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Improving Acceleration and Repeated Sprint Ability in Well-Trained Adolescent Handball Players: Speed Versus Sprint Interval Training

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Purpose: The aim of the current study was to compare the effects of speed/agility (S/A) training with sprint interval training (SIT) on acceleration and repeated sprint ability (RSA) in well-trained male handball players. ***Methods:*** In addition to their normal training program, players performed either S/A (n = 7) or SIT (n = 7) training for 4 wk. Speed/agility sessions consisted of 3 to 4 series of 4 to 6 exercises (eg, agility drills, standing start and very short sprints, all of <5 s duration); each repetition and series was interspersed with 30 s and 3 min of passive recovery, respectively. Sprint interval training consisted of 3 to 5 repetitions of 30-s all-out shuttle sprints over 40 m, interspersed with 2 min of passive recovery. Pre- and posttests included a countermovement jump (CMJ), 10-m sprint (10m), RSA test and a graded intermittent aerobic test (30-15 Intermittent Fitness Test, V_{IFT}). ***Results:*** S/A training produced a *very likely* greater improvement in 10-m sprint (+4.6%, 90% CL 1.2 to 7.8), best (+2.7%, 90% CL 0.1 to 5.2) and mean (+2.2%, 90% CL –0.2 to 4.5) RSA times than SIT (all effect sizes [ES] greater than 0.79). In contrast, SIT resulted in an *almost certain* greater improvement in V_{IFT} compared with S/A (+5.2%, 90% CL 3.5 to 6.9, with ES = –0.83). ***Conclusion:*** In well-trained handball players, 4 wk of SIT is likely to have a moderate impact on intermittent endurance capacity only, whereas S/A training is likely to improve acceleration and repeated sprint performance.

Keywords: team sports, speed training, agility, concurrent training

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In addition to sport-specific technical and tactical skills, strength, explosive power, speed, cardiorespiratory fitness and repeated sprint ability (RSA) have been shown to be important factors determining success in many team sports.[1–5] Consequently, the optimal design and implementation of training strategies that enhance these specific athletic qualities in talented young players is of significant interest to team sport coaches and players.

Improvement in athletic qualities such as peak sprinting speed or maximal aerobic speed is generally thought to be training specific, with specially designed speed and explosive strength training programs shown to improve peak running speed[6,7] and jumping height,[7,8] and high-intensity running exercises reported to develop both aerobic maximal power and endurance capacity in young team sport players.[3,9–11] However, the most effective strategy to enhance RSA is less evident. Repeated sprint ability is a complex quality and has been related to both neuromuscular (eg, peak locomotor speed, neural drive and motor unit activation) as well as metabolic factors (eg, oxidative capacity, PCr recovery and H^+ buffering).[12] As a consequence, the potential impact of speed- vs endurance-oriented training programs on RSA in team sport players is unclear. In addition, it is uncertain whether "dissociated" training (emphasis on separate fitness qualities individually) will have a greater impact on RSA than "compound" training (emphasis on both neuromuscular and metabolic fitness qualities simultaneously). Training studies focusing on the development of RSA in team sport players have reported inconsistent results and have mostly investigated the impact of dissociated training approaches.[3,9,13] For example, in young elite handball players, the addition of aerobic-oriented small-sided games to usual training contents was associated with slightly greater improvements in RSA than the addition of high-intensity intermittent runs.[3] However, adding high-intensity intermittent runs has been reported to be superior to the addition of very short (6 s) repeated sprint training.[9] Conversely, in junior soccer players, repeated 6-s sprint training sessions were shown to be superior to high-intensity aerobic running intervals of 4 min at improving RSA.[13] Consequently, while different training strategies that target each of these individual components may impact RSA, owing to the various metabolic, neural and mechanical determinants of RSA, it is unclear which is most effective.

Recently, the use of 30-s sprint interval training[14,15] has been proposed as an innovative and time-efficient method to induce rapid changes in exercise capacity and skeletal muscle energy metabolism.[16] The remarkable efficiency of this type of training is likely a result of the high simultaneous stress on both the anaerobic and aerobic energy systems.[16] Over a short period, sprint interval training has been shown to promote neural adaptations and increase muscle Cr and CK levels,[14] with simultaneous improvements in muscular oxidative capacity,[14,15] muscle glycogen content, as well as enhanced muscle buffer capacity,[15] which are all factors likely to benefit the maintenance of high-intensity exercise.[16] However, the impact of sprint interval training on RSA is yet to be investigated in a population of trained team sport players.

Repeated sprint ability has also been suggested to be strongly linked to the ability to develop maximal speed.[17] Thus, a training method focusing on the exclusive development of maximal sprinting speed and agility may also be a time-efficient method to improve RSA. Moreover, this method is likely to be particularly well suited to young players as it has been shown that neuromuscular function can be improved substantially following exposure to these types of training stimuli.[18] To date only one study has investigated the effect of a speed and agility training program on sprinting performance in young soccer players, but results have been encouraging.[6]

The aim of the current study was to compare the respective effects of an exclusive speed/agility-oriented training program with a sprint interval training program on RSA in well-trained male adolescent handball players. We hypothesized that both training programs would be equally effective at improving RSA though each training strategy would do so by stressing the different mediators of repeated sprint performance. Specifically, speed/agility training would improve RSA via improvements in neuromuscular-related factors (ie, jumping ability, acceleration and peak sprinting speed) and sprint interval training would improve RSA via improvement in both neuromuscular and metabolic (ie, aerobic fitness) factors.

Materials and Methods

Subject Recruitment

Sample size was estimated using acceptable precision or confidence limits a priori using the approach developed for magnitude-based inferences.[19] Assuming a between-group difference in mean RSA time of 1.2 ± 1.1%,[3,9] a within-subject standard deviation (typical error) of 0.8%,[20] and chances of type I and type II errors of 0.5% and 25%; 18 adolescent players (15.8 ± 0.9 y; 68.9 ± 10.0 kg; 1.80 ± 0.04 m; 5 $h \cdot wk^{-1}$ training + 1 game) were recruited to participate in the study. Each subject was free of cardiovascular and pulmonary disease and was not taking any medications. The study, which was approved by the institutional research ethics committee, conformed to the recommendations of the Declaration of Helsinki. Participants and their parents gave voluntary written informed consent to participate in the experiment.

Experimental Design

Using a fully controlled study design, participants were divided into two training groups that performed, in addition to their normal training sessions, either exclusive S/A (n = 9)[6] or 30-s SIT (n = 9).[15,21] We acknowledge that the present study design could have been more powerful with a nonintervention control group. However, the population to draw from in well-trained handball players is limited and dictated the approach taken. Players within each group were matched according to their initial athletic performance and years of practice, ensuring that both groups displayed equivalent pretraining mean values for each of the performance parameters. Tests were performed on an indoor synthetic track 1 wk before the commencement of training, and 1 wk following the training period (Table 1). Ambient temperature for all testing and training sessions ranged from 18 to 22°C, and tests were performed at the same time of day on both occasions. Tests included a counter movement jump (CMJ), a 10-m sprint, a RSA test, and a graded aerobic intermittent test ($30\text{-}15_{IFT}$). Players were familiarized with the exercise procedures before commencement of each test (ie, each subject had completed each of the test protocols at least once during the preseason period). Subjects were informed not to perform intense exercise on the day before a test, and to consume their last meal at least 3 h before the scheduled test time.

Table 1 Training contents for each training group

Week	Speed/Agility Training	Sprint Interval Training
0	Field tests	
1	3 × (10-m sprint + 2 × agility drills + 5-m shuttle sprint), r = 30 s and R = 3 min	3 × all-out 30 s (r = 2 min)
2	4 × (10-m sprint + 2 × agility drills + 5-m shuttle sprint), r = 30 s and R = 3 min	4 × all-out 30 s (r = 2 min)
3	4 × (2 × 10-m sprint + 2 × agility drills + 2 × 5-m shuttle sprints), r = 30 s and R = 3 min	5 × all-out 30 s (r = 2 min)
4	3 × (10-m sprint + agility drills + 5-m shuttle sprints), r = 30 s and R = 3 min	3 × all-out 30 s (r = 2 min)
5	Field tests	

Note. r = between-repetition recovery, R = between-set recovery.

Training Intervention

Subjects performed two specific training sessions per week, in addition to their normal training requirements for four consecutive weeks. Training programs were matched by total duration and followed a typical periodized plan (Table 1). The week before the initial tests (Week 0) included samples of the experimental exercises (ie, one to two incomplete series, performed once a week) and served as familiarization training sessions. Training load during that week was thus lower than for the week preceding posttests (Week 4). S/A training consisted of three to four series of 4–6 exercises aimed at exclusively improving speed, acceleration and agility (eg, agility drills, standing start and very short shuttle sprints, all of <5 s duration) as previously described;[6] each repetition and series interspersed with at least 30 s and 3 min of passive recovery respectively. SIT training consisted of three to five repetitions of 30-s all-out shuttle sprints over 40 m, interspersed with 2 min of passive recovery as adapted from previous studies.[15,21]

Lower Limb Explosive Power Test

Lower limb explosive power was assessed using a vertical countermovement jump with flight time measured by an Optojump (Microgate, Bolzano, Italy) to calculate jump height (CMJ; cm). Each trial was validated by visual inspection to ensure each landing was without any leg flexion and participants were instructed to keep their hands on their hips during all jumps. The depth of the countermovement was self selected. All athletes were verbally encouraged throughout the test and asked to jump as high as possible. The CMJ was performed three times, separated by 45 s of passive recovery, and the best performance was recorded.

Speed Tests

Running speed was evaluated by a 10-m standing-start sprint with the front foot placed 5 cm before the first timing gate. Time was recorded with photoelectric cells placed 10 m apart (Brower Timing System, Colorado, USA). As for the CMJ, subjects completed three 10-m sprints with the fastest sprint time recorded. All sprints were separated by at least 45 s of passive recovery.

Repeated Sprint Ability (RSA)

The RSA test involved six repetitions of maximal 2 × 15-m shuttle sprints (approximately 6s) departing every 20 s as has previously been described.[9] During the approximately 14-s recovery between sprints, subjects were required to stand passively. Two seconds before starting each sprint, the subjects were asked to assume the start position as detailed for the 10-m sprints and await the start signal from a compact disc. Strong verbal encouragement was provided to each subject during all sprints. This test was adapted from a previous running test that has been shown to produce reliable and valid estimates of RSA.[22] Three scores were calculated for the RSA test: the best sprint time (RSA_b; s), usually the first sprint; the mean sprint time (RSA_m; s) and the percent sprint decrement (%Dec; %) calculated as follows:[23]

$$100 - (\text{mean time} / \text{best time} \times 100)$$

Maximal Graded Aerobic Test

Maximal aerobic performance for each subject was assessed using a 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$) as previously described.[24] Briefly, the $30\text{-}15_{IFT}$ consists of 30-s stages interspersed with 15-s passive recovery periods. The initial running velocity was set at 8 $km \cdot h^{-1}$ for the first 30-s stage and speed was increased by 0.5 $km \cdot h^{-1}$ every 30 s stage thereafter. Subjects were instructed to complete as many stages as possible, and the test ended when the subject could no longer maintain the required running speed. The peak velocity achieved in the test ($km \cdot h^{-1}$) was determined as the subject's V_{IFT}. This test elicits peak HR and maximal oxygen uptake,[25] and the reliable final running speed (V_{IFT}; intraclass correlation coefficient = 0.96; typical error = 0.33 (95% CL, 0.26 to 0.46) $km \cdot h^{-1}$) has been shown to be an accurate tool for individualizing intermittent shuttle running exercise.[24]

Statistical Analyses

Data in text and figures are presented as mean ± standard deviation (±SD). Relative changes (%) in performance are expressed with 90% confidence limits (90% CL). The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. Student's unpaired *t* tests were used to examine differences between groups for baseline and final measurements. Data were first analyzed using a two-factor repeated-measure ANOVA with one between factor (*training type*; SIT *versus* S/A) and one within factor (*period*; pretraining *versus* posttraining). Each of these analyses was carried out with Minitab 14.1 Software (Minitab Inc, Paris, France) and the level of significance was set at $P < 0.05$. In addition to this null-hypothesis testing, these data were also assessed for clinical significance using an approach based on the magnitudes of change.[26,27] For within-/between-group comparisons, the chance that the true (unknown) values for each training program were *beneficial/better* (ie, greater than the smallest practically important effect, or the smallest worthwhile change, SWC [0.2 multiplied by the between-subject standard deviation, based on Cohen's effect size principle[28]]), *unclear or detrimental/worse* for performance were calculated. Quantitative chances of *beneficial/better* or *detrimental/poorer* effect were assessed qualitatively as follows: <1%, *almost certainly not*; 1% to 5%, *very unlikely*; 5% to 25%, *unlikely*; 25% to 75%, *possible*; 75% to 95%, *likely*; 95% to 99%, *very likely*; >99%, *almost certain*. If the chance of having *beneficial/better* or *detrimental/poorer* performances were both >5%, the true difference was assessed as *unclear*.[26,27] In addition, the standardized difference or effect size (ES) of changes in each fitness parameter between the S/A and SIT groups were calculated using the pooled pretraining standard deviation.[28] Threshold values for Cohen ES statistic were >0.2 (small), 0.5 (moderate) and >0.8 (large).

Results

Participants

Only players that participated in >85% of all training sessions were included in the final analysis. As a result, 4 out of the 18 participants (22%) were excluded from analysis. Accordingly, 14 players (16.0 ± 0.9 y, 71.6 ± 10.6 kg, and 1.81 ± 0.07 m) were included in the final analysis. The final sample size for each training group was n = 7 (16.0 ± 1.0 y, 72.0 ± 11.2 kg, and 1.82 ± 0.09 m) for SIT and n = 7 (16.0 ± 0.8 y, 71.2 ± 10.3 kg, and 1.81 ± 0.06 m) for S/A. As a result of the participants' exclusions, some players were no longer matched within both training groups; however, there were no significant differences between mean initial athletic performance and years of practice between final groups before and after training. The baseline anthropometric and physical performance measures of the study drop-outs were not significantly different from those who completed the study.

Changes in Physical Performance Parameters After Training

Raw values for all performance parameters are presented in Table 2. Following the training intervention, changes in measured performance variables were not statistically different between groups (all $P > .35$). However, practically worthwhile differences between the training groups were evident, as supported by large effect sizes and qualitative outcomes suggesting *possibly* to *almost certainly* true changes.

Within-Group Changes

Relative changes and qualitative outcomes from within-groups analysis are presented in Figure 1. Changes in CMJ were *unclear* following both interventions, as chances that the true changes were *beneficial/unclear/detrimental* were 25/29/46% and 19/26/55% for S/A and SIT training respectively. Changes in 10-m sprint time were *very likely beneficial* following S/A training (96/3/3%) but *unclear* following SIT (63/23/14%). Changes in RSA_b were *possible* (94/5/2%) following S/A training and *unclear* (50/28/22%) following SIT. Changes in RSA_m were *very likely*

Table 2 Changes in athletic performance following speed/agility (S/A) and sprint interval training (SIT) training

	Speed/Agility training (n = 7)		Sprint interval training (n = 7)		Differences in change observed for S/A compared with SIT		
	Pre	Post	Pre	Post	Standardized (Cohen) differences (90% CL)	Rating	% chances of better / trivial / poorer effect
CMJ (cm)	44.9 ± 2.8	44.4 ± 3.9	44.8 ± 4.2	43.6 ± 4.9	0.20 (0.27, 0.68)	*Small*	50/42/8
10 m (s)	1.88 ± 0.04	1.83 ± 0.05	1.90 ± 0.6	1.94 ± 0.11	–1.58 (–2.73, –0.44)	*Large*	97/2/1
RSA_{best} (s)	5.84 ± 0.09	5.72 ± 0.13	5.79 ± 0.16	5.83 ± 0.18	–1.15 (–2.27, –0.03)	*Large*	92/5/3
RSA_{mean} (s)	5.99 ± 0.11	5.81 ± 0.13	6.03 ± 0.20	5.98 ± 0.24	–0.79 (–1.66, –0.09)	*Large*	87/9/3
%Dec (%)	2.3 ± 1.0	1.5 ± 0.6	3.9 ± 1.6	2.4 ± 1.3	0.27 (–0.28, 0.82)	*Small*	7/33/60
V_{IFT} ($km \cdot h^{-1}$)	18.8 ± 1.2	18.5 ± 1.3	18.8 ± 1.2	19.5 ± 1.1	–0.83 (–1.10, –0.56)	*Large*	0/0/100

Note. Mean values (±SD) for countermovement jump (CMJ), 10-m sprint time (10 m), best (RSA_{best}) and mean (RSA_{mean}) times during the repeated-sprint ability test, percentage of speed decrement (%Dec) and velocity reached at the end of the 30-15IFT (V_{IFT}) for sprint interval training (SIT) and speed/agility (S/A) training.

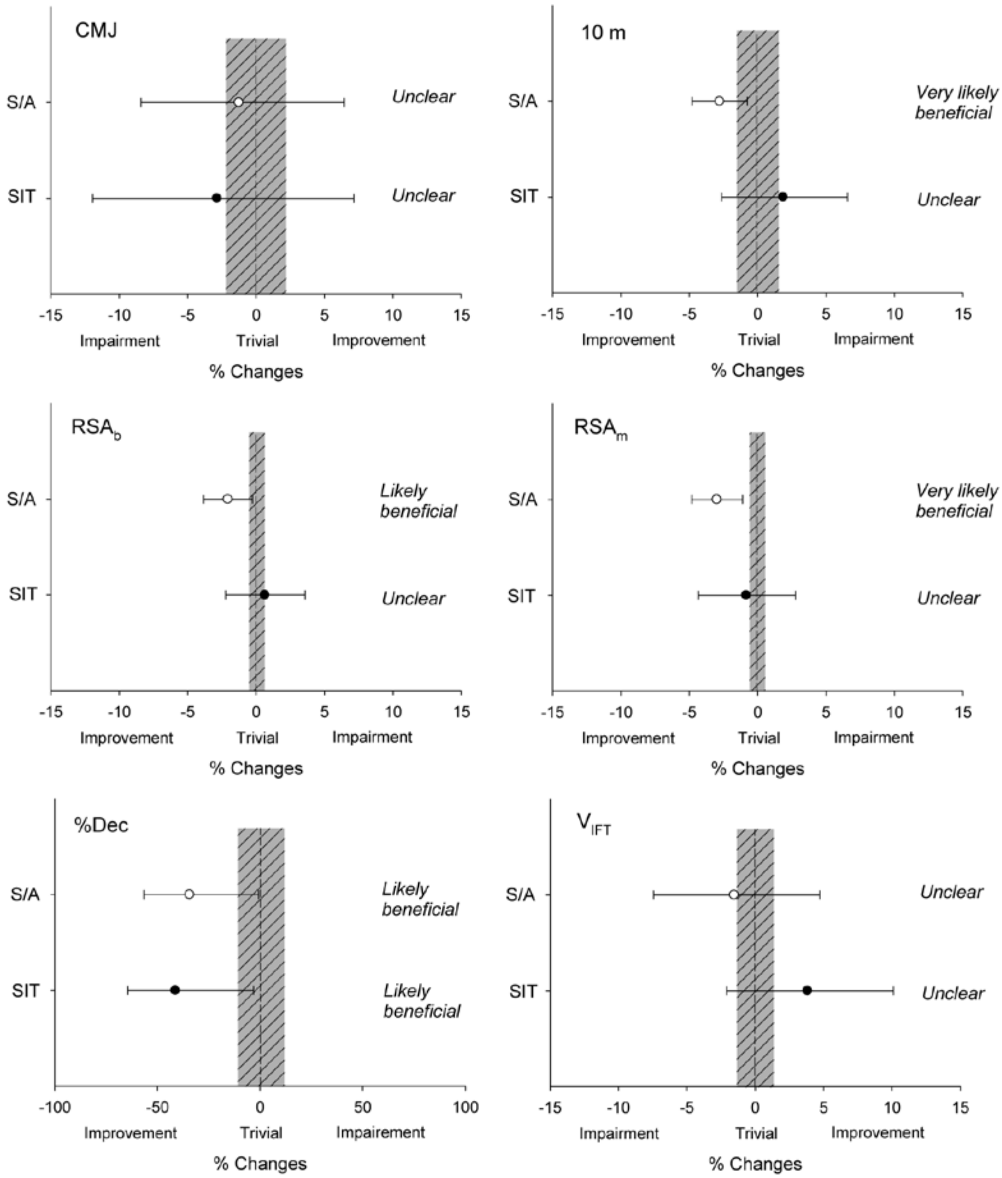

Figure 1 — Within-group relative changes for counter movement jump performance (CMJ) 10-m sprint time (10 m), best (RSA$_b$) and mean (RSA$_m$) sprint times on the repeated sprint ability test, percentage of speed decrement (%Dec) and speed reached at the end of the 30-15 Intermittent Fitness test (V$_{IFT}$) with speed/agility (S/A) and sprint interval (SIT) training programs (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial area was calculated from the smallest worthwhile change (see methods).

(98/1/1%) and *unclear* (51/28/21%) for S/A and SIT, respectively, whereas improvements in %Dec were *very likely* following both S/A and SIT training (chances of 91/7/2% and 92/6/2%, respectively). Changes in V_{IFT} were *unclear* following both S/A (21/27/52%) and SIT (77/16/7%) training.

Between-Groups Changes

Results from between-groups analysis are presented in Table 2 and illustrated in Figure 2. Following S/A training, changes in 10-m sprint time were *very likely* greater than SIT, whereas improvements in RSA_b and RSA_m were *possibly* greater. Large ES were also noted for differences in 10-m sprint, RSA_b and RSA_m. Difference in the changes in %Dec and CMJ were *unclear* (small ES), whereas SIT induced *almost certainly* greater improvement of V_{IFT} compared with S/A training (large ES).

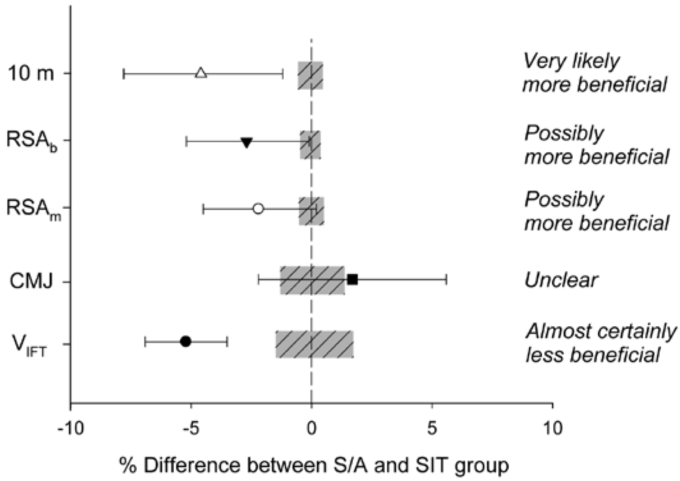

Figure 2 — Efficiency of the speed/agility (S/A) compared with the sprint interval (SIT) training programs to improve 10-m sprint time (10m), best (RSA_b) and mean (RSA_m) sprint times on the repeated sprint ability test, counter movement jump performance (CMJ) and speed reached at the end of the 30-15 Intermittent Fitness test (V_{IFT}) (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial area was calculated from the smallest worthwhile change (see methods). For figure clarity, mean difference for %Dec was not represented (i.e., 16.1% (90% CL –14.0, 56.8), rated as *unclear*).

Discussion

The current study is the first to use specific field tests and a controlled study design to compare the effectiveness of two distinct training approaches (ie, speed/agility-oriented training and sprint interval training) on acceleration, RSA and other relevant physical performance capacities of well-trained young team sport players. These results show that S/A training is *likely* an effective training tool for the improvement of acceleration and RSA, and SIT is *almost certainly* more effective than S/A training for the improvement of intermittent aerobic performance.

Effect of Sprint Interval Training on Athletic Determinants of Team Sport Performance

Previous studies investigating SIT have reported beneficial effects on several parameters of endurance and sprint performance.[14–16] However, in the current study, SIT had only an effect on %Dec and V_{IFT}, with no impact on sprint running performance (acceleration and RSA). While changes in V_{IFT} (+3.8%, Figure 1) were rated as *unclear* due to both the chances of benefit and harm being higher than 5% (ie, 77/16/7), our young handball players subjected to SIT had a 10-fold greater chance of their V_{IFT} performance being improved than impaired. In addition, SIT was *almost certainly likely* more beneficial than the S/A program for the improvement of V_{IFT} (100% chances of a beneficial difference, Figure 2). This improvement in cardiorespiratory fitness associated with SIT is further supported by the *likely* decrease in %Dec (Figure 1).[12] Compared with the physically active adults used in previously published investigations into the impact of SIT,[14,15] this study used young well-trained competitive handball players. Consequently, this type of "mixed" training performed over a short period of 4 wk, which was expected to induce both neuromuscular and metabolic adaptations, may not induce adaptations in some specific game-related fitness traits in already well-trained team sport athletes. In addition, due to the training status of the participants in the current study, the exercise stimuli during SIT may not have been high enough to overload the neuromuscular system to substantially improve maximal running speed,[29] and aerobic system solicitation may not have been long enough[30] to promote greater cardiorespiratory adaptations. As it has previously been suggested, placing high levels of stress on the athletic quality of interest (eg, maximal aerobic power, agility, maximal strength) is almost obligatory in highly trained athletes.[29,30] Consequently, utilizing SIT in already well trained athletes may not provide sufficient stimulus to promote practically relevant adaptations in some performance-related fitness variables (especially speed running performance).

Effect of Speed/Agility Training on Athletic Determinants of Team Sport Performance

The present results indicate that the S/A training program had a *very likely beneficial* impact on both single sprint speed and repeated sprint running performance (Figure 1) and that this effect was *very likely* greater than that of the SIT (Table 2 and Figure 2). However, following S/A training, no substantial changes in jump height were observed (Figure 1). Although no electromyographic or kinetic data were collected in this study, the changes in sprint running speed in this study are likely related to improvements in the neural component of speed (eg, inter-lower limbs muscle coordination, stride frequency) rather than explosive force production per se, which if improved, would have likely resulted in increases in jump height.[29] It is also likely that improved coordination and agility resulting from the S/A training improved the ability to change direction while running at maximal speed, which in turn improved repeated shuttle sprint performance in this study.[31]

The improvement in RSA (3.3% for mean sprint time) observed in the current study is similar to results previously reported in young handball players[3,8,9] after training programs containing similar speed/agility sessions, but combined with additional aerobic-oriented exercises. This highlights the effectiveness of targeted speed training sessions for the improvement of acceleration and RSA in young well-trained handball players, and suggests that the addition of supplemental aerobic conditioning[3,9] might not be as important as previously suggested,[12] at least to perform well on the shuttle RSA test used in the current study. However, it confirms that in well-trained team-sport athletes, maximization of RSA is linked to the ability of developing maximal speed.[17] It is also worth noting that, in the general setting of team sports, S/A training is only one component and should be complemented with specific training aimed at developing each of the physical determinants of team sport performance.

In conclusion, the present results indicate that repeating 30-s all-out sprints has only a moderate impact on cardiorespiratory fitness, whereas speed/agility training is *likely beneficial* for the improvement of both single (10-m sprint time) and repeated (RSA) sprint running performance. Since sprint interval training had previously been proposed as an effective training stimulus to improve both the aerobic and anaerobic system capacities,[14–16] it was expected to positively influence the RSA of the participants in this study. However, these results indicate that training strategies that attempt to stress multiple determinants of RSA simultaneously may not be as effective as targeted (acceleration) training. Consequently, these results suggest that in well-trained team sport athletes, fitness traits might need to be developed independently and the inclusion of specific speed and agility training is likely to have a beneficial impact on acceleration and RSA.

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References

1. Gorostiaga EM, Granados C, Ibanez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *Int J Sports Med*. 2005;26:225–232.
2. Rannou F, Prioux J, Zouhal H, Gratas-Delamarche A, Delamarche P. Physiological profile of handball players. *J Sports Med Phys Fitness*. 2001;41:349–353.
3. Buchheit M, Laursen PB, Kuhnle J, Ruch D, Renaud C, Ahmaidi S. Game-based Training in Young Elite Handball Players. *Int J Sports Med*. 2009;30:251–258.
4. Rampinini E, Bishop D, Marcora SM, Ferrari Bravo D, Sassi R, Impellizzeri FM. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *Int J Sports Med*. 2007;28:228–235.
5. Mujika I, Santisteban J, Impellizzeri FM, Castagna C. Fitness determinants of success in men's and women's football. *J Sports Sci*. 2009;27:107–114.
6. Venturelli M, Bishop D, Pettene L. Sprint training in preadolescent soccer players. *Int J Sports Physiol Perform*. 2008;3:558–562.
7. Christou M, Smilios I, Sotiropoulos K, Volaklis K, Pilianidis T, Tokmakidis SP. Effects of resistance training on the physical capacities of adolescent soccer players. *J Strength Cond Res*. 2006;20:783–791.

8. Buchheit M, Leblond F, Leblond F, Renaud C, Kuhnle J, Ahmaidi S. Effect of complex vs. specific aerobic training in young handball players. *Coaching & Sport Science Journal*. 2008;3:22.
9. Buchheit M, Millet GP, Parisy A, Pourchez S, Laursen PB, Ahmaidi S. Supramaximal training and post-exercise parasympathetic reactivation in adolescents. *Med Sci Sports Exerc*. 2008;40:362–371.
10. Helgerud J, Engen LC, Wisloff U, Hoff J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc*. 2001;33:1925–1931.
11. McMillan K, Helgerud J, Macdonald R, Hoff J. Physiological adaptations to soccer specific endurance training in professional youth soccer players. *Br J Sports Med*. 2005;39:273–277.
12. Spencer M, Bishop D, Dawson B, Goodman C. Physiological and metabolic responses of repeated-sprint activities:specific to field-based team sports. *Sports Med*. 2005;35:1025–1044.
13. Bravo DF, Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Wisloff U. Sprint vs. Interval Training in Football. *Int J Sports Med*. 2008;29:668–674.
14. Burgomaster KA, Howarth KR, Phillips SM, et al. Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *J Physiol*. 2008;586:151–160.
15. Gibala MJ, Little JP, van Essen M, et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol*. 2006;575:901–911.
16. Gibala MJ, McGee SL. Metabolic adaptations to short-term high-intensity interval training: a little pain for a lot of gain? *Exerc Sport Sci Rev*. 2008;36:58–63.
17. Pyne DB, Saunders PU, Montgomery PG, Hewitt AJ, Sheehan K. Relationships between repeated sprint testing, speed, and endurance. *J Strength Cond Res*. 2008;22:1633–1637.
18. Branta C, Haubenstricker J, Seefeldt V. Age changes in motor skills during childhood and adolescence. *Exerc Sport Sci Rev*. 1984;12:467–520.
19. Hopkins WG. *Estimating sample size for magnitude-based inerences*. Sportscience; 2006:63–70.
20. Impellizzeri FM, Rampinini E, Castagna C, et al. Validity of a Repeated-Sprint Test for Football. *Int J Sports Med*. 2008;29:899–905.
21. Burgomaster KA, Hughes SC, Heigenhauser GJ, Bradwell SN, Gibala MJ. Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *J Appl Physiol*. 2005;98:1985–1990.
22. Spencer M, Fitzsimons M, Dawson B, Bishop D, Goodman C. Reliability of a repeated-sprint test for field-hockey. *J Sci Med Sport*. 2006;9:181–184.
23. Buchheit M, Cormie P, Abbiss CR, Ahmaidi S, Nosaka KK, Laursen PB. Muscle deoxygenation during repeated sprint running: Effect of active vs. passive recovery. *Int J Sports Med*. 2009;30:418–425.
24. Buchheit M. The 30-15 Intermittent Fitness Test: accuracy for individualizing interval training of young intermittent sport players. *J Strength Cond Res*. 2008;22:365–374.
25. Buchheit M, Al Haddad H, Leprêtre PM, Millet G, Newton M, Ahmaidi S. Cardiorespiratory and cardiac autonomic responses to 30-15 Intermittent fitness test. *J Strength Cond Res*. 2009;23:93–100.
26. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41:3–13.
27. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform*. 2006;1:50–57.
28. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Hillsdale: Lawrence Erlbaum; 1988:599.

29. Ross A, Leveritt M, Riek S. Neural influences on sprint running: training adaptations and acute responses. *Sports Med*. 2001;31:409–425.
30. Midgley AW, Mc Naughton LR. Time at or near VO2max during continuous and intermittent running. A review with special reference to considerations for the optimisation of training protocols to elicit the longest time at or near VO2max. *J Sports Med Phys Fitness*. 2006;46:1–14.
31. Young WB, McDowell MH, Scarlett BJ. Specificity of sprint and agility training methods. *J Strength Cond Res*. 2001;15:315–319.