot kg^{-1}$ and 2.7% for $P0 \cdot kg^{-1}$, 10 N and

2.7% for F0, 0.14 $N \cdot kg^{-1}$ and 2.7% for $F0 \cdot kg^{-1}$, and 1.7 $(N \cdot (m \cdot s^{-1})^{-1}$ and 3.4% for FV slope, based on sprint trial 1 and 2 from the pre-training tests.

Intervention

The sprint training intervention took place from the middle of January to the middle of March, corresponding to the late middle of the handball season for the participants. All sprint-training sessions were supervised and completed at the same time of day for both groups during the entire intervention. There was a minimum of 48 h between each sprint-training session. Identical warm-up procedures as for the pre-and post-training tests were performed prior to each sprint training. The intervention protocol was periodised with a gradual increase in the number of weekly-performed sprints during the first half of the intervention, followed by a corresponding decrease in sprint repetitions (for tapering purposes) the last three weeks prior to the post-training test (Table 2). Each sprint training session followed a stepwise change (increase/decrease) in resistance/assistance, to ensure a gradual and smooth progression. The number of sprints was equal for all participants during all sprint-training sessions, and recovery between each sprint was 3-4 min. The players were encouraged to perform all sprints with maximal effort.

Table 2 about here

CG performed 30-m sprints (sprinting under normal conditions, no assistance or resistance) during the entire intervention. 1080 Sprint (1080 Motion AB, Stockholm, Sweden), a portable resistance/overspeed training device that uses a servo motor (2000 RPM OMRON G5 Series Motor, OMRON Corporation, Kyoto, Japan), was used by ITG during all sprint sessions. The cord from the motor was attached to the sprinting athlete with a belt around the waist. The resistance/assistance load (Table 2) was determined and controlled by the Quantum computer application (1080 Motion, Lidingö, Sweden). Gear 1 and isotonic resistance mode were used for the winch system. For the resisted 30-m sprints, the players started 5 m in front of and ran away from the machine. The variable resistance mode was used the last three weeks (i.e., the tapering phase) for ITG_1 and in two training sessions in the middle of the intervention for ITG_3 to ensure a smooth transition from resisted to assisted sprinting. In this mode, the resistance drops linearly from 9 kg at start to 1 kg when achieving a certain speed (corresponding to each individual´s documented peak velocity at running with 9 kg resistance, assessed by the 1080 device). For the assisted 25-m sprints, the subjects started 45 m in front and ran towards the machine. The assisted sprints were slightly shorter to ensure sufficient braking distance. During the assisted sprints, participants were advised to focus on high step frequency when they approached their maximal velocity, as previously recommended (Mero & Komi, 1986; Cissik, 2005). No other technical instructions were provided. Overall, sprinting with 5, 8 and 11 kg resistance induced 11, 18 and 25% reduction in maximal sprint velocity on average, based on assessments of the sprint training sessions. Similarly, sprinting with 0.3, 1.3, 2.2 and 3.2 kg assistance induced 1, 6, 11 and 14% higher maximal velocity. All the stated resistance/assistance values are averaged over the entire step cycle. The variability for each assistance/resistance load was very low (CV < 1%, calculated from 201 runs), indicating high reliability.

Statistics

Shapiro Wilks tests revealed that none of the variables deviated statistically from distribution of normality. Data from pre- and post-training tests are presented as mean ±SD. Magnitudes of between-group differences were assessed by standardisation (mean difference divided by the harmonic mean of the SD of the compared groups). The thresholds for assessing the observed difference in means were 0.2, 0.6 and 1.2 for small, moderate and large, respectively (Hopkins, Marshall, Batterham, & Hanin, 2009). To make inferences about true values of effects, we used non-clinical magnitude-based inference rather than null-hypothesis significance testing (Hopkins et al., 2009). Magnitudes were evaluated mechanistically: if the confidence interval overlapped substantial positive and negative values, the effect was deemed unclear; otherwise effects were deemed clear and shown with the probability that the true effect was substantial or trivial (whichever was greater) using the following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; > 99.5%, most likely (Hopkins et al., 2009).

Results

Table 3 about here

Sprint performance and mechanical outputs between and within groups from pre- to post-training test are shown in Table 3. Both groups improved their 30-m sprint performance by 0.05-0.06 s on average (~ 1%; small effect). Both groups improved V0 by ~ 2% (moderate effect), while only trivial or small effect magnitudes were observed for the other mechanical outputs. All between-group differences observed from pre- to post-training test were trivial and unclear.

Figure 2 about here

Figure 2 shows the changes in 30-m sprint time and V0 from pre- to post-training tests on an individual level. No clear trends between treatment conditions and performance enhancements were observed.

Discussion

To the authors' knowledge, this is the first study to evaluate the effect of an individualised sprint-training program based on horizontal force-velocity profiling. Our main finding was that the individualised training was no more effective than a generalised sprint training program (control) in elite female handball players. Hence, all between-group differences were trivial. Both the individualised training group and the control group displayed moderate improvements in maximal velocity (V0) and small enhancements in 0-30 m sprint times. Only trivial or small effect magnitudes were observed for variables related to horizontal force- and power production within both groups.

Individualised training is generally more challenging to organise (i.e., time consuming) for team-sport staff than common training sessions where "one size fits all." Consequently, many coaches perform similar training for most players on the team, despite considerable potential variances in capacity profiles. Interestingly, even though applying individualised training is theoretically and scientifically sound (Haugen et al., 2014; Morin & Samozino, 2016; Jiménez-Reyes et al., 2017[A]), the lack of substantial between-group differences observed in the present study do not support individualised sprint training. However, several considerations must be taken into account and discussed in order to avoid a potential type II error conclusion.

When optimally evaluating an intervention, it is important to consider (i) the actual change in performance (the signal), (ii) the noise associated with that particular assessment, and (iii) the smallest practical or meaningful change (SWC) (Hopkins, 2004). SWC for team sport athletes is 1% for 10- to 40-m sprints and 2% for maximal velocity sprinting (Haugen & Buchheit, 2016). Considering that the actual change in performance (~ 1% for both groups over 30-m sprint) was practically identical with the measurement noise observed (1% CV for 0-30-m sprint time) and SWC for team sport athletes, the usefulness of the sprint training programs performed by both groups was relatively poor. However, we did observe large variations in individual responses (Figure 2). Ten out of 17 athletes (five from ITG and five from CG) improved their 30-m times by more than 1% (SWC), indicating that the intervention was useful for these players, while three athletes (all from ITG) worsened their 30-m sprint times correspondingly by more than 1%. Similarly, nine players (five from ITG and 4 from CG) displayed advances in V0 greater than 2% (SWC), while one player decreased V0 by more than 2%. The reasons for these variations remain unclear. No meaningful differences were observed between the groups in terms of sprint performance level, total training- or match-load characteristics during the intervention period. Moreover, a visual inspection of the present individual results revealed no clear trends in favour of any playing position.

Both groups displayed larger enhancements for maximal velocity sprinting than for accelerated sprint performance. Similar to our findings, Tønnessen, Shalfawi, Haugen, & Enoksen (2011) observed unaltered accelerated sprint performance and improved maximal velocity as a result of weekly repeated 40-m sprints in young male elite soccer players. A recent review by Rumpf et al. (2016) showed that training effects (in terms of effect size) increased with increasing sprint distance. Collectively, this suggests that team sport players respond most strongly to somewhat longer and less team-sport specific sprint distances. Indeed, team sport players perform a high number of brief accelerations (~ 5-10 m) during training and games, while longer sprints (> 30 m) rarely occur (Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010; Michalsik, Madsen, & Aagaard, 2014; Suarez-Arrones et al., 2014). Therefore, we speculate that most well-trained players have largely maximized their accelerated sprint performance potential (at least when compared to maximal velocity sprinting) during regular team-sport training.

Performance in sprint is determined by a complex interaction of technical and physiological variables (Morin, Edouard, & Samozino, 2011; Haugen et al., 2017[A]; Haugen, Paulsen, Seiler, & Sandbakk, 2017[B]). In the context of this study, it is important to keep in mind that ineffective sprinting (e.g., too much upper body raise during initial acceleration) may influence the mechanical outputs. That is, horizontal force- and power production may be underestimated for powerful athletes with poor running technique. Morin et al. (2011) have developed a model to calculate ratio of force and force application technique, but these computations require force data from instrumented treadmills or multiple force plates in series, equipment that the vast majority of athletes do not have access to.

The categorisation criteria that formed the basis for the present individualised sprint training need to be further discussed. Recently, Jimenez-Reyes et al. (2017) performed an intervention with a similar approach to enhance vertical jump performance, and their allocation to the different training protocols was based on percentage deviation from the theoretically optimal FV profile. As no such reference values exist for horizontal sprinting, a relative allocation model was chosen for the present study. Due to the strong relationship between FV slope and body mass (we observed a 0.80

correlation between these variables based on pre-training tests), it is crucial to normalise FV slope to body mass prior to group allocation, as performed in this study. However, it remains unclear whether the participants conducted an optimal training protocol based on the principle of targeting their least developed capacity (e.g. force-deficit or velocity-deficit). Morin & Samozino (2016) suggested that individual training programs should be based on comparisons of the relative strengths and weaknesses in each player's horizontal profile compared to the rest of the team. However, a limitation of using this approach is that it is directly affected by group homogeneity. Theoretically, the players included in this study might be clustered around a smaller part of the entire spectrum of mechanical sprint running profiles, leading to the possibility that the prescribed individualised training was too differentiated.

Due to the varying natures and specificities across team sports, the importance of sprint-specific mechanical outputs will vary. Giroux, Rabita, Chollet, & Guilhem (2016) observed that the chronic practice of an activity leads to differently balanced force-velocity profiles in squat jumping. Further research should therefore aim to establish the requirements of sprint-specific mechanical outputs across a broad range of sports disciplines and playing positions in order to provide a holistic picture of the capacity profile continuum. Differences in force-velocity profiles raise potential sources of performance improvement in elite athletes. As such, it is reasonable to assume that the effect of individualised training increases with athlete heterogeneity.

Despite some potential methodological weaknesses associated with the current individualisation of sprint training, no indications in favour of either resisted or assisted sprint training were observed (Figure 2). The hypothesis behind assisted sprint running is that supramaximal sprinting can lead to higher stride-frequency, shorter ground contact times and higher angle velocities (Cissik, 2005). Comparisons of assisted sprint-training protocols across studies are even more challenging than for resisted sprinting, due to fewer scientific publications and even greater variations in methods and devices (e.g., downhill running, treadmill, elastic cord devices, etc.). Clark et al. (2009) suggested that a towing load corresponding to ~4% of body weight decreases ground contact times without any negative effects on other kinematic parameters. In the present study, pulling forces in the range 0.3-3.2 kg (i.e., 0.7-4.4% of mean body mass) were used, inducing 1-14% increase in maximal sprint velocity. Because no kinematic recordings of test-runs were performed, the possible influence of the overspeed load on sprint kinematics remains unclear.

The horizontal resistances applied in the current study were 5, 8 and 11 kg, leading to a reduction in maximal velocity in the range 11-25%. According to the classifications outlined by Petrakos et al. (2015), this reduction in running velocity corresponds to moderate to heavy resistance. According to Cross, Brughelli, Samozino, Brown, & Morin (2017), the optimal loading for maximising power during sled-resisted sprinting is a resistance that reduces the maximal velocity by □50%. However, Morin et al. (2016) tested the use of very heavy sleds and observed a substantial, increased horizontal force production when compared to non-resisted sprinting. Still, only trivial between-group differences were observed for power output and sprint velocity. Future studies should therefore investigate the effect of heavier or lighter loads after individualisation of force-velocity profiles.

Intervention studies involving high-level athletes are typically shaped by training-related constraints within the overall training program. Such constraints are an important aspect of assessing the practical efficacy of training interventions in team sports. This intervention was performed in-season, and it is possible that the results would have been different if the study was undertaken off-season or pre-season. However, the present results add further support to the notion that sprinting skills over short distances are hard to improve within the constraints of overall team sport training (Tønnessen et al., 2011 and 2015; Haugen et al., 2015, Los Arcos & Martins, 2018). If the primary goal for well-trained players is to improve their sprinting skills, future investigations should explore whether it is more effective to restructure the players` weekly team sport training rather than introducing an additional physical training regime.

Considering both the present findings and previous research (Haugen et al., 2014; Petrakos et al., 2016; Rumpf et al., 2016), no specific sprint training methods have so far emerged as superior. However, there are many parameters left that need to be explored within the individualised FV-profile approach (e.g., other volume/load, proportions of assisted/resisted sprinting relative to normal sprinting, categorisation criteria for FV-profiling of athletes, sprint training at other season times, etc.). Therefore, the current findings must be interpreted with caution.

Conclusion

In the present study, elite female handball players were followed over 8 weeks in season. An individualised sprint-training program, based on horizontal force-velocity profiling, was found to be no more effective than a generalised sprint-training program in improving accelerated and maximal velocity sprinting performance. The moderate sample sizes may mask possible significant outcomes within the groups, but based on the trivial or small effect magnitudes observed, it is not likely that larger sample sizes would provide significant between-group differences. However, several other considerations must be taken into account and addressed in future studies before the hypothesis can be rejected, the most important being the development of sport-specific categorisation criteria based on FV-profiling of athletes. Although the present investigation must be considered a pilot, it provides a point of departure for future studies.

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Table 1. Weekly training characteristics for the participants during the intervention period

	Specific (*n*)	**Non-specific (*n*)**	**Games per week (*n*)**	**Total training volume ($h \cdot w^{-1}$)**	**Session RPE**	**PRS**
ITG	3.1±0.5	1.0±0.2	1.3±0.3	9.3±0.7	5.6±0.7	6.2±0.5
CG	2.7±0.4	1.1±0.4	1.4±0.3	8.8±0.8	5.8±0.5	6.7±1.1

Values are mean ± SD. Specific = handball-specific training on court. Non-specific = non-specific handball training off-court (e.g., upper-body work, core stability, recovery training, etc.). Session RPE = session rated perceived exertion. PRS = perceived recovery status. All between-group differences were small or moderate.

Table 2. Sprint training intervention protocol

Sprint session	*n*	Resistance (kg) during 30-m sprints for ITG_1	Assistance (kg) during 25-m sprints for ITG_2	Resistance (session 1-8) and assistance (session 9-16) for ITG_3 (kg)
1	6	5-5-8-11-8-5	0-0-0.3-1.3-0.3-0	5-5-8-11-8-5
2	6	0-5-8-11-8-5	0-0-0.3-1.3-0.3-0.3	0-5-8-11-8-5
3	7	0-5-5-8-11-8-5	0-0.3-0.3-1.3-0.3-1.3-0.3	0-5-5-8-11-8-5
4	8	5-5-8-8-11-11-8-5	0-0-0.3-0.3-1.3-2.2-1.3-0.3	5-5-8-8-11-11-8-5
5	10	5-5-8-8-8-11-11-8-8-5	0-0-0.3-0.3-1.3-1.3-2.2-3.2-2.2-0	5-5-8-8-8-11-11-8-8-5
6	8	0-5-8-8-11-11-8-5	0-0-0.3-1.3-2.2-1.3-0.3-0	0-5-8-8-11-11-8-5
7	11	5-5-8-8-8-11-11-8-8-8-5	0-0-0.3-0.3-1.3-1.3-2.2-2.2-3.2-2.2-0	0-5-8-8-8-8-11-11-11-11-11
8	8	0-5-8-8-11-11-8-5	0-0-0.3-1.3-2.2-1.3-0.3-0	0-5-8-8-11-11-11-11
9	12	5-5-8-8-8-11-11-11-8-8-8-5	0-0-0.3-0.3-1.3-1.3-2.2-2.2-3.2-2.2-1.3-0	0-0-0-0.3-0.3-1.3-1.3-2.2-1.3-0-0-0
10	8	0-5-8-8-11-11-8-5	0-0-0.3-1.3-2.2-1.3-0.3-0	0-0-0.3-1.3-2.2-1.3-0.3-0
11	12	0-5-8-8-8-11-11-11-11-11-11-11	0-0-0.3-0.3-1.3-1.3-2.2-2.2-3.2-2.2-1.3-0	0-0-0.3-0.3-1.3-1.3-2.2-3.2-2.2-1.3-0-0
12	8	0-0-5-8-11-11-11-11	0-0-0.3-1.3-2.2-1.3-0.3-0	0-0-0.3-1.3-2.2-1.3-0.3-0
13	10	0-0-5-8-8-11-11-11-11-11	0-0-0.3-1.3-2.2-3.2-3.2-2.2-1.3-0	0-0-0.3-1.3-2.2-3.2-3.2-2.2-1.3-0
14	8	0-0-5-5-8-11-11-11	0-0-0.3-1.3-2.2-3.2-2.2-0	0-0-0.3-1.3-2.2-3.2-2.2-0
15	8	0-0-0-5-8-11-11-11	0-0-0.3-1.3-2.2-3.2-2.2-0	0-0-0.3-1.3-2.2-3.2-2.2-0
16	6	0-0-0-0-5-11	0-0-0.3-1.3-0-0	0-0-0.3-1.3-0-0

n = sprint repetitions (for CG and ITG). Underlined numbers denote sprints with variable resistance (linearly falling from 11 to 3 kg at a running velocity that corresponds to an individual peak velocity with 11 kg resistance). All stated resistance/assistance values are averaged over the entire step cycle.

Table 3. Sprint performance and mechanical outputs within and between groups from pre- to post-training test.

Variable	Individualised training group (ITG)			Control group (CG)			Between-group difference
	Pre	*Post*	*Δ*	*Pre*	*Post*	*Δ*	*Mean, ±90%CL; effect*
0-30 m sprint (s)	4.38 ± 0.17	4.33 ± 0.09	-0.05 ± 0.11	4.40 ± 0.11	4.35 ± 0.11	-0.05 ± 0.05	-0.01, ±0.04; trivial
V0 ($m \cdot s^{-1}$)	8.1 ± 0.4	8.2 ± 0.3	0.10 ± 0.3	8.0 ± 0.3	8.2 ± 0.3	0.2 ± 0.1	0.0, ±0.1; trivial
P0 (W)	1076 ± 122	1100 ± 72	24 ± 70	1050 ± 92	1061 ± 117	11 ± 43	16, ±35; trivial
$P0 \cdot kg^{-1}$ ($W \cdot kg^{-1}$)	14.7 ± 1.5	15.0 ± 0.9	0.3 ± 0.9	14.6 ± 0.8	14.8 ± 0.9	0.2 ± 0.6	0.1, ±0.5; trivial
F0 (N)	534 ± 47	539 ± 43	5 ± 27	527 ± 41	522 ± 51	-4 ± 24	10, ±22; trivial
$F0 \cdot kg^{-1}$ ($N \cdot kg^{-1}$)	7.3 ± 0.5	7.4 ± 0.4	0.0 ± 0.4	7.3 ± 0.3	7.3 ± 0.3	0.0 ± 0.3	0.1, ±0.3; trivial
FV-profile ($slope \cdot kg^{-1}$)	0.90 ± 0.06	0.89 ± 0.07	-0.01 ± 0.05	0.91 ± 0.04	0.89 ± 0.04	-0.02 ± 0.05	0.01, ±0.04; trivial

V0 = theoretical maximal velocity, P0 = maximal horizontal power, F0 = maximal horizontal force, FV-profile = force-velocity profile.

All inferences for between-group differences were unclear.

Figure 1. Schematic overview of the study process

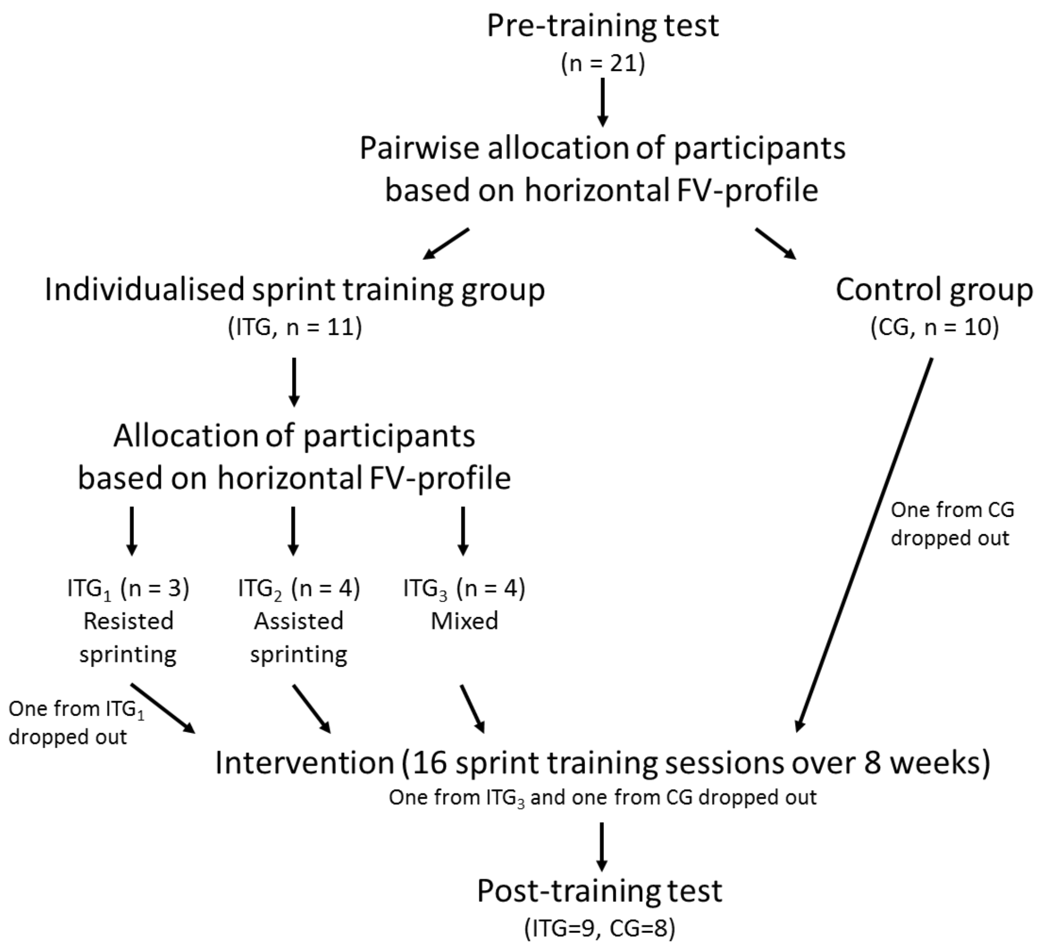

Figure 2. Individual relative changes in 30-m sprint time (Panel A) and theoretical maximal velocity (V0) (Panel B) from pre- to post-training tests. Striped bars = CG, black bars = ITG_1, grey bars = ITG_2, white bars = ITG_3. Dotted lines denote smallest worthwhile change.