# Tabata training in perspective

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**Running title:**

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# Abstract

Originally developed as a specific form of exhaustive intermittent training involving 6-8 X 20-seconds of supramaximal-intensity cycling exercises with 10-seconds of recovery for athletes, Tabata training has become universally recognized around the world. The purpose of this review article is to provide a perspective on Tabata training and discuss how this popular style of intermittent training has evolved and been applied over the last ~30 years. The article will review the original motivation behind Tabata training with relevance to concepts such as maximal accumulated oxygen deficit (MAOD) and maximal oxygen uptake ($Vo_2$max) and discuss how Tabata training has been adapted to involve resistance exercise, cross training, and sport-specific training. Studies of Tabata training on physiological responses and adaptations in muscle, blood vessels, bone, and brain across different populations will be reviewed. Finally, research on how Tabata-style training was applied to counteract inactivity during the COVID19 pandemic will be discussed. Evolving from the study of athletes, Tabata training represents an example of how high intensity intermittent/interval training can be adapted and applied in various settings to enhance performance and health.


**Key Words:** Tabata training, $Vo_2$max, Maximal accumulated oxygen deficit (MAOD), PGC1 $\alpha$, sport performance, high-intensity interval training (HIIT), health promotion

**Take home message**

This article summarizes applied and basic evidence of Tabata training, and proposes research on how this training might improve health- and sport-oriented outcomes, while exploring the physiological and molecular mechanism underlying these effects.

# Introduction

Tabata training (Tabata 2019; Tabata 2022) was originally developed for highly motivated athletes. However, as the training has been used not only by a small number of elite athletes, but also by an extremely large number of exercise lovers, I feel a sense of responsibility to provide scientific evidence as to whether this training is beneficial or hazardous. I here present evidence of both the effects of Tabata training on the performance of athletes ranging from elite to school level, and on the possible effects of health promotion in the general public by preventing non-communicable diseases. I further recognize that in addition to such applied physiological research, Tabata training conducted with experimental animals can be used as a tool for finding intensity-related cellular signals induced by exercise, and for elucidating molecular mechanism(s) regarding their effects on muscle cell metabolism and expression of proteins with physiological functions.

In this paper, I propose future research arising from the evidence gained by my initiatives after the publication of the two historical papers (Tabata et al. 1996; Tabata et al. 1997), as well as by those of my colleagues who have challenged, expanded, and used Tabata-style training on specific populations (e.g., breast cancer survivors (Tsuji et al. 2019; Ochi et al. 2021).

## Terminology

*Tabata or Tabata-style training*

The original Tabata training was defined as exercising at an intensity that exhausts subjects at the end of the 6th, or during the 7th or 8th set of 20-sec bicycle exercise bouts with a 10-sec rest between bouts (Tabata, 2022). This exercise training was first developed for drills on a stationary bicycle (Tabata et al.

1996; Tabata et al. 1997). Now, more than 20 years after the publication of those original studies, it appears that the original exercise intensity has not been emphasized; only the training procedure has been featured, especially among general exercisers. Following such a protocol (8 sets of a 20-sec exercise with a 10-sec rest between bouts) using walking as the exercise, for example, cannot be expected to result in improved maximal oxygen uptake ($Vo_2$max). It seems likely that the intensity of the hard interval portion of Tabata training is important for inducing physiological adaptations. Adopting a protocol with an exercise intensity that exhausts the subject at the end of the 6$^{th}$, or during the 7$^{th}$ or 8$^{th}$ set of 20-sec exercise bouts will elevate both $Vo_2$max and maximal accumulated oxygen deficit (MAOD) (Medbø et al. 1988) to the extent that was reported by the original investigation (Tabata et al. 1996).

Such increases in the two energy-releasing systems (i.e., the aerobic and anaerobic systems) cannot be obtained by walking or low-intensity intervals, where exercise intensity is estimated to be <30% $Vo_2$max in the Tabata protocol. Therefore, the term 'Tabata training' should be applied to exercise protocols that emphasize not only the procedure but also exercise intensity. Since measuring oxygen deficit during bodyweight-bearing exercise is not easily accomplished, and, as discussed later, oxygen uptake during such exercises does not necessarily amount to $Vo_2$max measured for cycling or running, it is not feasible to ensure that a specific weightbearing exercise stresses both the aerobic and anaerobic energy-releasing systems maximally, which is the key characteristic of authentic Tabata training (Tabata et al. 1997). Moreover, various ‘Tabata training’ enjoyed by exercisers do not seem to induce fatigue in people (particularly not elite athletes), which is a necessary condition for eliciting $Vo_2$max and MAOD during authentic Tabata training exercise (Tabata et al. 1997). Therefore, such exercises, including weightbearing exercise, should not be called ‘Tabata training’. I propose that they instead be called

'Tabata-style training', which can, irrespective of exercise intensity (not exhaustive but nearly exhaustive), consist of 8 sets of 20-s exercise with 10-s rest between bouts. In fact, such Tabata-style training using weight bearing exercises was reported to improve aerobic performance by original investigations (McRae et al. 2012; Islam et al. 2020) and summarized in a recent review article (Viana et al. 2019).

**Effects of combining Tabata and resistance training on MAOD and $Vo_2$max**

Essentially, MAOD is a combined quantity determined by muscle volume, concentration of creatine phosphate and maximal lactate concentration that an individual can tolerate. In order to find training that further increases MAOD, we therefore investigated change of MAOD after 6 weeks of Tabata training, and 6 weeks of combined Tabata and resistance training (RT) that enlarged muscle volume (Hirai and Tabata 1996; Tabata 2019; Tabata 2022). This training model has been also adopted by a team led by Mr. Irisawa who first introduced "Tabata training" and was a head coach of the Japanese National Speed Skating Team (Tabata et al. 1996).

During the first 6 weeks, subjects (age: 23 ± 1 year; height: 172 ± 5 cm; weight: 71 ± 8kg; $Vo_2$max : 52.0 ± 7.2 ml/kg/min) trained using the Tabata training 5 days a week. For Tabata+RT period, they performed the Tabata training 3 days and resistance training 3 days a week for another 6 weeks. RT consisted of: (1) 4 sets of squat and leg curl exercises for 12 repetitions max (RM) with 30-sec rest between sets; (2) 2 sets of maximal bouts of the same exercise with a load of 90%, 80%, and 70% of 1 RM. After the Tabata+RT periods, 12 RM for squat increased by 108±8%. The first Tabata training increased MAOD by 18 ± 9% (pre: 69.4 ± 6.4 ml/kg; 5th week: 82.1 ± 11.6 ml/kg). Tabata+RT further increased

MAOD by 38 ± 19% (post: 95.8 ± 16.4 ml/kg), suggesting that an increase in muscle volume by resistance training can also enhance MAOD.

$Vo_2$max increased during the 6-week of Tabata training by 11 ± 2 %, while no significant change was observed during the Tabata+RT period. This result may indicate that in terms of high-intensity interval training (HIIT), a different strategy is necessary to further improve the aerobic energy-releasing system.

During the Tabata training, neither maximal power during the Wingate test nor the circumference (cm) of the thigh muscle were changed. However, after the Tabata+RT, maximal power was significantly increased by 10±3% ($p<0.05$), together with a significant increase in the thigh muscle circumference (3±1%, $p<0.01$). These results suggest that (i) Tabata training itself does not affect muscle mass and anaerobic power, and (ii) an increase in muscle mass may be necessary to induce an increase in anaerobic power. Interestingly, Scribbans et al. (2014) reported improvements in anaerobic power following Tabata training. These results may suggest that Tabata training alone is capable of improving anaerobic power in some instances.

Other investigators have extended our original findings using Tabata-style training in female university students. Foster et al. (2015) reported that 8 weeks of Tabata training increased the capacity of aerobic and anaerobic energy releasing systems of sedentary female university students. Lu et al. (2023) reported that a 12-week Tabata-style functional exercise training for female university students improved cardiorespiratory fitness ($Vo_2$max), body composition, some cardiometabolic biomarkers (e.g., blood pressure, blood lipids, fasting insulin, and insulin resistance assessed by HOMA-IR), as well as daily habitual physical activity.

Finally, studies observing changes in $Vo_2$max and MAOD after Tabata training (detraining) are needed to establish an adequate tapering strategy for athletes. In this context, Islam et al. (2020) demonstrated that cardiorespiratory benefits of Tabata-style training using whole body exercises was largely lost following 2 months of detraining, but whether this applies to athletes tapering is unclear.

**Effects of different types of HIIT on $Vo_2$max and MAOD**

To develop new HIIT methods, we compared several high-intensity intermittent exercise (HIIE) protocols in terms of recruitment of aerobic and anaerobic energy-releasing systems (Kouzaki and Tabata 1998; Tabata 2019; Tabata 2022). To identify a better exercise intensity for a new Tabata training protocol that may be superior to the authentic Tabata training (170% $Vo_2$max; Tabata et al., 1997), we wanted to incorporate higher exercise intensity, because we hypothesized that the higher the intensity, the higher the oxygen uptake, even for extremely high intensity (i.e., supramaximal, and short [20-sec] duration). However, if the exercise intensity of the first 20-sec bout were higher than 170% $Vo_2$max, subjects could not complete 6 or 7 X 20-sec bouts with only 10-sec rest between sets, and exercise intensity during the later sets of 20-sec exercise would be gradually reduced.

To design the new training, we measured oxygen uptake during supramaximal intensity exercises. Nine male students (age: 22 ± 2 years; height: 171 ± 5 cm; weight: 66.2 ± 6.7 kg; $Vo_2$max: 53.8 ± 2.6 ml/kg/min; MAOD: 72.6 ± 4.1 ml/kg) exercised on a bicycle ergometer to exhaustion for a fixed time: 10 sec (12 ± 2 sec), 20 sec (20 ± 1 sec), 30 sec (29 ± 1 sec), 40 sec (39 ± 1 sec), 60 sec (68 ± 6 sec), and 120 sec (131 ± 13 sec). Exercise intensity corresponded to 284 ± 16, 256 ± 18, 223 ± 11, 187 ± 7, 148 ± 8, and 130 ± 6% $Vo_2$max, respectively. As a result, oxygen uptake during the exercises increased from the onset to the end. Oxygen uptake up to 20 sec of exercise at 40–20 sec to exhaustion (180–250% $Vo_2$max) did not differ, but was higher than that observed at 60 and 120 sec to exhaustion (150 and 130% $Vo_2$max). More specifically, oxygen uptake during the first 10 sec of exercise depends on exercise intensity up to the 30 sec exhaustive exercise (220% $Vo_2$max), then plateaus at higher intensities. Although there have been arguments as to whether or not pulmonary oxygen uptake at exercise onset represents metabolism in exercising muscles (Krogh and Lindhard 1913; Casaburi et al. 1989), these data suggest that exercise intensity over 220% $Vo_2$max stimulates the aerobic energy-releasing system maximally.

Therefore, we first designed a protocol of 1st and 2nd sets at 220%, 3rd and 4th sets at 200%, and 5th and 6th sets at 180% $Vo_2$max. We found, however, that oxygen deficit accumulated during relatively higher intensities (>180% $Vo_2$max) did not amount to MAOD, suggesting that such exercise does not maximally stimulate the anaerobic energy-releasing system. Since the intensity of the last set of the first designed protocol was 180% $Vo_2$max, oxygen deficit during such intermittent exercise might not reach MAOD. Therefore, we designed a second protocol with 1st and 2nd sets at 200%, 3rd and 4th sets at 180%, and 5th and 6th sets at 160% $Vo_2$max. We found that oxygen uptake during the 1st to 4th sets of the new HIIT protocols was significantly higher than that observed for Tabata training. This suggested that this protocol could stimulate aerobic energy-releasing systems more and faster than the original Tabata training (Kouzaki and Tabata 1998; Tabata 2019; Tabata 2022).

Peak oxygen uptake during the last sets of the new HIIT exercise protocols was not different from that observed at the end of the Tabata training exercise (Tabata training: 47.6 ± 4.5 ml/kg/min; New protocol: 49.1 ± 4.5 ml/kg/min). In addition to the aerobic energy-releasing system, the new protocol was found to be the most demanding on the anaerobic energy-releasing system. This was because the oxygen deficit during the new protocol was not significantly different from that observed during Tabata training. Furthermore, peak blood lactate concentration after the new protocol was significantly higher than that observed for Tabata training. After the 8-week training using the new protocol, MAOD increased significantly by 32%, while $Vo_2max$ was also significantly elevated by 14% (Kouzaki and Tabata 1998; Tabata 2019; Tabata 2022). These effects on aerobic and anaerobic energy-releasing systems were comparable to those observed in the original Tabata studies (Tabata et al. 1996).

Like the new protocol, we considered that in terms of stimulating both aerobic and anerobic energy-releasing systems, there might be still better training(s) using other types of HIIE than Tabata. Therefore, using Tabata training as a positive control, we needed to conduct extensive investigations to explore the best protocol for athletes.

**Tabata cross training**

Tabata training is performed with an all-out effort. It is meant to completely exhaust the subject. Therefore, Tabata training might not be safe for some individuals, given the potential risk of physical accidents and increased blood pressure. Furthermore, even elite athletes may not choose to execute the authentic Tabata training during tapering period prior to main competitions. We therefore designed a non-exhaustive high-intensity intermittent cross-exercise (HIICE) protocol for HIIT (Tabata cross training) in an effort to achieve the same aerobic effects as the Tabata training, but with wider applications to different populations, including health-oriented people and athletes (Xu et al. 2024). It consists of 4 and 3 bouts of 20-sec high-intensity running and bicycle ergometer exercises, respectively, with a 10-sec rest between bouts. This HIICE adopts running [dominantly recruited muscle: calf muscles (Winter 1983; Kyröläinen et al. 2001)] on a treadmill for bouts 1, 3, 5, and 7, and cycle ergometer exercise [dominantly recruited muscle: thigh muscles (Gollnick et al. 1973; Vøllestad et al. 1992, )] for bouts 2, 4, and 6. The exercise intensity for the HIICE is that which exhausts subjects at the end of the 6th or during the 7th set of the 20-sec exercise. This intensity corresponds to ~170% $Vo_2$max for the bicycling exercise, and ~160% $Vo_2$max for the running.

Rating of perceived exertion (RPE) (Borg 1970; Onodera and Miyashita 1976) after this modified HIICE (Tabata cross training) was 15±2 (n=8; age, 23± 2 years; height, 1.73 ± 0.07 m; body mass, 67.3 ± 5.2 kg), suggesting that it is not exhaustive. Furthermore, peak blood lactate concentration after the Tabata cross training exercise was 12.8±1.0 mmol/l, significantly less than that after Tabata running (15.8±1.4 mmol/l) or bicycling (15.6±1.5 mmol/l) alone training exercises (n=8, $p<0.001$). This may have been because the Tabata cross training involved only 3 and 4 bouts of bicycle and running exercise, respectively, and thus the exercise did not consume the MAOD for running and bicycle exercise. The MAOD is related to exhaustion, and produced by an individual's highest lactate concentration and depletion of creatine phosphate in the dominantly recruited muscles for a specific exercise.

On the other hand, we observed that $\dot{V}O_2$ during the last bouts of bicycling (52.2 ±5.0 ml/kg/min) and running (53.0±4.8 ml/kg/min) in the Tabata cross training exceeded $\dot{V}O_2$max measured for bicycling alone (48.0±5.4 ml/kg/min), and was not significantly different from that of running (54.4±5.0 ml/kg/min) (n=30; age, 23± 1 years; height, 1.74 ± 0.07 m; body mass, 67.7 ± 5.2 kg), suggesting that, without exhaustion, the Tabata cross training does maximally stimulate the aerobic energy-releasing system for both running and bicycle exercise, which might improve $Vo_2$max for both running and bicycling exercise.

 



We preliminary reported that 3 days a week for 6-week of above-mentioned Tabata cross training did increase both running and bicycling $\dot{V}O_2max$ (Liu et al. (in press)).

**Tabata style training using exercise adopted for a specific sport**

We were interested in designing Tabata-style training using bodyweight exercise resembling the exercises in specific sports. For example, we measured $Vo_2max$ before and after a period of Kendo Tabata-style training (Tabata et al, 2021; Tabata 2022). Kendo is a traditional Japanese martial art using bamboo swords (https://en.wikipedia.org/wiki/kendo). The Kendo Tabata-style training consisted of 8 sets of 20-sec maximal Kakari-keiko exercise (see the Wikipedia reference above) with 10-sec rest between sets (https://youtu.be/1SbtX901piU). Seven male Kendo players (age: 20 ± 1 years; height: 174 ± 5 cm; weight: 80.6 ± 19.7kg, n=7) performed the Kendo Tabata-style training 3 times a week for 6 weeks; as the control, 5 male players belonging to the same team trained with the Kendo Tabata-style training group but without the Kendo Tabata-style training (age: 19 ± 1 years; height: 177 ± 4 cm; weight: 69.3 ± 10.5kg, n=5). After the training period, the running $Vo_2max$ of the training group was significantly increased (pre: 50.9 ± 8.4ml/kg/min; post: 54.1 ± 8.0ml/kg/min, $p<0.05$, 6.8±5.6%), while there was no change in the control group (pre: 51.8 ± 3.9ml/kg/min; post: 52.6 ± 3.6 ml/kg/min). We also reported the effects of Tabata-style training using bodyweight-bearing exercises adopted in specific sports such as football, baseball, and badminton (Tabata, 2022). Recommended weight-bearing exercises for Tabata-style training involve dynamic exercises that use large muscle groups like those of the lower extremities. Exercises using small muscle groups, for example, push-up, and isometric exercises are not recommended, because these do not elevate oxygen uptake during the Tabata-style training.

Since such Tabata-style training can be done on sport fields without the need for specific apparatus, it is easier to introduce Tabata-style training to athletes, especially those in many-member teams. Furthermore, such training could be recommended for children. However, studies on Tabata-style training using body weight are rare, although there are some promising data using Tabata-style training called "FUNtervals" used in school children (Ma et al. 2015). Therefore, future studies of practical Tabata-style training with adults and kids are needed.

**Effects of Tabata training on skeletal muscle metabolism and protein expression**

In order to prescribe science-based training, more basic research on HIIT involving Tabata training is needed to further delineate the mechanisms underlying the beneficial effects on sport-oriented and health-oriented outcomes, both of which contribute to improved quality of life. Since Tabata training induces the expression of proteins related not only to sports performance but also to health promotion (Miyamoto-Mikami et al. 2018), more research on the possible effects of Tabata training and other training Tabata-style training on health outcomes is needed.

We demonstrated that Tabata-style swimming training in rats increases glucose transport activity, stimulated by both muscle contraction and insulin, along with increased expression of glucose transporter 4, mitochondrial enzymes (Terada et al. 2001), and enzymes for fatty acid metabolism (Terada et al. 2004). Tabata-style swimming training in rats also increases peroxisome proliferator-activated receptor γ coactivator 1-α (PGC1α) (Terada et al. 2005), which is a candidate for a common molecule (protein) that regulates expression of various proteins and has been shown to increase after training. We first reported this after swimming exercise training (Goto et al. 2000).

For the purpose of screening candidate proteins induced by Tabata-style training, we used a proteomic technique that enabled us to analyze global changes in protein (Yamaguchi et al. 2010). Proteomic profiling revealed that, out of ~800 detected and matched spots, 13 proteins exhibited changes by the rat swimming model of Tabata training compared with sedentary rats, with especially increased expression of glycogen phosphorylase (the first enzyme of glycogenolysis) (Yamaguchi et al. 2010).

Miyamoto-Mikami et al. (2018) reported the effects of Tabata training on skeletal muscle in 11 healthy young men (age: 23.3 ± 2.8 years; height: 173.7 ± 7.2 cm; weight: 67.1 ± 7.1 kg; ($Vo_2$max: 48.2 ± 4.4 ml/kg/min). Subjects completed a 6-week of Tabata bicycle training, exercising 4 days a week. The training significantly increased $Vo_{2max}$ and MAOD by 9.2% ± 7.1% and 20.9% ± 15.8% (mean ± SD), respectively. The expressions of 79 genes in the vastus lateralis (VL) muscle collected by biopsy were significantly increased after the Tabata training. Gene ontology analysis showed that glucose metabolism, mitochondrial membrane, extracellular matrix, and angiogenesis were significantly enriched categories among the Tabata training-induced genes.

In particular, three newly identified exercise-related genes—carnosine synthase 1(CARNS1), PPP1R3C, and serum/glucocorticoid regulated kinase 1 (SGK1)—are interesting. Since muscle buffer capacity is a major biochemical component of MAOD, increase in CARNS1, which may be related to increased anaerobic capacity, might enhance sport performance. In addition, Tabata training enhanced expression of PPP1R3C, which is related to glycogen synthase expression, and (SGK1), which may be related to insulin-dependent glucose uptake in skeletal muscle, and thus might improve glucose metabolism. This investigation further revealed that in humans, Tabata training increased expression of skeletal muscle proteins that have physiological functions, such as phosphofructokinase, citrate synthase, and PGC1 $\alpha$ (Miyamoto-Mikami et al. 2018).

We found that Tabata-style training in rats reduced the number of chemically induced aberrant crypt foci (ACF) compared to sedentary controls (Matsuo et al. 2017). Since ACF is a precancerous cell in colon cancer, HIIT, including Tabata-style training may have preventive effects on colon cancer. Furthermore, secreted protein acidic and rich in cysteine (SPARC), a myokine, in the epitrochlearis muscle was increased after 5 consecutive days of Tabata-style swimming training in rats (Matsuo et al. 2017). SPARC protein in the VL muscle of human also increased after 6 weeks of Tabata training (Miymoto-Mikami et al. 2018). Since SPARC was found to induce apoptosis of ACF (Aoi et al. 2012), the preventive effects of Tabata-style training on colon cancer might be due to the effect of Tabata-style training exercise increasing serum SPARC, which is proportional to the skeletal muscle protein (Tabata 2022) stimulated by training-intensity-dependent expression of PGC1 $\alpha$ (Matsuo et al. 2017).

Nevertheless, there have only been a few studies of low-volume all-out style HIIT (Burgomaster et al. 2008; Gibala et al. 2006) and Tabata-style training (Bonafiglia et al. 2017; Scribbans et al. 2014; Scribbans et al. 2014) on skeletal muscle adaptation. Bonafiglia et al. (2017) reported a strong correlation between mRNA of PGC1 $\alpha$ after an acute bout of Tabata training and increase in SDH activity in skeletal muscle after Tabata training, further implicating PGC1 $\alpha$ as a potential mediator of the adaptive response to training in skeletal muscle.

I would like to emphasize further research on Tabata or Tabata-style training conducted with both human and rats as a tool to maximally elevate cellular signals to the highest level in order to elucidate mechanisms promoting adaptations in cell metabolism and function after exercise training.

 



**Effects of Tabata training on arterial characteristics**

Hasegawa et al. (2018) showed that Tabata-style training in rats significantly reduced aortic pulse wave velocity (PWV), an index of central arterial stiffness, to a level comparable to that of aerobic training, suggesting that this style of HIIT was as effective for central arterial stiffness as conventional aerobic training. Meanwhile, the negative correlation between aortic PWV and eNOS phosphorylation or plasma NOx level observed in this study suggested that Tabata training reduces central arterial stiffness via an increase in aortic NO bioavailability. For the human experiment in this investigation, untrained young male subjects trained 4 days a week for 6 weeks, performing the authentic Tabata bicycle training. The aerobic training group instead performed 45 min of bicycle ergometer exercise at an intensity of 60–70% $Vo_2$max with a 5-min warm up and cool down at 40% $Vo_2$max for each exercise session 3 days week for 8 weeks. $Vo_2$max was significantly increased in both aerobic training (pre: 47.0 ± 2.5ml/kg/min; post: 51.5 ± 2.5 ml/kg/min) and Tabata training (pre: 47.9 ± 2.5 ml/kg/min; post: 52.1 ± 1.9ml/kg/min) groups.

The cfPWV was significantly reduced in both the aerobic training and Tabata training groups compared to the control group, and Tabata training-induced reduction of cfPWV was equal to that of aerobic training. Moreover, the amount of change in plasma NOx level was significantly elevated in both aerobic and Tabata training groups compared to the control, and Tabata training-induced elevation of plasma NOx level was equal to that resulting from aerobic training. These results correspond to those observed in the rat study, suggesting that mechanism(s) explaining Tabata training-induced reduction of arterial stiffness in humans may be similar to those proposed by the animal study described above. These findings were further supported by Dulsky et al. (2023) who reported that high-intensity intermittent exercise training reduced arterial stiffness in police officers.

**Effects of Tabata training on bone metabolism**

Last year, the journal *Medicine and Sciences in Sports and Exercise* published a debate between Foster et al. (2022) and Burnley et al. (2022) regarding periodization of training. The discussion was valuable for trainers, coaches, and athletes designing training progrmas in terms of the benefits and risks associated with specific training.

In this regard, it has been reported that, during prolonged moderate intensity exercise (MIE), serum Ca concentration tended to decrease, resulting in elevation of serum parathyroid hormone (PTH) (Barry and Kohrt, 2007), which may acutely stimulate the resorption of Ca from bone (Chappard et al. 2001). Therefore, repeated disruptions of Ca homeostasis during this type of exercise may contribute to bone loss (Kohrt et al. 2018). For athletes such as long-distance runners who intend to improve their performance by increasing their aerobic power with prolonged training, while the training may improve their aerobic fitness, it could be hazardous for their bone health. In fact, male competitive cyclists were reported to have reduced bone density at the total hip, neck, trochanter, and shaft regions after one year of intensive training and competition (Barry and Kohrt 2008).

In contrast, high intensity exercise increases serum Ca concentration due to hemoconcentration (Cunningham 1985). This finding led us to hypothesize that Tabata training exercise may not induce an increase in serum PTH. Accordingly, we measured serum PTH and related factors after Tabata training and compared them with those measured after 1-h MIE (70% $Vo_2$max) (Hamano et al. 2021). Serum PTH concentration observed 10 min after the Tabata training exercise was significantly decreased from the pre-exercise value ($p<0.05$). Serum PTH concentrations at other time periods were not significantly different from the pre-exercise value. For MIE, significant increases in serum PTH concentration from the pre-exercise values were observed immediately and 10 min after the exercise. Both PTH concentration levels were significantly higher than those observed at the same time points of the Tabata training exercise ($p<0.001$). Serum PTH did not change immediately after Tabata training exercise when serum ionized calcium concentration (iCa) was elevated, and was significantly reduced 10 min after the HIIE (−27%) with elevated iCa compared to the pre-exercise value, suggesting that 10 min of high serum iCa might reduce the secretion of PTH.

Many elite endurance athletes, even junior and high school students, suffer bone injuries that prevent them from training and competing (Changstrom 2015; Hamano et al. 2022). If the exercise-induced increase in PTH leads to an excessive activation of bone absorption during conventional training regimens composed mainly of moderate-intensity long-distance exercise, this could contribute to the risk of bone injury. Therefore, since the responses of PTH to the Tabata training exercise were not found to be hazardous in terms of bone metabolism, endurance athletes may be able to optimize their cardiorespiratory fitness and reduce their risk of bone injury by using HIIT, including Tabata training. This potentially unique favorable feature of Tabata training on bone might be another area of future research interest.

**Effects on cognitive function**

Ma et al. (2014) demonstrated that Tabata-style exercise (FUNtervals) reduces off-task behaviour in grade 2 and 4 primary school students, particularly in students with high rates of such behavior, suggesting that FUNtervals let primary school student be more concentrated in classrooms.

Ma et al. (2015) also demonstrated that selective attention of primary school students aged 9-11 yrs olds was improved by participation in 4-min Tabata-style classroom-based activity (FUNtervals), suggesting that the inclusion of FUNtervals in elementary school classrooms may be utilized as both a means of improving focus and attention in the classroom.

We showed that Tabata training exercise elevated serum brain-derived neurotrophic factor (BDNF) (Nakashima et al. 2023). BDNF is predominantly expressed in the cortex and hippocampus (Rasmussen et al. 2009). Further, circulating BDNF levels were reported to be related to the age-related decline in hippocampal volume, and that the decline in hippocampal volume mediates the decrease in spatial memory performance (Erickson et al., 2010). Because BDNF in blood and brain is associated (Klein et al. 2011), peripheral BDNF is often used as an index to evaluate the potential effects of physical activity on cognitive decline. Cooper et al. 2016 and Kujach et al. 2020 reported that serum BDNF levels increased after high intensity intermittent exercise in conjunction with improved cognitive performance tests scores. Furthermore, non-exhaustive Tabata-style training exercise consisting of 5 sets of 20-sec exercise at the same intensity adopted in previous Tabata training exercise also significantly increased serum BDNF, suggesting that both exhaustive and non-exhaustive Tabata-style training holds potential to improve cognitive function.

However, Zotcheva et al. (2023) reported that occupational high-intensity physical activity may be a risk factor for reduced cognitive function and dementia. Reitlo et al. (2023) found that compared to controls, although within normal range, the HIIT (4x4 min intervals at ~90% peak heart rate) group had significantly increased hippocampal atrophy located at CA1 and the hippocampal body. These recent reports suggested that HIIT may not be beneficial in terms of brain health. HIIT adopted in this specific study (Reitlo et al. 2023) was different from Tabata training. Therefore, further studies on the effects of Tabata training on the brain, especially the hippocampus, are needed.

**Study of the effects of Tabata training on young populations**

The effects of Tabata-style training on young populations have been reported. Chuensiri et al. (2018) found that arterial stiffness, brachial-ankle pulse wave velocity, and carotid intima-media thickness decreased after 12 weeks of Tabata-style training on a bicycle (3 times a week) ($p. < 0.05$) in 48 preadolescent boys (aged 8–12 years) living with obesity, suggesting that Tabata-style training has favorable effects on aerobic capacity, metabolic rate, vascular function and structure in this population.

Alonso-Fernández (2017) studied the effects of Tabata-style training (2 times a week for 8 weeks) consisting of bodyweight-bearing and functional exercise, including a coordination exercise on a ladder, in female handball players (15.2±0.6 years old). The results showed that the training increased $Vo_2max$ significantly by 6.2% (pre: 43.96±2.80 ml/kg/min, post: 46.68±2.60 ml/kg/min, $p<0.05$), and that body fat percent decreased marginally (pre: 30.13±4.16%, post: 29.09±3.59%, $p<0.05$). Subsequently, Alonso-Fernández (2019), showed that effects of Tabata-style bodyweight training (2 times a week for 7 weeks) significantly increased $Vo_2max$ in male and female adolescents (n=13) aged 15–16 years by 10.21% (pre: 42.91±6.91 ml/kg/min, post: 47.29±7.72 ml/kg/min, $p<0.001$), and also decreased body fat mass significantly (pre: 12.76±3.90 kg, post: 11.87±3.79 kg, $p<0.001$). This training also increased fat-free mass significantly (pre: 36.00±8.95 kg, post: 38.25±8.59 kg, $p<0.001$).

The dropout rate in the Chuiesiri et al. (2018) study of pre-adolescent boys with obesity was quite low (6.3%), and Logan et al. (2016) reported a high adherence rate among inactive volunteer adolescents to an all-out-type HIIT using various types of weight-bearing exercise; 90% of their subjects completed the regimen. These rates suggest that these Tabata-style training protocols were tolerable and positively accepted by young populations.

My colleagues have been studying the effects of bodyweight-bearing Tabata-style training after morning assembly in an elementary school on the schoolgrounds. Videos from the school show that most pupils appear to enjoy Tabata-style training. The training seems to be welcomed more easily than in an adult population. One teacher asked the students to design their own Tabata-style training sessions, which may help with adherence and enjoyment.

Since physical activity and exercise habits are not expected to increase in this population in the future, the incidence of non-communicable diseases (NCDs) may increase. To protect youngsters from NCDs, HIIT including Tabata-style training should be encouraged in schools (Ma et al. 2015). For these reasons, we should collect more evidence of Tabata training in terms of feasibility and beneficial effects, particularly in younger populations.

**Effects of Tabata training on energy consumption and body weight**

After moderate-submaximal to high-intensity exercise, oxygen uptake is elevated above resting level, depicted as excess post-exercise oxygen uptake (EPOC) (Bahr et al. 1987). EPOC continues for several hours, and has been considered important from the viewpoint of increased exergy expenditure due to exercise (US DRIs; Food and Nutrition Board, Institute of Medicine 2002). However, most previous studies reported EPOC after exercise at submaximal intensity.

There were rumors that Tabata training is effective for weight loss, even though we had not reported reduction of body weight after our original Tabata training studies and this was not the focus of the original work. Since it is well known that energy expenditure during exhaustive intermittent exercise is relatively small as comparted to prolonged moderate intensity continuous exercise, the rumors attributed its effect on body weight to EPOC after Tabata training. Therefore, using a metabolic chamber, we had started to quantify EPOC and elevated oxygen uptake by diet (diet-induced thermogenesis, $\Delta$DIT) after Tabata bicycle training (Tsuji et al. 2017).

We found that elevated energy expenditure by the Tabata training including oxygen uptake during a 10-min warm up exercise at 50% $Vo_2$max, during a Tabata training exercise, EPOC and $\Delta$DIT (Tsuji e al. 2017) was 834 ± 52 kJ for subjects (age: 23 ± 1 years; height: 171 ± 5 cm; weight: 64.4 ± 6.0 kg; $Vo_2$max:52.1 ± 6.6 ml/kg/min). As frequency of the Tabata training is generally 2-3 times a week, weight-reducing effect of Tabata training seems to be minimal. In fact, after 6 weeks of Tabata training, subjects' body weight was not changed (Tabata et al. 1996; Liu et al. (in press)). These findings are supported by the meta-analyses by Viana et al. (2019), who failed to find evidence supporting weight loss following studies utilizing Tabata-style training.

I have heard that Tabata training reduces body weight. The body weight of some individuals provided with personal lessons that included Tabata training and dietary instruction by a leading Japanese fitness club was significantly decreased. This might have been related to the change in eating habits during training. Our unpublished chamber experiment demonstrated that energy expenditure from the start to 3.5 h after exercise, including exhaustive, body-weight-bearing Tabata-style training sandwiched between 5-min stretching and an 10-min intensive warm-up, and followed by 5-min core exercise and 10-min intensive cool down (total exercise time: 29 min), was greater than the resting oxygen uptake of young male subjects by 244 ± 67 kcal (age: 23 ± 3 years; height: 171 ± 5 cm; weight: 75.7 ± 14.1 kg; $Vo_2max$ :46.1 ±9.2 ml/kg/min, n=8) (Tabata, 2022). This suggests that if such exercise, including Tabata training, were carried out for a longer time period, it might significantly reduce body weight (Stroebele, 2011), unless compensated for by an increased food intake. Therefore, instructors are encouraged to create programs for weight reduction including not only Tabata training but also prolonged warm ups and cool downs (and other exercises), even though energy expenditure with such programs two or three times a week remains small. Such programs may facilitate recovery from the hard exercise of Tabata training in addition to improving aerobic fitness.

Another possibility is that the elevation of aerobic fitness by Tabata training may increase daily physical activities (Cao et al. 2009; Cao et al. 2010), resulting in increased energy expenditure and subsequent decrease in body weight. Lu et al. (2020) demonstrated a compensatory increase in sedentary time (ST) (4.4 ± 6.0%, $p < 0.01$) and decrease in light-intensity physical activity (LPA) (-7.3 ± 16.7%, $p < 0.05$) after 3 days of maximal Tabata-style weightbearing exercise in one week. Meanwhile, moderate-intensity physical activity (MPA), vigorous-intensity physical activity (VPA), and total physical activity (TPA) increased following exercise. Sleep duration and prolonged sedentary time were reduced ($p < 0.05$). Exercise intensity and aerobic capacity were associated with changes in ST. The results from the study indicated that participating in a low-volume HIIE may have encouraged participants who were previously inactive to become more active, despite changes in ST.

Future studies using Tabata training for longer durations will be required before we decide whether Tabata training is effective for weight reduction.

**Tabata training against COVID 19 pandemic-induced inactivity**

Souza et al. (2020) suggested that HIIT, including Tabata training, is a potential strategy to prevent symptoms induced by reduced physical activity due to the COVID19 pandemic. We demonstrated that Tabata-style bodyweight training was effective for improving the aerobic power of male students who could not commute to university and were forced to stay home during the pandemic. This bodyweight-bearing Tabata-style training consisted of two, 20-sec sets of thigh lifts, scissor jumps, back kicks, and burpee jumps with 10-sec rest between sets (https://youtu.be/lwlfyR_CuKA) (Tabata 2022). Seven male students (age: 21 ± 1 years; weight: 64.1 ± 4.3 kg; $Vo_2$max: 46.6 ± 2.8 ml/kg/min) trained using the Tabata-style protocol 3 days a week for 6 weeks. After the training, $Vo_2$max was significantly increased to 49.5 ± 2.7 ml/kg/min (6.5±4.8%) ($p<0.05$). In addition, RPE and heart rate [(HR) beats per minute (bpm)] observed at the end of 10-min treadmill running exercise at a speed of 90 m/min on an inclination of 10% were significantly reduced [HR (pre: 177 ± 10 bpm; post: 169 ± 6, $p<0.01$); RPE (pre: 13 ± 1; post: 11 ± 1, $p<0.01$)], suggesting that this training allowed subjects to exercise more easily at the same absolute intensity. Since these students did not attend university for the whole training period and only visited campus to determine $Vo_2$max (3-5 days), it is likely their physical activity levels appeared very low during the training days due to COVID 19 pandemic.

Alonso-Fernández et al. (2022) reported that men and women confined at home due to the COVID19 pandemic reported reduced depression symptoms after a well-organized 8-week weightbearing Tabata-style training. The body weight of the subjects in this study did not change significantly, although the body weight of the control group, who did not exercise during the training, increased significantly.

Although I hope not to see another pandemic of infectious disease, we must collect evidence regarding increase in the aerobic energy-releasing system by HIIT, including Tabata or Tabata-style training, to prepare for inactivity due to the risk of future pandemics.

## Effects of HIIT on longevity

Investigating the effect of HIIT, including Tabata training, on longevity is another important future undertaking. Holloszy (Hollogzy 1983; Holloszy1993) wrote that due to the rate-of-living theory formulated by Pearl (1928), the medical and scientific society in the US and Europe from about 1925 to roughly 1960 were very conservative in their attitude toward exercise more vigorous than walking for people beyond school age. According to the rate-of-living theory, "the greater the rate of energy expenditure and oxygen utilization, the shorter the life-span". No evidence was found to support the rate-of-living theory. Instead, there were reports that light-, moderate-, and vigorous-intensity exercise improved $Vo_2max$, which represents the functional capacity of the cardiovascular system. The beneficial effects of exercise training at various intensity ranges up to $Vo_2max$ (aerobic training) began to be recognized in terms of health promotion.

Holloszy (Holloszy 1983; Holloszy 1993) recommended light- to moderate-intensity exercise/training, but remained unsure that there was sufficient evidence for vigorous/strenuous intensity (>70% $Vo_2max$) exercise on health promotion. In this context, epidemiological research on the effects of HIIT at higher intensity than "vigorous" on longevity will be challenging. Whether for or against, however, it is important to collect evidence without preconceptions as to whether HIIT including Tabata training may be beneficial for longevity.

## Conclusion

The current perspective summarizes evidence on Tabata training reported after the publication of our original papers (Tabata et al. 1996; Tabata et al. 1997), and proposes future directions for studies on HIIT, including Tabata training, for everyone from highly motivated athletes to young kids, and health promotion for everyone from children to the elderly in terms of effectiveness and safety. In addition, basic molecular biological research is needed to clarify the mechanism(s) that explain the effects of Tabata training on skeletal muscle and systemic adaptations, which has relevance for explaining the benefits of low-volume vigorous-intensity exercise on sport performance (Little et al. 2019) and health promotion (Gibala and Little 2020; Islam et al. 2022).

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## Competing interest

The author has no competing interests to report.

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This manuscript does not report data.

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