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Should we individualize training based on force-velocity profiling to improve physical performance in athletes?

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The present study aimed to examine the effectiveness of an individualized training program based on force-velocity (FV) profiling on jumping, sprinting, strength, and power in athletes. Forty national level team sport athletes (20 ± 4years, 83 ± 13 kg) from ice-hockey, handball, and soccer completed a 10-week training intervention. A theoretical optimal squat jump (SJ)-FV-profile was calculated from SJ with five different loads (0, 20, 40, 60, and 80 kg). Based on their initial FV-profile, athletes were randomized to train toward, away, or irrespective (balanced training) of their initial theoretical optimal FV-profile. The training content was matched between groups in terms of set x repetitions but varied in relative loading to target the different aspects of the FV-profile. The athletes performed 10 and 30 m sprints, SJ and countermovement jump (CMJ), 1 repetition maximum (1RM) squat, and a leg-press power test before and after the intervention. There were no significant group differences for any of the performance measures. Trivial to small changes in 1RM squat (2.9%, 4.6%, and 6.5%), 10 m sprint time (1.0%, −0.9%, and −1.7%), 30 m sprint time (0.9%, −0.6%, and −0.4%), CMJ height (4.3%, 3.1%, and 5.7%), SJ height (4.8%, 3.7%, and 5.7%), and leg-press power (6.7%, 4.2%, and 2.9%) were observed in the groups training toward, away, or irrespective of their initial theoretical optimal FV-profile, respectively. Changes toward the optimal SJ-FV-profile were negatively correlated with changes in SJ height ($r = -0.49$, $p < 0.001$). Changes in SJ-power were positively related to changes in SJ-height ($r = 0.88$, $p < 0.001$) and CMJ-height ($r = 0.32$, $p = 0.044$), but unrelated to changes in 10 m ($r = -0.02$, $p = 0.921$) and 30 m sprint time ($r = -0.01$, $p = 0.974$). The results from this study do not support the efficacy of individualized training based on SJ-FV profiling.

KEYWORDS
jumping, performance, sprinting, strength training

1 | INTRODUCTION

Force-velocity (FV) profiling has received increasing attention as a tool for individual training prescriptions in athletes.[1-3] Individualizing training based on the FV-profile is founded on the concept of a theoretical optimal FV-profile.[4,5] Samozino et al.[1,2,4] showed that the difference between the theoretical optimal FV-profile and the actual measured FV-profile, termed FV Imbalance (FV_{IMB}), is both theoretically and experimentally related to jumping performance. This means that the theoretical framework can predict athletes jump height based on their FV_{IMB} and FV-maximal power (P_{max}), as well it shows that larger FV Imbalance predicts lower jump heights for a given P_{max}. Individual differences in the measured FV-profile are further hypothesized to reflect underlying neuromuscular properties, and to give valuable information for the design of training programs to improve jumping performance.[2] Recently, several studies have indeed shown that an individualized training program based on FV_{IMB}, targeting the least developed capacity of the participants, is an effective strategy to improve jumping performance.[3,6-8] Specifically, the athletes that have a "force-oriented profile" perform predominantly high-velocity exercises, whereas athletes with "velocity-oriented profiles" perform predominantly high force exercises in their training.[3,6-8] Thereby, improving jumping performance by reducing the athletes individual $FV_{IMB,}$ without changes in P_{max}.

Despite the large increases in jump performance previously observed after FV_{IMB}-individualized training,[3,6-8] a number of questions remain unanswered. Firstly, as shown by several studies, muscular power is a strong predictor for explosive type athletic performance.[9-11] It is unknown if a reduction in the squat jump (SJ)-FV_{IMB} without changes in P_{max} will be advantageous for other relevant performance measures such as countermovement jump (CMJ) and sprinting performance. A shift in the FV-profile, without a concomitant increase in P_{max}, implies that power has decreased either at high or low velocities.[3] This might be problematic if there are several desired performance outcomes or if the desired performance outcome is a complex movement task including power production at both low and high velocities (ie, in sprint running). It is therefore of interest to investigate the effectiveness of such individualized training on multiple performance outcomes that are usually assessed and of interest to coaches, such as CMJ height, maximal strength, 10, 30 m sprint and measures of power in other movements than the SJ.

Additionally, considering the research on responders and non-responders, it can be speculated whether participants that have a especially developed capacity (ie, being force or velocity oriented), possess this quality precisely because they are responding well to this mode of training.[12] An important question is therefore whether some athletes should focus their training on what they already are good at, instead of their weaknesses (ie, opposite to the FV_{IMB} minimization approach). Lastly, not all previous research have found individualized training based on FV-profiling effective, and others have questioned the measurement accuracy of the methods used to obtain the FV-profiles.[13-16] It is therefore crucial to explore the aforementioned unexplored aspects regarding the FV-training approach.

Hence, the present study aimed to (i) examine whether training toward an optimal FV-profile would induce superior increases in SJ and CMJ height, 1RM strength, 10, 30 m sprint and leg-press power compared to participants either focusing on developing their already strong capacity (ie, training further away the optimal FV-profile) or balanced training (irrespective of their initial FV-profile); (ii) explore the association between changes in SJ-power and SJ height, CMJ height, 10 and 30 m sprint time.

We hypothesized that training toward an optimal FV-profile would induce superior increases in SJ height, but not for the other performance measures, compared to the groups training away or irrespective of their FV-profile. Further, we hypothesized that changes in SJ-power would predict changes in CMJ and SJ height, as well as 10 and 30 m sprint time.

2 | MATERIALS AND METHODS

2.1 | Participants

A total of 40 male athletes participated (age 20 ± 4 years; height 184 ± 9 cm; and body mass 83 ± 13 kg). The athletes were national level team sport players in handball (n = 14), ice-hockey (n = 16), and soccer (n = 10). The handball and ice-hockey players were at elite level, and the soccer players at club level. Written informed consent was obtained before participation. The study was approved by the ethical board of the faculty of sport science and physical education at the University of Agder, and the Norwegian Centre for Research Data, and was performed in agreement with the Declaration of Helsinki.

2.2 | Study design

First, all participants were familiarized with testing procedures, followed by a pre-test, a 10-week training period, and thereafter a post-test. The pre-test was performed approximately 1 week before the first training session, whereas the post-test was performed approximately 1 week after the last training session. The athletes performed the testing sessions at the same time of the day (±2 h), at both pre-test and post-test. Each athlete underwent an incremental loading protocol during the SJ to determine their individual FV-profile, theoretical optimal profile, and FV_{IMB} according to Samozino et al.[17] The participants were allocated to the different training groups by stratified randomization based on their baseline FV_{IMB}. More specific, by sorting the participants from the largest to the smallest FV_{IMB}, each 3rd pair were randomized to either conduct heavy strength training, high-velocity strength training, or a combination of these two. The cutoff for FV deficits was set according to the FV-profile in % of optimal: <90% and >110% for force and velocity deficits, and 90%–110% was considered as well-balanced.[3] Consequently, the participants that were randomized to reduce their FV_{IMB} (ie, force deficit participants training heavy strength, velocity deficit participants training high-velocity strength, and well-balanced participants training a combination of these two) were considered as the group training toward their optimal profile. The participants randomized to train to increase their FV_{IMB} (ie, force deficit participants training high-velocity strength, velocity deficit participants training heavy strength, and well-balanced participants training either high velocity or heavy strength training) were considered as the group training away from their optimal profile. The non-optimized balanced training group consisted of the participants who got randomized to balanced heavy and velocity training and having either a force or a velocity deficit at baseline. Consequently, this allocation resulted in the three groups intended to train toward ($n = 9$), away ($n = 20$), or irrespective ($n = 11$) of their initial theoretical optimal FV-profile.

The training program consisted of 2 sessions per week for 10 weeks and are shown in Table 1 and supplementary Tables S1-S3. The sessions were separated by a minimum of 48 h. The training program was inspired by previous research on individualized training based on FV_{IMB}.[3] The force program consisted of mostly exercises with high loads whereas the exercises in the velocity program consisted of exercises with low loads and high velocity. The balanced heavy and velocity program entailed a combination of both types of exercises. All exercises were performed with maximal intentional velocity. Additionally, the sessions were supervised by the research team to ensure proper execution of the programs. The intensity of the heavy exercises was controlled using reps in reserve with rep ranges that corresponded to relative intensity of 70% 1RM and higher.[18] The exercises with lower loads and higher velocities consisted of various jumping exercises with body mass, light loads or unloading using rubber bands.

The athletes got verbal feedback during the sessions from the research assistants and coaches. Additionally, on a select number of sessions (4–5 sessions) the athletes also got objective feedback on some of the explosive exercises using linear transducers.

The study is based on data collected from multiple regional Olympic training and testing centers, where the same equipment and test leaders were constant at each testing center.

2.3 | Testing procedures

All participants were instructed to prepare for the test days as they would for a regular competition in terms of nutrition, hydration, and sleep as well as refrain from

TABLE 1 Training content for the three different training programs

	Exercises	Rep scheme	Load	Weekly sets	Focus	% of sets
Force program	Deadlift, Hip-thrust, Front squat, Squat, Stiff-leg dead lift, Bulgarian split squat, Trapbar, Calf-raises	3–10	1–6 RIR	14	Strength	82%
	Trapbar	5	50–70% 1RM	4	Power	17%
Balanced program	Deadlift, Front squat, Bulgarian split squat, Hip-thrust, Deadlift	3–10	1–6 RIR	13	Strength	46%
	Box jumps, Stair jumps, Single leg stair jumps, Squat jump w/rubber band, Stair jumps, Trapbar jumps	5–10	Negative-50% 1RM	15	Power	54%
Velocity program	Half Squat, Hip-thrust	3–8	1–2 RIR	6	Strength	21%
	Squat jumps, Trapbar jumps, Step up, Squat jump w/rubber band, countermovement jumps, box jumps, Clean Pull, Stair jumps, Single leg stair jumps	5–10	Negative-50% 1RM	22	Power	79%

Abbreviations: RIR, Reps in reserve; 1RM, One repetition maximum; reps, repetitions; Set, training sets.

strenuous exercise 48 h before testing. Testing was performed indoors, and the participants were instructed to use identical footwear and clothing on each test day. Body mass was measured wearing training clothes and shoes. A standardized ~10-min warm-up procedure before testing, consisting of jogging, local muscle warm-up (hamstring and hip mobility), running drills (eg, high knees, skipping, butt-kicks, and explosive lunges), and body mass jumps were performed. Breaks (5–10 min) were given between the different tests to ensure proper recovery. The testing protocol consisted of a series of SJ, CMJ, 30-m sprints, 1RM back-squat, and a leg-press test with incremental loads and in the corresponding order. Ultrasound measurements were performed on either a separate day (during familiarization) or before the physical tests for some of the participants. Reliability of the FV and performance measures has been reported previously.[15]

The SJs were performed with an incremental loading protocol consisting of 0.1, 20, 40, 60, and 80 kg. A broomstick was used as the 0.1 kg load. Two valid trials were registered with each load. Countermovement was verbally forbidden for the SJ and checked visually with the direct force output from the force plate. The recovery time between each attempt was 2–3 min. For the SJ, participants were asked to maintain their individual starting position for about 2 s and then apply force as fast as possible and jump for maximum height before landing with their ankles in an extended position. The starting position for both SJ and CMJ was standardized to the athletes' self-selected starting position and kept constant for all jumps and testing sessions using a rubber band beneath the thighs and visually confirmed by the test leaders. If these requirements were not met, the trial was repeated. The CMJ test was performed with only body mass in the same procedure as SJ, without a pause in the bottom position. All vertical jumps were measured with a force plate (Musclelab; Ergotest AS), obtained from the flight time measures. Rate of force development (RFD) was obtained as the peak derivative within 30 ms from the unloaded SJ force-time measure.[19] The force signal was sampled at 200 Hz and up sampled to 1000 Hz by spline integration using the integrated software. The leg press was performed using a Keiser A300 horizontal leg-press dynamometer (Keiser Sport), and the FV parameters were derived from its software with a 10-repetition FV test with incremental loads based on each participant´s 1RM load (acquired at the familiarization session). The seating position was adjusted for each participant aiming at a vertical femur, equivalent to an 80-90° knee angle, and feet placed with heals at the bottom end of the foot pedal. Participants were asked to extend both legs with maximum effort during the entire 10-repetition FV test. The test started with two practice attempts at the lightest load, corresponding to ~15% of 1RM. Thereafter, the load was gradually increased with fixed steps (~20–30 kgf) for each attempt until reaching the ~1RM load and a total of 10 attempts across the FV curve (15%–100% of 1RM). The rest period between attempts got longer as the load increased. The rest period between attempts was ~10–20 s for the initial five loads, with 20–40 s for the last four rest periods. Due to the pneumatic semi-isotonic resistance, maximal effort does not cause ballistic action, and the entire push-off was performed with maximal intentional velocity. The leg press was performed as a concentric only action without countermovement, as the pedals are resting in their predetermined position prior to each repetition. The eccentric phase was submaximal and not registered. Power from the leg press was then derived from the theoretical maximal power from the FV-profile. For the 30-m sprint, the participants performed 2–4 maximal sprints with 3–5 min of rest between each trial. The timing started when the front foot left the ground and was measured with 5-m intervals using wireless timing gates (Musclelab, Ergotest innovation AS). The trial with the best 30 m time was used for further analysis. The 1RM back-squat was performed using a standardized protocol with incremental loads until 1RM was obtained. Squat depth was standardized to thighs parallel to the ground (top surface of the legs at the hip joint is lower than the top of the knees) and was confirmed visually by the test leaders. The standardized squat depth was kept constant at all testing time points. The increase in load was individual, but constant for each testing session. The minimum increase in load was 2.5 kg, and breaks between attempts were 2–3 min. The heaviest load successfully lifted with the standardized depth was recorded as the participant's 1RM.

2.4 | Data analysis

Average force and average velocity were calculated using two equations considering only simple input variables: body mass, jump height, and push-off distance.[20] A linear regression was fitted to the average force and velocity measurements to calculate the individual FV parameters. F_0 and V_0 are the intercept of the linear regression for the corresponding force and velocity axis. P_{max} is calculated as $F_0 \cdot V_0/4$. The FV-profile in % of optimal and FV_{IMB} was calculated according to Samozino's method.[2] The vertical push-off distance was determined as previously proposed,[21] corresponding to the difference between the extended lower limb length with maximal plantar flexion and the crouch starting position of the jump.

2.5 | Statistical analyses

The sample size was calculated using G*power 3.1.9.2. With a power of 80% and an alpha of 5%, we needed a minimum of 34 participants to detect a significant group difference with an effect size (Cohen's f) of 0.5.[3] One-way ANCOVA was used to analyze between-group differences, with baseline measures as the covariate. Analyses for within group pre-post changes were conducted using a paired sample *t* test. Pearson product-moment correlation coefficient (Pearson *r*) was used to determine the relationships between the FV-variables and the performance measures. Multiple regression analyses were performed to determine how much of the variance in SJ height could be explained by the changes in P_{max} and FV_{IMB}. Standardized effect size (ES) was calculated from the pre-post changes divided by the pooled pre-SD (from all participants) and interpreted categorically as (< 0.20 trivial; 0.20–0.60 small; 0.60–1.20 moderate; 1.20–2.00 large; and >2 extremely large).[22] Means with corresponding variance are presented with SD unless stated otherwise. Confidence limits for all analyses were set at 95% and significance level at <0.05. All statistical analyses were performed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA) and IBM statistical package (version 25; SPSS Inc).

3 | RESULTS

All SJ-FV-profiles showed strong linearity at all testing time points ($R^2 = 0.97 \pm 0.01$). The participants completed on average 15 ± 3 out of the 20 scheduled training sessions (75%), with no differences between the groups in terms of attendance (Toward: 14 ± 4, Away: 15 ± 3, and irrespective: 15 ± 2 $p > 0.05$). At baseline, five participants were categorized with a velocity deficit, 20 with a force deficit and 15 as well-balanced. There were no significant differences in FV_{IMB} reduction between the groups training toward (−3 ± 21%), away (−6 ± 15%), or irrespective of their FV-profile (−1 ± 16%) ($p > 0.05$) after the training intervention (Figure 1). Results for the SJ-FV parameters are presented in Table 2, divided by each deficit and training program. There were no significant group differences for changes in any of the performance measures ($F = 0.14$–2.73, $n^2 = 0.01$–0.13, $p = 0.08$–0.87; Figure 2). Results for the post-hoc analysis from the main analysis are presented in Table 3.

Changes in SJ-power were significantly related to changes in SJ-height ($r = 0.88$, $p < 0.001$) and CMJ-height ($r = 0.32$, $p = 0.044$), but unrelated to changes in 10 m ($r = -0.02$, $p = 0.921$) and 30 m sprint time ($r = -0.01$, $p = 0.974$). Further, changes toward the optimal SJ-FV-profile were negatively correlated with changes in SJ height ($r = -0.49$, $p < 0.001$; Figure 3). Multiple linear regressions showed that 88% ($p < 0.001$) of the variance for the change score in SJ height was explained by changes in SJ-P_{max} ($B = 0.81$, $p < 0.001$) FV_{IMB} ($B = 0.13$, $p = 0.004$), body mass ($B = -1.31$, $p < 0.001$), and SJ baseline performance ($B = -0.004$, $p = 0.017$).

Table 4 shows sub-analyses results for each training program (irrespective of FV-training groups) for the performance measures. Participants training the heavy strength

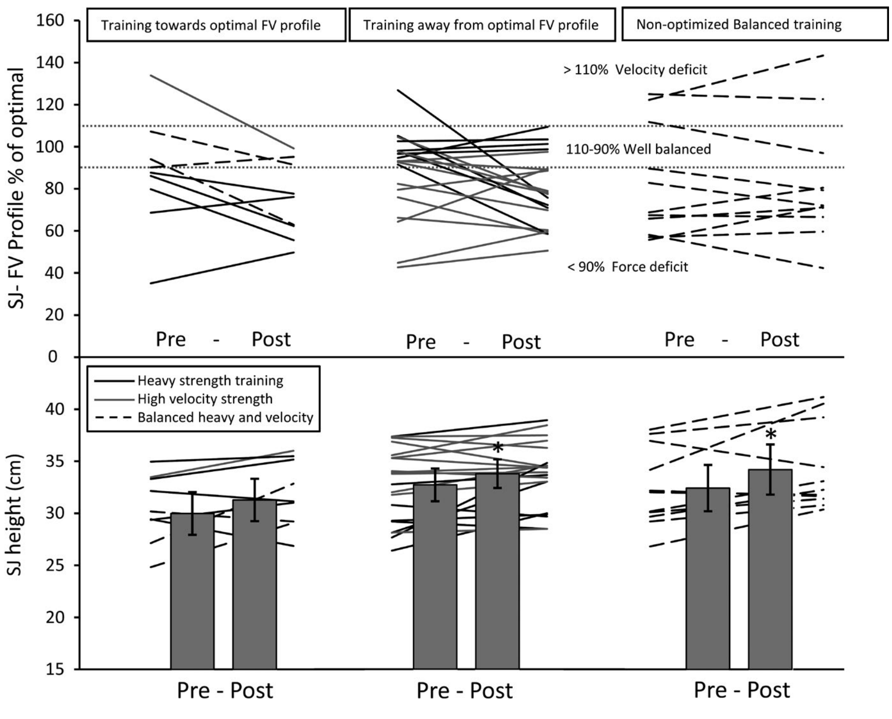

FIGURE 1 The upper panel show individual pre-post changes in the force-velocity (FV) profile expressed as % of optimal between the group training toward, away or irrespective of the FV-profile. The lower panel show individual and pre-post changes in squat jump (SJ) height. Lines represent individual changes in SJ-FV optimal profile and SJ-height. Black lines represent participants training heavy strength, gray lines represent participants training high-velocity strength, and broken lines represent participants training balanced heavy and high-velocity strength. Error bars represent 95% confidence intervals. *$p < 0.05$ pre-post changes

program increased leg press F_0 (5.9 ± 3.7%, $p = 0.01$) and P_{max} (7.7 ± 4.3%, $p = 0.005$), while participants training the high-velocity program did not increase V_0 (2.8 ± 3.0%, $p = 0.09$), and participants training the balanced heavy and velocity program increased P_{max} (3.8 ± 2.6%. $p = 0.01$) but not F_0 (2.3 ± 2.1%, $p = 0.09$) and V_0 (1.6 ± 1.7%, $p = 0.08$).

4 | DISCUSSION

The main finding of the present study was that training toward an optimal SJ-FV-profile was just as effective for improving SJ and CMJ height, 1RM strength, 10 and 30 m sprints, and leg-press power, compared to participants training away

TABLE 2 Results for the SJ-Force-Velocity variables from all subgroups

				Pre	Post	Change
	Deficit	**Training programs**	***n*=**	**Mean ± SD**	**Mean ± SD**	**Δ% ± SD**
Optimal FV (%)	Force	Strength	5	71 ± 22	64 ± 12	−3.4 ± 30.1
		Balanced	8	68 ± 12	68 ± 12	0.6 ± 17.7
		Velocity	7	65 ± 16	68 ± 15	7.8 ± 24.2
	Velocity	Strength	1	127 ± na	76 ± na	−40.3 ± na
		Balanced	3	120 ± 7	121 ± 23	0.7 ± 15.4
		Velocity	1	134 ± na	99 ± na	−25.9 ± na
	No-deficit	Strength	6	97 ± 4	91 ± 20	−6.7 ± 19.8
		Balanced	3	97 ± 9	83 ± 18	−14.1 ± 19.4
		Velocity	6	98 ± 6	82 ± 10	−15.4 ± 13.8
P_{max} (W/kg)	Force	Strength	5	24.9 ± 4.3	24.7 ± 2.2	1.0 ± 13.4
		Balanced	8	25.3 ± 3.1	27.2 ± 3.3	7.8 ± 7.5
		Velocity	7	25.9 ± 4.2	25.4 ± 4.7	−2.0 ± 8.0
	Velocity	Strength	1	24.7 ± na	26.3 ± na	6.4 ± na
		Balanced	3	20.2 ± 2.0	20.8 ± 0.6	3.3 ± 7.2
		Velocity	1	22.2 ± na	23.4 ± na	5.6 ± na
	No-deficit	Strength	6	21.2 ± 2.2	23.0 ± 2.7	9.0 ± 14.3
		Balanced	3	20.0 ± 1.6	23.1 ± 2.1	15.8 ± 12.6
		Velocity	6	21.8 ± 3.1	23.3 ± 2.9	6.8 ± 4.8
F_0 (N/kg)	Force	Strength	5	31.4 ± 2.7	30.2 ± 1.5	−3.3 ± 8.2
		Balanced	8	31.5 ± 2.2	32.4 ± 3.3	2.8 ± 7.1
		Velocity	7	30.4 ± 3.5	30.8 ± 2.8	2.0 ± 8.1
	Velocity	Strength	1	40.7 ± na	32.3 ± na	−20.8 ± na
		Balanced	3	35.5 ± 2.4	36.1 ± 3.7	1.5 ± 6.7
		Velocity	1	39.6 ± na	34.9 ± na	−11.8 ± na
	No-deficit	Strength	6	34.4 ± 3.2	34.2 ± 3.8	−0.7 ± 5.6
		Balanced	3	33.9 ± 0.8	33.3 ± 2.8	−1.8 ± 6.6
		Velocity	6	33.7 ± 3.5	31.6 ± 2.9	−5.8 ± 6.3
V_0 (m/s)	Force	Strength	5	3.2 ± 0.8	3.3 ± 0.3	5.8 ± 21.5
		Balanced	8	3.2 ± 0.3	3.4 ± 0.4	5.8 ± 10.9
		Velocity	7	3.5 ± 0.7	3.3 ± 0.5	−3.0 ± 15.5
	Velocity	Strength	1	2.4 ± na	3.3 ± na	35.3 ± na
		Balanced	3	2.3 ± 0.1	2.3 ± 0.2	2.0 ± 11.7
		Velocity	1	2.2 ± na	2.7 ± na	19.8 ± na
	No-deficit	Strength	6	2.5 ± 0.0	2.7 ± 0.5	10.8 ± 20.5
		Balanced	3	2.4 ± 0.2	2.8 ± 0.5	19.2 ± 21.5
		Velocity	6	2.6 ± 0.2	2.9 ± 0.2	14.1 ± 11.7

(Continues)

TABLE 2 (Continued)

	Deficit	Training programs	n=	Pre Mean ± SD	Post Mean ± SD	Change Δ% ± SD
SJ heigth (cm)	Force	Strength	5	31.8 ± 2.4	31.9 ± 3.5	0.2 ± 6.2
		Balanced	8	33.2 ± 3.9	35.4 ± 4.3	6.5 ± 7.1
		Velocity	7	34.4 ± 3.0	34.1 ± 2.7	−0.9 ± 3.7
	Velocity	Strength	1	37.4 ± na	39.0 ± na	4.2 ± na
		Balanced	3	30.3 ± 3.1	31.3 ± 0.8	3.6 ± 8.4
		Velocity	1	33.5 ± na	36.0 ± na	7.6 ± na
	No-deficit	Strength	6	29.6 ± 1.9	31.6 ± 2.6	7.0 ± 11.9
		Balanced	3	27.4 ± 2.7	30.4 ± 2.1	11.7 ± 13.0
		Velocity	6	32.8 ± 3.8	34.6 ± 3.1	5.7 ± 5.2

Note: Mean values are presented with standard deviations (SD). Δ% equals percent change from pre-post ES, Effect size; W, watts; N, Newtons; m/s, Meters per seconds; Cm, Centimeters; Kg, Kilograms. The cutoff for FV deficits was set according to the FV-profile in % of optimal: <90% and >110% for force and velocity deficits, and 90%–110% was considered as No-deficit/well-balanced. Strength program = mostly exercises with low velocity and high loads. Velocity program = mostly exercises with low loads and high velocity. Balanced program = combination of both types of exercises.

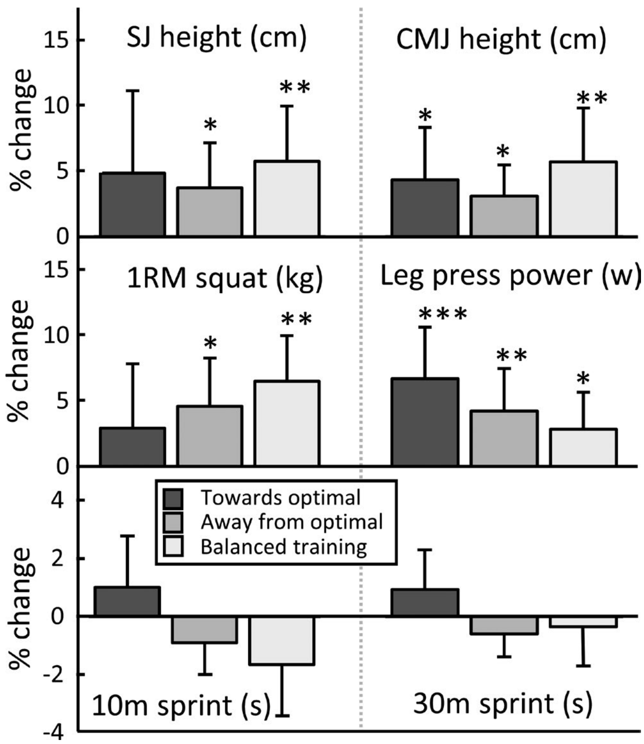

FIGURE 2 Percent change from pre to post in the performance measures in the three groups training toward, away or irrespective (balanced training) of their initial theoretical optimal FV-profile. SJ, Squat jump; CMJ, Countermovement jump; 1RM, one repetition maximum. Kg, Kilograms; S, seconds; Cm, centimeters; and w, watts. Error bars represent 95% confidence intervals. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

or irrespective of their initial FV-profiles. Additionally, increasing SJ- P_{max} was positively associated with increases in both SJ and CMJ height but not 10 and 30 m sprint times.

To the authors' knowledge, four studies have previously evaluated the effectiveness in individualized training based on FV_{IMB},[3,6-8] which generally have shown small to large effect sizes ranging from 0.37 to 1.45. Contrarily to previous studies, we only observed small improvements in jump height (ES = 0.30–0.50) and no clear differences between groups. The small changes observed could be due the lower training attendance in the present study, where the participants completed ~15 sessions in the 10-week period (compared to 18 sessions[3]). The discrepancy in training effect between the present and previous studies might also be attributed to differences in training status of the participants. Nevertheless, two of the studies were conducted in trained athletes (rugby and soccer), with similar baseline SJ height (33 and 31 cm) to the present study (32 cm).[3,6] Only the study by Simpson et al.,[7] where they included highly trained rugby players (SJ height = 40 cm), showed comparable increases in SJ height (ES = 0.37) as the present study. We should, however, also consider that jump heights were measured by different devices (force plate vs iPhone) in these studies, which could have affected the absolute values.[3,6-8] Furthermore, only two of the studies included a control group performing a non-optimized training regimen for comparison.[3,6-8]

Intriguingly, we were not able to either reduce or increase the FV_{IMB} of the groups training toward or away from their optimal FV-profile. The lack of changes in FV_{IMB} might be due to the large measurement variation in the slope of the FV relationship obtained from vertical jumping (±20%[15]), which is used for the calculation of FV_{IMB}.[2] It is therefore likely that many real changes in FV_{IMB} were smaller than the detection threshold of testing procedure. Nevertheless, despite large measurement variation in FV_{IMB}, the participants were likely allocated

TABLE 3 Results from the main groups, training towards, away, or irrespective of their initial theoretical optimal FV-profile

		Pre	Post	Change		Between group difference (ANCOVA)			
Variables & groups	***n*=**	**Mean ± SD**	**Mean ± SD**	**Δ% ± SD**	**ES ± 95% CI**	**Group**	**Mean**	**95% CI [LB, UB]**	***p*-Value**
1RM squat (kg)									
TOW	9	125.6 ± 19.4	128.6 ± 18.2	2.9 ± 7.5	0.13 ± 1.00	TOW VS AWA	−1.4	[−10.2, 7.3]	0.97
AW	20	123.3 ± 22.8	128.0 ± 21.0	4.6 ± 8.4*	0.20 ± 0.64	TOW VS BAL	−6.4	[−16.3, 3.5]	0.31
BAL	11	134.3 ± 26.8	142.7 ± 27.1	6.5 ± 5.9**	0.36 ± 0.89	BAL VS AWA	−4.9	[−13.3, 3.4]	0.38
10 m sprint (s)									
TOW	9	1.72 ± 0.12	1.74 ± 0.14	1.0 ± 2.7	0.15 ± 1.00	TOW VS AWA	0.04	[−0.011, 0.083]	0.18
AW	20	1.70 ± 0.11	1.69 ± 0.10	−0.9 ± 2.5	−0.14 ± 0.64	TOW VS BAL	0.05	[−0.006, 0.101]	0.09#
BAL	11	1.67 ± 0.14	1.64 ± 0.15	−1.7 ± 3.0	−0.22 ± 0.89	BAL VS AWA	0.01	[−0.033, 0.056]	0.88
30 m sprint (s)									
TOW	9	4.25 ± 0.24	4.29 ± 0.28	0.9 ± 2.1	0.22 ± 1.00	TOW VS AWA	0.07	[−0.021, 0.154]	0.18
AW	20	4.20 ± 0.17	4.17 ± 0.15	−0.6 ± 1.8	−0.14 ± 0.64	TOW VS BAL	0.05	[−0.047, 0.153]	0.48
BAL	11	4.13 ± 0.18	4.11 ± 0.24	−0.4 ± 2.3	−0.07 ± 0.89	BAL VS AWA	−0.01	[−0.097, 0.068]	0.96
SJ height (cm)									
TOW	9	30.5 ± 3.3	31.9 ± 3.2	4.8 ± 9.7	0.37 ± 1.00	TOW VS AWA	−0.3	[−2.6, 2]	0.98
AW	20	32.7 ± 3.6	33.7 ± 3.1	3.7 ± 7.8*	0.30 ± 0.64	TOW VS BAL	−1.0	[−3.5, 1.6]	0.73
BAL	11	32.5 ± 3.8	34.2 ± 4.1	5.7 ± 7.1*	0.50 ± 0.89	BAL VS AWA	−0.7	[−2.8, 1.4]	0.81
CMJ height (cm)									
TOW	9	35.6 ± 3.7	37.0 ± 3.9	4.3 ± 6.2	0.38 ± 1.00	TOW VS AWA	0.1	[−2.2, 2.3]	1.00
AW	20	38.0 ± 3.1	39.1 ± 2.9	3.1 ± 5.4*	0.29 ± 0.64	TOW VS BAL	−0.8	[−3.3, 1.7]	0.80
BAL	11	37.5 ± 5.0	39.5 ± 5.6	5.7 ± 6.9*	0.54 ± 0.89	BAL VS AWA	−0.9	[−2.9, 1.1]	0.62
Leg-press power (W)									
TOW	9	1471 ± 295	1559 ± 261	6.7 ± 6.0**	0.24 ± 1.00	TOW VS AWA	20	[−81.6, 120.7]	0.95
AW	20	1606 ± 354	1666 ± 350	4.2 ± 7.4*	0.17 ± 0.64	TOW VS BAL	22	[−95.2, 139.2]	0.95
BAL	11	1778 ± 425	1826 ± 428	2.9 ± 4.8	0.13 ± 0.89	BAL VS AWA	3	[−93, 98]	1.00
SJ- RFDmax (N/s)									
TOW	9	8400 ± 3279	6992 ± 1687	−9.3 ± 30.9	−0.49 ± 1.00	TOW VS AWA	−168	[−2655, 2319]	1.00
AW	20	7796 ± 2821	6858 ± 2785	−7.3 ± 34.1	−0.33 ± 0.64	TOW VS BAL	−1394	[−4194, 1406]	0.53
BAL	10	8014 ± 2546	8611 ± 2790	8.4 ± 21.7	0.21 ± 0.94	BAL VS AWA	−1226	[−3551, 1098]	0.48

(Continues)

TABLE 3 (Continued)

Variables & groups	n=	Pre	Post	Change		Between group difference (ANCOVA)			
		Mean ± SD	Mean ± SD	Δ% ± SD	ES ± 95% CI	Group	Mean	95% CI [LB, UB]	*p*-Value
Body mass (kg)									
TOW	9	77.9 ± 6.4	78.8 ± 7.2	1.1 ± 1.9	0.07 ± 1.00	TOW VS AWA	0.8	[−1, 2.5]	0.63
AW	20	83.3 ± 14.0	83.1 ± 13.1	−0.1 ± 2.1	−0.01 ± 0.64	TOW VS BAL	0.0	[−1.9, 2]	1.00
BAL	11	86.6 ± 13.5	86.9 ± 12.5	0.6 ± 1.9	0.03 ± 0.89	BAL VS AWA	−0.7	[−2.3, 0.9]	0.60

Note: Mean values are presented with standard deviations (SD). Δ%: percent change from pre-post. *p*-Values for between group differences are obtained from the ANCOVA, post hoc comparison analysis, whereas within group analysis are from paired sample *t* test. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. †Baseline difference at $p < 0.05$.

Abbreviations: TOW, group training towards optimal force-velocity (FV) profile; AW, group training away from optimal FV-profile; BAL, group training balanced, irrespective of FV-profile; kg, kilogram; s, seconds; cm, centimeters; W, Watts; N/s, Newtons per seconds; mm, millimeters; deg°, Degrees; RFD, Rate of force development.

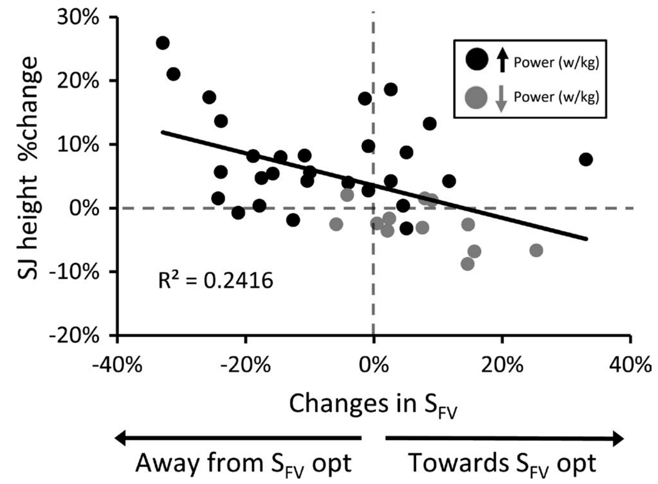

FIGURE 3 The association between changes in squat jump (SJ) height and changes either toward or away from the optimal (opt) force-velocity (FV) profile. The black dots represent increase (>0% change) in SJ relative theoretical maximal power (P_{max}/kg), and the gray dots represent decrease (<0% change) in relative P_{max}. S_{FV}, slope of the force-velocity profile

to their correct groups as evidenced by the larger between vs. within variation (Table 2). Practically speaking, only 11 out of the 40 participants changed "deficit" from pre to post (Figure 1), suggesting that majority of the participants were allocated to the correct group. Further, we would argue that our results indicate that the participants changed their FV-characteristics in the intended direction. This change is not evident in the measures from the SJ-FV-profile, probably due to the measurement variation.[15] However, the results from the less variable leg-press measures (±5%[15]) show that the heavy strength program increased F_0 while the balanced program increased P_{max}. Based on this we could expect similar results as the previous studies.[3,6-8] Moreover, the "optimized" group (training toward optimal profile) showed similar magnitude of increase in jump height (although not statistical significant) as the study by Simpson et al.[7] (ES = 0.37 vs 0.37). As discussed, the effect on jump height might be small compared to other studies due to training status (elite athletes) and a relatively low number of training sessions. Interestingly, both the "away" group and non-optimized balanced group also increased jump height (ES = 0.30 and 0.50, $p < 0.05$, respectively). Contrarily, in the studies of Jiménez-Reyes et al.[3] and Simpson et al.,[7] the balanced ("non-optimized") group did not increase jump height (ES = 0.14 and 0.12). The lack of increase in the "non-optimized" group was attributed to large individual variations in training response due to not targeting the individuals FV_{IMB}.[3] This is highly intriguing, as most previous strength and power training interventions are conducted irrespective of differences in FV-profiles and show generally small to large effect sizes in jump height and power following various resistance

TABLE 4 Results from the sub-groups based on only training programs, irrespective of their initial theoretical optimal FV-profile

		Pre	Post	Change		Between group difference (ANCOVA)			
Variables & groups	n=	Mean ± SD	Mean ± SD	Δ% ± SD	ES ± 95% CI	Group	Mean	95% CI [LB, UB]	p-Value
1RM squat (kg)									
Str	12	125.0 ± 26.2	131.7 ± 24.2	6.3 ± 10.2	0.28 ± 0.85	Str vs Bal	4.1	[−4.5, 12.8]	0.56
Bal	14	131.6 ± 24.1	138.6 ± 25.3	5.4 ± 5.7**	0.30 ± 0.78	Str vs Vel	−1.0	[−9.7, 7.7]	0.99
Vel	14	123.6 ± 20.2	126.3 ± 18.1	2.8 ± 6.5	0.11 ± 0.78	Vel vs Bal	−5.2	[−13.5, 3.2]	0.35
10 m sprint (s)									
Str	12	1.70 ± 0.11	1.70 ± 0.12	−0.4 ± 2.5	−0.05 ± 0.85	Str vs Bal	0.01	[−0.04, 0.06]	0.97
Bal	14	1.69 ± 0.14	1.68 ± 0.16	−0.8 ± 3.3	−0.11 ± 0.78	Str vs Vel	0.01	[−0.04, 0.06]	0.98
Vel	14	1.69 ± 0.12	1.68 ± 0.12	−0.8 ± 2.6	−0.11 ± 0.78	Vel vs Bal	0.00	[−0.05, 0.05]	1.00
30 m sprint (s)									
Str	12	4.18 ± 0.17	4.17 ± 0.19	−0.2 ± 1.7	−0.05 ± 0.85	Str vs Bal	0.01	[−0.08, 0.1]	0.98
Bal	14	4.19 ± 0.22	4.19 ± 0.27	0.1 ± 2.5	0.04 ± 0.78	Str vs Vel	−0.02	[−0.11, 0.07]	0.95
Vel	14	4.20 ± 0.18	4.18 ± 0.17	−0.5 ± 2.0	−0.11 ± 0.78	Vel vs Bal	−0.03	[−0.11, 0.06]	0.78
SJ height (cm)									
Str	12	31.2 ± 3.0	32.4 ± 3.5	3.9 ± 9.5	0.33 ± 0.85	Str vs Bal	−0.2	[−2.5, 2.1]	0.99
Bal	14	31.4 ± 4.1	33.4 ± 4.0	7.0 ± 8.5**	0.59 ± 0.78	Str vs Vel	−0.9	[−3.1, 1.2]	0.64
Vel	14	33.7 ± 3.2	34.4 ± 2.7	2.6 ± 5.4	0.22 ± 0.78	Vel vs Bal	−0.7	[−2.9, 1.4]	0.78
CMJ height (cm)									
Str	12	37.3 ± 3.0	38.1 ± 3.4	2.3 ± 6.5	0.21 ± 0.85	Str vs Bal	−0.6	[−2.7, 1.5]	0.87
Bal	14	36.7 ± 5.1	38.8 ± 5.3	6.0 ± 6.6**	0.53 ± 0.78	Str vs Vel	−1.2	[−3.3, 0.9]	0.42
Vel	14	38.0 ± 3.3	39.3 ± 3.1	3.7 ± 4.6**	0.34 ± 0.78	Vel vs Bal	−0.6	[−2.7, 1.4]	0.84
Leg-press power (W)									
Str	12	1489 ± 291	1594 ± 289	7.7 ± 7.7**	0.29 ± 0.85	Str vs Bal	63	[−35.2, 160.2]	0.31
Bal	14	1660 ± 442	1717 ± 435	3.8 ± 4.9*	0.15 ± 0.78	Str vs Vel	41	[−55.5, 138.1]	0.65
Vel	14	1701 ± 347	1735 ± 345	2.3 ± 6.1	0.09 ± 0.78	Vel vs Bal	−21	[−112.6, 70.2]	0.92
SJ- RFDmax (N/s)									
Str	12	8254 ± 3205	6764 ± 1679	−9.7 ± 32.2	−0.52 ± 0.85	Str vs Bal	−123	[−2497, 2250]	1.00
Bal	13	7670 ± 2311	8460 ± 2554	11.4 ± 21.3	0.28 ± 0.81	Str vs Vel	−1682	[−4082, 719]	0.24
Vel	14	8064 ± 3019	6789 ± 3140	−12.6 ± 33.6	−0.45 ± 0.78	Vel vs Bal	−1558	[−3858, 742]	0.27
Body mass (kg)									
Str	12	80.2 ± 8.1	81.3 ± 9.3	1.3 ± 2.0*	0.09 ± 0.85	Str vs Bal	1.7	[0.2, 3.3]	0.03*
Bal	14	83.4 ± 13.5	83.8 ± 12.7	0.7 ± 1.7	0.03 ± 0.78	Str vs Vel	0.6	[−1, 2.1]	0.76
Vel	14	85.0 ± 15.1	84.1 ± 13.7	−0.8 ± 1.9	−0.06 ± 0.78	Vel vs Bal	−1.2	[−2.6, 0.3]	0.16

Note: Mean values are presented with standard deviations (SD). Δ%:percent change from pre-post. *p*-Values for between group differences are obtained from the ANCOVA, post hoc comparison analysis, whereas within group analysis are from paired sample *t*-test. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$. †Baseline difference at $p < 0.05$.

Abbreviations: Str, participants training the heavy strength training program; Vel, participants training low-load high-velocity training; Bal, participants training combination of strength and velocity. Kg, kilogram; s, seconds; cm, centimeters; W, Watts; N/s, Newtons per seconds; mm, millimeters; deg°,**Degrees; RFD, Rate of force development.

and power training regiments.[23-27] It is unclear whether the participants and coaches in the "optimized" and "non-optimized" groups in the studies of Jiménez-Reyes et al. and Simpson et al were aware of their group allocation, which could play an important role for the effectiveness of the training due to a potential nocebo and placebo effect.[28]

Contrary to our hypothesis, we did not observe any difference in SJ height between the groups training toward, away or irrespective of their optimal profile. Nevertheless, a reduction in FV_{IMB} was positively associated with an increase in SJ height when accounting for changes in P_{max}. These results are in accordance with previous research and indicate that reducing FV_{IMB} might be beneficial for increasing SJ height.[3] However, the influence of FV_{IMB} on changes in SJ height was weak ($B = 0.14$) compared to P_{max} ($B = 0.84$). Additionally, a reduction in FV_{IMB} without accounting for changes in P_{max}, was moderately associated with decreases in SJ height (Figure 3), which illustrates the importance of changing P_{max} over FV_{IMB}.

Furthermore, the changes in FV_{IMB} were unrelated to changes in CMJ and sprinting performance, whereas changes in P_{max} were related to changes in CMJ performance. Changes in FV_{IMB} and the slope of the FV-profile, without a concomitant increase in P_{max}, imply that power decrease either at high or at low velocities. Complex sporting movements require power production at a variety of joint angles and contraction speeds, where it probably would be more advantageous with a right shift of the entire FV curve and improve power at both high and low velocities. Moreover, the concept of FV_{IMB} and the existence of an optimal FV-profile assume that individual variations in the FV parameters reflect underlying physiological differences.[2] The first study that experimentally tested the existence of an optimal FV-profile argued that the force dominant participants (rugby players) and velocity dominant participants (soccer players) exhibited their corresponding FV-profile due to their sporting training history.[2] However, a recent investigation of loaded CMJ's has shown that 68% of the variation in the load that maximized power (ie, directly related to the slope of the FV-profile) can be explained by individual variation in strength and anthropometric measures, and was unrelated to training history.[29] Similarly, the study by Jiménez-Reyes, Samozino, Brughelli, and Morin[3] showed clear anthropometric differences in the participants classified with either force deficit (body mass 72.7 ± 8.3 kg, body height 1.78 ± 0.06 m) or velocity deficit (body mass 80.6 ± 9.6 kg, body height 1.81 ± 0.04 m); interestingly, where changes in body mass were not reported. Although several studies have shown the influence of specific training on the FV-profile,[30-34] it is of great relevance to elucidate how much of differences in the slope of FV-profiles obtained from multi-joint movements (thereby FV_{IMB}) that reflect differences in intrinsic physiological characteristics.

Regarding the training effects of the specific programs, it appears that the heavy strength and balanced training programs induced the expected adaptations, that is, improved in 1RM and leg-press power, consistent with the literature.[32,33,35-37] However, the high-velocity program had no clear changes in RFDmax or V_0 in the leg press. The exercises in the velocity program consisted of light loads and high-velocity actions with comparable training volume as previous investigations.[3] However, it can be speculated whether the participants were accustomed to high-velocity movements from their respective sports, and thereby did not receiving sufficient stimuli for velocity-related adaptations.[38] Previous studies that have compared light load training with heavy or combined load training generally show larger adaptations in the force part vs the velocity part of the FV curve.[30-34,38] Hence, it is possible that heavy loading induces a more potent stimulus, and/or there are larger potential for adaptation in force-generating capacities at slow velocities compared to high velocities.[38] Interestingly and consistent with the present study, participants training with a combination of heavy and light loads tend to show greater increases in power across the entire FV curve compared to training with either heavy or light loads.[30-34]

The present study included a large sample of highly trained athletes from handball, soccer, and ice-hockey. The training included experienced coaches with close follow-up during the sessions. Although the study was conducted as a multicenter study, the same test leaders and equipment were used across the different centers. Unfortunately, most participants were categorized as velocity dominated, or well-balanced which caused an uneven allocation between groups. Additionally, the stratified randomization to three different training programs led to an over-allocation to the AW group. This uneven allocation led to smaller statistical power compared to what was calculated in one of the groups. Consequently, comparisons across smaller subgroups such as different training programs within different deficits are not possible. Additionality, due to the lower statistical power, we used three categories for FV deficits, compared to 5 groups used in previous investigations.[3,6-8]

Training toward an optimal SJ-FV-profile did not show favorable effects in SJ height, CMJ height, 10 and 30 m sprint time, 1RM strength or leg-press power compared to participants either training away from their optimal profile or balanced training irrespective of their initial FV-profile. Increasing SJ- P_{max} was positively associated with increases in both SJ and CMJ height but not with 10 and 30 m sprint times. The results from this study do not support the efficacy of individualized training based on FV profiling.

5 | PERSPECTIVE

The present study questions the proposed use of FV-profiles to guide training prescriptions in athletes and rather suggests that power should be prioritized over reducing a theoretical FV Imbalance. It seems to be important to work on shifting the entire FV curve to the right, improving power across the entire FV-continuum, regardless of initial FV-profiles.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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