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LEADING ARTICLE

# Interference Phenomenon with Concurrent Strength and High-Intensity Interval Training-Based Aerobic Training: An Updated Model

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## Abstract

Previous research has suggested that concurrent training (CT) may attenuate resistance training (RT)-induced gains in muscle strength and mass, i.e., the interference effect. In 2000, a seminal theoretical model indicated that the interference effect should occur when high-intensity interval training (HIIT) (repeated bouts at 95–100% of the aerobic power) and RT (multiple sets at ~ 10 repetition maximum;10 RM) were performed in the same training routine. However, there was a paucity of data regarding the likelihood of other HIIT-based CT protocols to induce the interference effect at the time. Thus, based on current HIIT-based CT literature and HIIT nomenclature and framework, the present manuscript updates the theoretical model of the interference phenomenon previously proposed. We suggest that very intense HIIT protocols [i.e., resisted sprint training (RST), and sprint interval training (SIT)] can greatly minimize the odds of occurring the interference effect on muscle strength and mass. Thus, very intensive HIIT protocols should be implemented when performing CT to avoid the interference effect. Long and short HIIT-based CT protocols may induce the interference effect on muscle strength when HIIT bout is performed before RT with no rest interval between them.

**Key Points**

HIIT-based concurrent training minimizes the chance of the interference effect on muscle strength gains and muscle hypertrophy when repeated-sprint training (RST) and sprint interval training (SIT) HIIT models are performed.

HIIT-based concurrent training may induce the interference effect on muscle strength gains but not on muscle hypertrophy when long HIIT protocols are performed (e.g., long bout durations i.e., > 1 min.) before the RT protocol with no rest interval between them.

## 1 Introduction

Concurrent training (CT) is characterized by performing resistance training (RT) and aerobic training in the same training routine [1–8]. Due to the increase in muscle strength (i.e., maximum voluntary contraction) and mass (i.e., whole muscle or muscle fiber cross-sectional area—hypertrophy), and aerobic power (i.e., $VO_{2max}$), CT programs have been highly recommended to improve both sport performance and overall health [1, 9–17]. However, CT may attenuate muscle strength and mass gains compared to RT alone, a phenomenon termed as the 'interference effect' [17–24].

Since the publication of the first evidence of the interference effect [18], several experimental studies have attempted to determine the training-related variables contributing to its occurrence [1, 17, 19, 21–23]. However, the heterogeneity of experimental designs and training protocols among studies has produced equivocal findings [6]. Alternatively, David Docherty and Ben Sporer [5] proposed an elegant model based on specific characteristics of the RT and aerobic training that may induce the interference effect (see original study for a detailed depiction of the model [5]). The authors suggested that when aerobic training is performed at intensities close to the maximum aerobic power (95–100%

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$VO_{2max}$) using high-intensity interval training (HIIT) protocols and RT is performed with more than 10 repetition maximum (RM), gains in muscle strength and mass are blunted compared to RT alone due to antagonistic training-induced adaptations. However, more intensive HIIT protocols (e.g., repeated sprint training—RST, and sprint interval training—SIT) were not considered in the original model.

In the past, HIIT was generically characterized by repeated maximal-to-supramaximal and short-to-long duration efforts (e.g., 7 s up to 5 min) with relief periods between them [5, 6]. Specifically, Docherty and Sporer [5] model mentioned that HIIT-based CT protocols were characterized by long exercise durations and relief periods (e.g., 3 min:3 min, equal work to rest ratio 1:1). Seeking to better organize HIIT prescription, Buchheit and Laursen [25, 26] proposed an empirical model using the intensity and duration of the efforts as control variables that mediate the training-induced adaptations and training features (e.g., number of efforts and relief period duration). The authors classified HIIT into four intensity prescription zones as follows: (1) long HIIT intervals (intensity: ≈ 90–110% of $VO_{2max}$ velocity—$vVO_{2max}$; duration: > 60 s); (2) short HIIT intervals (intensity ≈ 110–130% of $vVO_{2max}$; duration: < 60 s); (3) repeated-sprint training (RST—intensity: ≈ 140–170% of $vVO_{2max}$ or 75–85% of the maximal sprint speed; duration: 3 to 10 s); and (4) sprint interval training (SIT—intensity: > 170% of $vVO_{2max}$ or > 85% of the maximal sprint speed; duration: 30–45 s). Importantly, all the aforementioned HIIT prescription zones effectively enhance maximum aerobic power [25], but results regarding HIIT-induced neuromuscular adaptations are equivocal. Compared to long HIIT, high-speed HIIT protocols (i.e., RST and SIT) impose greater neuromuscular demand as assessed by higher muscle activation during efforts and blood lactate concentrations during effort and relief periods [26–30]. Also, the work to rest ratio (about 1:8) for RST and SIT protocols ensures that every effort is supramaximal and recovery periods are long enough to maintain the intensity of the efforts [25, 26]. As a result, one may suggest that skeletal muscle anaerobic performance-related adaptations (e.g., gains in muscle strength and mass) may be greater in RST and SIT than long and short HIIT protocols. However, this suggestion requires further scrutiny due to equivocal findings.

Thus far, not many studies have investigated the effect of HIIT on muscle strength and mass [31–36]. Two studies showed increases in muscle cross-sectional area (CSA) between 5 and 7% [35, 36] after short HIIT and RST protocols, while others have failed to do so. The equivocal results were possibly due to methodological issues, such as differences in training volume and duration, muscle mass assessment (i.e., whole muscle vs muscle fiber cross-sectional area), and small sample sizes [31, 33, 34, 37, 38]. Recently, additional studies have investigated the effect of HIIT-based CT models on muscle strength and mass [3, 8, 11, 16, 19, 21, 39–47]. Interestingly, data suggest that HIIT-based CT protocols (i.e., RST and SIT) impair neither muscle strength nor muscle mass gains compared to RT alone [11, 40–44]. These results are exciting due to the potential practical application of those CT protocols in sport and health contexts. Considering the recent framework used to prescribe HIIT protocols (i.e., long and short HIIT, RST and SIT) [25, 26], their respective neuromuscular adaptations and, thus, the chance of producing the interference effect, the purpose of this paper was to present an updated version of the CT interference phenomenon model proposed by Docherty and Sporer [5]. The literature was searched using PubMed, Web of Science and Google Scholar up to August 2020.

## 2 Interference in Muscle Strength Gains in HIIT-Based CT Protocols

The original Docherty and Sporer model [5] proposes that low-intensity high-volume aerobic training and high-intensity low-volume RT produce mainly central adaptations (cardiovascular and nervous system, respectively). Due to those specific characteristics, they are at opposing extremes of the CT adaptations continuum and should not produce the interference effect on muscle strength [5]. Conversely, high-intensity interval training (HIIT) and RT usually implemented in CT protocols are not at the extremes of the continuum, producing not only central adaptations but also peripheral ones (i.e., skeletal muscle). The peripheral adaptations induced by HIIT and RT can be in opposite directions, which has been deemed to be a leading cause of the interference effect. According to the original interference phenomenon model [5], long HIIT can induce the interference effect. As the other three HIIT prescription zones [25] impose distinct demands on skeletal muscles compared to long HIIT [26], the occurrence of the interference effect when using them requires further scrutiny. For instance, RST and SIT models have higher glycolytic demand than long and short HIIT models [26]. Additionally, RST and SIT include maximum or near maximum sprints, which enhance muscle activation and force production compared to long and short HIIT [29, 30]. Similarly, moderate-to-high intensity RT (i.e., > 10 RM) requires high muscle activation, force production and rate of energy production (i.e., glycolytic demand) [48–52], factors associated with increases in muscle strength [53, 54]. Taken together, it is reasonable to suggest that RST- and SIT-based CT protocols should not produce antagonistic adaptations and thus not impair muscle strength gains [55].

Sabag and colleagues [11] published a meta-analysis showing a marginal interference effect on muscle strength of HIIT-based CT (effect size = − 0.248; 95% confidence interval − 0.495 to − 0.001) compared to RT alone.

However, the authors did not use the prescription zones as a moderator variable in their statistical model to determine the likelihood of each zone producing the interference effect. Thus, we critically analyzed the 12 studies included in Sabag and colleagues' [11] work, and two additional studies retrieved in the search process [47, 56]. Only three studies [19, 44, 56] showed reduced gains in muscle strength when comparing HIIT-based CT protocols with RT alone. Fyfe et al. [19] and Robineau et al. [44] used long and short HIIT-based CT protocols, respectively, with no rest interval between the HIIT and RT bouts. Similarly, Chtara et al. [56] also used a long HIIT-based CT protocol with a 15 min rest interval between bouts. The rest interval between exercise bouts has been considered as an important CT-related variable [23] that may favor the occurrence of the interference effect. Accordingly, Robineau et al. [43] compared the effect of 0 h, 6 h and 24 h interval between the RT and short HIIT bouts on muscle strength gains, the 6 h interval attenuated the interference effect and the 24 h interval eliminated it. Other training-related variables, such as exercise mode (i.e., running or cycling), exercise order (HIIT-RT or RT-HIIT), previous training experience, intervention duration, between-individual variability and high variability of the prescribed training protocols, can modulate the occurrence of the interference effect [1, 6, 11, 17, 23, 44, 47, 56]. However, designing studies able to control for those confounding variables is challenging and efforts should be made to standardize training protocols. Thus, current evidence indicates that Docherty and Sporer's interference model [5] should be updated, as more intensive HIIT protocols (RST and SIT) are unlikely to hamper muscle strength gains (Fig. 1) while long and short HIIT protocols could blunt them (Fig. 1).

Even though most of the studies have determined the effect of HIIT-based CT protocols on muscle strength gains, improvements in muscle power (i.e., countermovement jump [CMJ] height) could also be considered in the interference model [3, 19, 39, 43, 44, 47, 56], due to its importance to sport performance and daily life activities. Three studies demonstrated lesser improvements in CMJ height when using long and short HIIT-based CT protocols [19, 47, 56], while studies using RST- and SIT-based CT protocols did not show the interference effect [3, 39, 43, 44]. Similar to muscle strength, adding a rest interval between the HIIT and RT bouts (no interval vs. more than 6 h of interval) also seems to decrease the odds of occurrence of the interference effect [44]. However, most of the studies used traditional RT protocols and, thus, there is a paucity of data on the occurrence of the interference effect when performing more power-oriented RT protocols and exercises (e.g., velocity-based training and bench throw, respectively).

## 3 Muscle Hypertrophy Interference Model Based on HIIT Evidence

Current exercise prescription guidelines indicate that RT-induced gains in muscle mass are obtained by performing multiple sets of 3–12 RM (70–100% 1-RM) (depending on training status) [53, 54]. Recently, mounting evidence suggests that low-intensity RT (20–50% 1-RM), performed close to concentric failure, produces similar gains in muscle mass to high-intensity RT [57, 58]. Thus, effort duration, rest interval, and skeletal muscle metabolic demand seem to be similar between hypertrophy-oriented RT and all four HIIT prescription zones, indicating that the gains in muscle mass should not be affected by HIIT-based CT protocols. In fact, there is evidence that specific HIIT prescription zones can increase the mass of the exercised muscles.

Accordingly, Linossier et al. [35] submitted healthy and physically active young men to an RST (5 s sprint, 55 s rest; two sets of 15 sprints) protocol for nine weeks, four

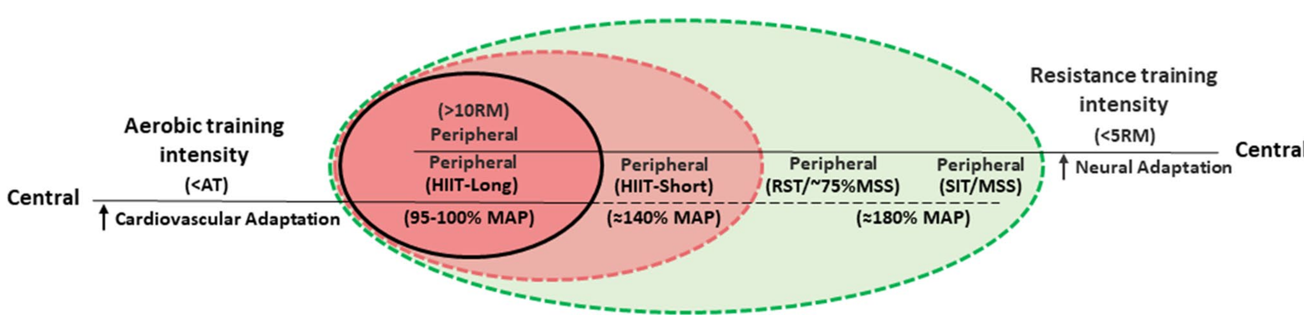


**Fig. 1** Updated concurrent training interference effect model for muscle strength. *AT* aerobic threshold, *MAP* maximal aerobic power, *RM* repetition maximum, *HIIT* high-intensity interval training, *MSS* maximal sprinting speed, *RST* repeated-sprint training, *SIT* sprint interval training. The pink area inside the solid black ellipse line indicates the original interference zone; the light pink area inside the dashed red ellipse line indicates a slight interference zone; and the green area inside the dashed green ellipse line indicates a non-interference zone (adapted from Docherty and Sporer [5])

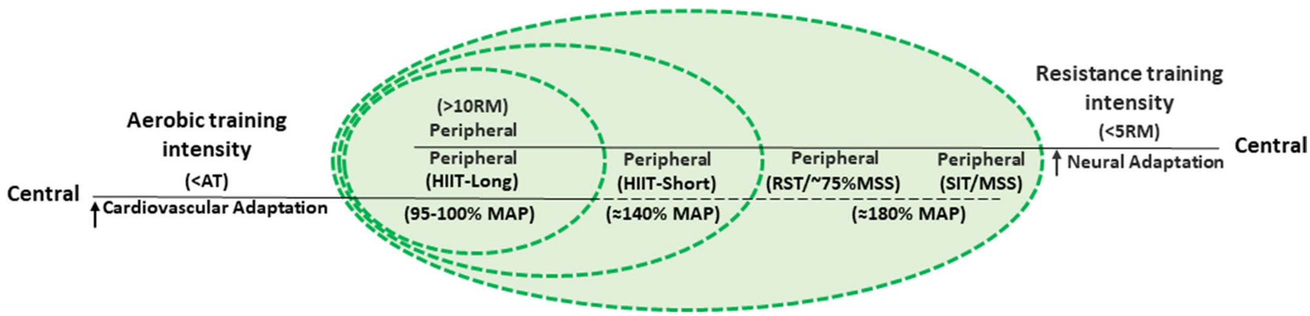


**Fig. 2** Updated concurrent training interference effect model for muscle mass. *AT* aerobic threshold, *MAP* maximal aerobic power, *RM* repetition maximum, *HIIT* high-intensity interval training, *MSS* maximal sprinting speed, *RST* repeated-sprint training, *SIT* sprint interval training. The green area inside the dashed green ellipse lines indicate non-interference zones (adapted from Docherty and Sporer [5])

times per week. Subjects increased quadriceps, vastus lateralis, and vastus lateralis type II fiber cross-sectional area (CSA) by 5%, 6%, and 45%, respectively. Similarly, Osawa et al. [36] reported an 11% increase in quadriceps CSA after a 16 week short HIIT (60 s sprint, 60 s rest; 8–12 sprints; > 90% $VO_{2peak}$) protocol, twice a week. In fact, not only RST and short HIIT but also long HIIT seems to increase muscle mass. Estes et al. [59] reported an 11% increase in vastus lateralis CSA in recreationally active young participants after 10 weeks of long HIIT (24 sessions; 4 min effort at 90–95% HRmax and 3 min relief at 70% HRmax). On the other hand, others have failed to demonstrate RST- and SIT-induced gains in muscle fiber CSA [31, 33, 37, 38]. Thus, there is some evidence that HIIT can induce muscle hypertrophy, but additional studies are required to determine its effects at the muscle fiber level.

Other studies have compared the gains in muscle mass between HIIT-based CT protocols and RT alone protocols [8, 19, 22, 39–42]. As evidence suggests that HIIT protocols can increase [35, 36, 59] or have no effect [31, 33, 37, 38] on muscle mass, it is reasonable to suggest that HIIT-based CT models could preclude the occurrence of the interference effect on muscle mass. One may even suggest an additive effect, as HIIT can increase muscle mass per se; however there is no empirical evidence of this additive effect [40–42]. There are studies comparing long HIIT, short HIIT, RST- and SIT-based CT protocols with RT alone on muscle mass gains. Independently of HIIT prescription zone, no interference effect was observed on muscle mass [22, 39, 40, 42]. Considering the HIIT-based CT literature, only Fyfe et al. [19] showed a possible interference effect on muscle mass gains when comparing a RT protocol with a long HIIT-based CT one (4.1 ± 2.0% and 1.8 ± 1.6%, respectively). However, change in lower-body lean mass was used as a proxy of muscle mass gain, which may have biased the findings. Changes from pre- to post-training were small and represented the sum of the changes in mass of all lower body muscles (i.e., false positive). Furthermore, training sessions followed a HIIT-RT order, which may favor the interference effect [23].

Taken together, Sabag and colleagues' meta-analysis [11], Murach and Bagley [17], and Lee et al. [47] do not suggest the occurrence of the interference effect on muscle mass when performing HIIT-based CT protocols (Fig. 2). Evidently, additional studies are necessary to test if differences in total training volume, exercise order, training frequency, training experience, and exercise mode may induce the interference effect when performing HIIT-based CT. For instance, Murach and Bagley [17] suggested that cycling HIIT-based CT protocols might produce the aforementioned additive effect on muscle hypertrophy when compared to running HIIT-based CT protocols. On the other hand, Sabag and colleagues [11] did not find differences in muscle mass gains between running and cycling HIIT-based CT protocols. Considering that most of the studies investigating different HIIT-based CT protocols showed no interference effect on muscle mass, it is reasonable to suggest that different combinations of HIIT and RT protocols may be used without compromising muscle mass gains (Fig. 2).

## 4 Conclusion

More intense HIIT protocols, such as RST and SIT, when combined with RT can promote similar gains in muscle strength, mass, and power to RT alone. It is noteworthy that if HIIT induces the interference effect, it affects muscle strength and CMJ height gains mainly when using long and short HIIT protocols. Finally, performing a long or short HIIT bout after RT with a proper rest interval between them (> 6 h) may decrease the probability of occurrence of the interference effect on muscle strength.

### 4.1 Practical Implications

The evidence presented herein suggests that different HIIT protocols may be used when performing CT. Thus, the selection of specific HIIT protocols should be based on personal preferences and training goals (e.g., different sport's needs, health, or physical fitness promotion). If the interference effect has to be avoided at all costs, evidence suggests that RST and SIT should be preferred as the likelihood of occurrence of the interference effect on muscle strength, mass and power is then low.

## Declarations

**Authorship contributions** FC conceived the idea, wrote the first draft, worked on all drafts and formatted the manuscript for submission. MSC, GDT CAL and CU helped develop the main idea and draft the paper. All authors read and approved the final version of the manuscript.

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