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Maintaining Physical Performance: The Minimal Dose of Exercise Needed to Preserve Endurance and Strength Over Time

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Abstract

Maintaining physical performance: the minimal dose of exercise needed to preserve endurance and strength over time, Spiering, BA, Mujika, I, Sharp, MA, and Foulis, SA. *J Strength Cond Res* XX(X): 000–000, 2020—Nearly every physically active person encounters periods in which the time available for exercise is limited (e.g., personal, family, or business conflicts). During such periods, the goal of physical training may be to simply maintain (rather than improve) physical performance. Similarly, certain special populations may desire to maintain performance for prolonged periods, namely athletes (during the competitive season and off-season) and military personnel (during deployment). The primary purpose of this brief, narrative review is to identify the minimal dose of exercise (i.e., frequency, volume, and intensity) needed to maintain physical performance over time. In general populations, endurance performance can be maintained for up to 15 weeks when training frequency is reduced to as little as 2 sessions per week or when exercise volume is reduced by 33–66% (as low as 13–26 minutes per session), as long as exercise intensity (exercising heart rate) is maintained. Strength and muscle size (at least in younger populations) can be maintained for up to 32 weeks with as little as 1 session of strength training per week and 1 set per exercise, as long as exercise intensity (relative load) is maintained; whereas, in older populations, maintaining muscle size may require up to 2 sessions per week and 2–3 sets per exercise, while maintaining exercise intensity. Insufficient data exists to make specific recommendations for athletes or military personnel. Our primary conclusion is that exercise intensity seems to be the key variable for maintaining physical performance over time, despite relatively large reductions in exercise frequency and volume.

Key Words: fitness, soldiers, tactical, training, sports

Introduction

Exercise and sport professionals typically focus on enhancing the physical performance of their athletes and clients. By prescribing specific exercises at appropriate doses and with sufficient recovery periods, exercise and sport professionals can evoke substantial improvements in physical performance (2,25). That said, instances exist in which simply maintaining physical performance may be the goal of training. Oftentimes, athletes and clients are faced with situations in which they cannot or should not devote more time to training (e.g., in the event of other time commitments or during periods of busy competition schedules). Generally speaking, if the overall dose of exercise is reduced to only that which is essential to maintain physical performance, then athletes and clients can re-allocate their available time toward other commitments or recovery. The purpose of this brief, narrative review is to: (a) elaborate on the importance of maintaining physical performance in the general population, and certain special populations (i.e., athletes and military personnel); (b) attempt to identify the minimal dose of exercise (i.e., frequency, volume, and intensity of training) needed to maintain physical performance; and (c) identify areas of future research aimed at enhancing exercise and sport professionals' ability to effectively prescribe exercise with the explicit goal of maintaining physical performance.

Noteworthy, four important caveats help define the scope of this review paper. First, this review paper focuses on maintaining physical performance, but will not focus on the minimal dose of exercise required to maintain body weight, body composition, physiological adaptations (e.g., bone mineral density, cardiac function), or health status (e.g., insulin sensitivity, blood pressure, other indicators of disease risk). Second, to streamline comparisons among a broad array of studies, we have operationally defined "performance" as common adaptations to endurance training (i.e., changes in endurance and maximal aerobic capacity [$\dot{V}O_2max$]) and common adaptation to strength training (i.e., changes in strength and muscle size). This review paper will not focus on maintaining other adaptations to training (e.g., muscle power, agility, flexibility), as relatively few studies have investigated the minimal dose of exercise necessary to maintain these variables. Third, to separate "reduced training research" (i.e., the reduction of training over the long-term [weeks to months] with the goal of maintaining performance) from "tapering research" (i.e., the reduction in training over the short-term [days to weeks] with the goal of reducing temporary fatigue, enhancing recovery, and subsequently improving competitive performance), only studies in which the reduced training period lasted >4 weeks have been included in this review paper (39). For more information on optimizing competitive

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performance through tapering, the reader is referred to relevant review papers (4,35,43,46,60). Finally, this paper used a narrative review format. To gather relevant scientific papers, we searched PubMed and Web Of Science using standard search criteria. Importantly, although narrative reviews can be useful for describing general themes in the scientific literature, they are also susceptible to study selection bias and subjective interpretation of study findings. Therefore, we caution the reader to exercise judgement when interpreting the overall conclusions of this review paper.

The Importance of Maintaining Physical Performance in the General and Selected Special Populations

General Population

In addition to improving many aspects of physical and mental health, exercise also improves physical performance (18). These performance improvements impart beneficial effects on activities of daily living, and promote "successful aging" (i.e., protecting against aging-related declines in physical ability) (9). That said, nearly every physically active person has or will encounter a period in which external conflicts limit the time available for exercise. For example, personal conflicts, family commitments, caring for an ill family member, extended travel for personal or business reasons, or heightened business responsibilities present common limits for time availability. Although occasional short-term training cessation (days to weeks) may provide physical and psychological rejuvenation from training—and theoretically reduce the risk of overuse injuries—significant losses in endurance and strength performance can occur when training cessation extends beyond ~2–4 weeks (although the magnitude and rate of decay vary between studies and depend on previous training history, initial performance values, and the outcome variable of interest) (3,38–41). Given the common obstacles to performing exercise experienced by the general population, individuals are confronted with a simple choice: (a) eliminate training for a period of time and face the consequences of training cessation on physical performance; or (b) conduct the minimal amount of exercise necessary to preserve physical performance. Encouragingly, available scientific evidence indicates that the minimal amount of exercise needed to maintain physical performance may be lower than one might assume (discussed in detail below).

Athletes

Athletes typically focus on improving their physical performance before the competitive season to optimize individual performance and maximize the likelihood of victory (62). During the competitive season, however, many athletes experience conflicting demands (e.g., practices, competitions, travel, meetings with coaches and teammates, etc.), which reduce the time available for training sessions and increase the need for recovery. Therefore, during the competitive season, many athletes (particularly team sport athletes) focus on simply maintaining physical performance, while using their remaining time to improve technical, tactical, and mental aspects of their sport and to recover from practices and competitions (37). With this goal in mind, one could wonder whether the physical demands of practices and competitions are sufficient to maintain endurance and strength performance during the competitive season. If this was the case, then supplementary strength and conditioning sessions would not be necessary. With respect to endurance performance, the cardiovascular demands of practices and competitions are likely to substantially vary between sports, and even vary among events, positions, and different teams playing the same sport. Therefore, it is not prudent to make a one-size-fits-all recommendation regarding whether to include supplementary endurance exercise during the competitive season. Instead, a more pragmatic approach would be for exercise and sport practitioners to quantify the cardiovascular demands of practices and competitions, measure the performance level of individual athletes, and subsequently determine whether supplementary endurance exercise is necessary. Simplified methods for quantifying the cardiovascular demands of practices and competitions have been reported in the literature (10,57); although recent advances in technology and analysis have yielded more sophisticated approaches (5). With respect to strength performance, evidence exists that insufficient strength training during the competitive season results in loss of strength (as well as reduced indicators of athletic performance) (49). Conversely, research has also shown that too much supplementary strength training during the competitive season can overstress the athlete and ultimately impair strength (as well as other indicators of athletic performance) (30). Overall, these findings emphasize the importance of identifying a minimal dose of exercise to effectively maintain performance during the competitive season.

After the competitive season, many athletes cease training during the off-season as a method to recover physically and psychologically. Although training cessation can be restorative, it also causes reductions in physical performance that must be addressed before the next season resumes (55). As such, Silva et al. (55) have referred to the off-season as a "window of opportunity" in which a minimal dose of exercise can be used to maintain or blunt the loss of performance, and address any imbalances that may predispose athletes to injury when training resumes. This assertion by Silva et al. (55) is substantiated by Mujika et al. (36) and Rønnestad et al. (48). Mujika et al. (36) found that attenuating the decline in performance during the off-season was associated with further enhancement of performance during the subsequent season when compared with the previous season. Similarly, Rønnestad et al. (48) found that adding supplementary high-intensity endurance training not only maintained endurance performance during the off-season, but it also allowed for further improvement in endurance performance during the subsequent season. Conversely, in that same study (48), the group that did not perform supplementary high-intensity endurance training experienced a decline in performance during the off-season, and performance during the subsequent season merely returned to the previous seasons' values. Therefore, the minimal training recommendations provided herein would also be valuable guidance for athletes during the off-season.

Military Personnel

Military personnel often have physically demanding occupations. Job-related tasks can include load carriage and heavy lifting (53), for example, and performance on these tasks is strongly associated with aerobic capacity and strength (17). To ensure that soldiers possess sufficient physical fitness to adequately perform their occupational tasks, the military allots time for daily physical training and conducts bi-annual physical performance testing. During deployment, military personnel may have access to exercise facilities and equipment; however, in consideration of their unit's operational tempo and the individual's duty requirements, it is their personal responsibility to complete their physical training. Without evidence-based guidance on the optimal dose of exercise to maintain their physical performance while deployed, it is possible that military personnel could under-train or over-train (especially given

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their physically demanding occupational tasks, which can be performed frequently over several months of deployment) (6).

After reviewing the changes in physical performance in response to deployment, general trends emerge (summarized in Table 1). Specifically, available studies demonstrate that military personnel tend to maintain (or even improve) their muscular strength and lean mass during deployment (14,15,31,64) (although one study revealed a 3.5% decline in lean mass during deployment with no corresponding change in muscle strength (54)). Conversely, a majority of studies indicate that running endurance and $\dot{V}O_2$max decline during deployment (16,31,54,64), although some indicate maintained endurance performance (14,44,47). Sharp et al. (54) attempted to identify the mechanism for reduced $\dot{V}O_2$max during deployment by examining self-reported exercise habits. They found that 80% of soldiers performed endurance exercise for at least 3 sessions per week during the year leading up to deployment, whereas only 35% reported doing so during deployment. Conversely, for strength training, there was no difference in the percentage of soldiers performing strength training for at least 3 sessions per week before deployment vs. during deployment. These findings perhaps explain why endurance performance declined during deployment whereas strength performance was maintained (54). Reduced endurance performance during deployment is doubly concerning because of its association with increased injury risk (29). Warr et al. (64) reported that reduced aerobic capacity during deployment was associated with increased utilization of medical resources. In fact, Warr et al. (64) concluded that: "…results from this study suggest that if military leaders were able to ensure that their soldiers maintained their predeployment level of aerobic fitness, then overall medical resource utilization could be significantly decreased." Alternatively, in a separate study, soldiers who performed longer strength training sessions (>30 minutes) while deployed were at increased risk of injury compared with those who performed shorter strength training sessions (≤30 minutes) (50). Collectively, these studies underscore the importance of evidence-based, minimal-dose training guidelines for maintaining physical performance during deployment.

The Minimal Dose of Exercise Necessary to Maintain Physical Performance

Before describing the minimal dose of exercise needed to maintain performance, we must first define the variables of interest (i.e., frequency, volume, and intensity of exercise). With respect to endurance training, "frequency" refers the number of training sessions per week that endurance exercise was performed (e.g., 3 sessions per week); "volume" refers to the amount of time spent exercising (e.g., 30 minutes per session); and "intensity" refers to the percent of maximal capacity sustained during exercise, such as percent maximal heart rate (HRmax) (e.g., 80% of HRmax). Regarding strength training, "frequency" refers to the number of sessions per week that strengthening exercises were performed (e.g., 2 sessions per week). Although, strictly speaking, the "volume" of strength training equals the number of sets multiplied by the number of repetitions, the studies referenced in this paper have manipulated volume by altering the number of sets and keeping the number of repetitions per set (and thus the exercise load) the same; therefore, in this paper, "volume" will simply refer to the number of sets per exercise (e.g., 3 sets). Finally, although multiple methods exist for defining the "intensity" of strength training (8,33), the studies referenced in this review paper have defined "intensity" as the load used relative to the individual's maximal ability. More specifically, "intensity" was prescribed either as a percent of one-repetition maximum (e.g., 80% of one repetition maximum [1RM] [1RM is the maximal load that can be successfully lifted for one repetition]) or as a maximal load that can be lifted for a given number of repetitions (e.g., the maximal load that can be lifted for 10 repetitions [10RM]).

All of the studies referenced in this section used similar experimental designs to identify the minimal dose of exercise necessary to maintain physical performance. Figure 1 provides an overview of the experimental design of these studies, and the possible range of subsequent performance outcomes. Importantly, except where specifically indicated, the studies referenced in this section used relatively untrained participants of various ages from the general population. Therefore, caution is warranted when attempting to extrapolate these findings to special populations (i.e., athletes and military personnel).

Maintaining Adaptations to Endurance Training (i.e., Endurance and $\dot{V}O_2$max)

Hickson and colleagues (23–25) performed a series of experiments in which moderately active, yet previously untrained subjects performed the same dose of continuous and interval

Table 1

Effects of a military deployment on physical performance.*

		Deployment		Physical performance			
Ref.	Population	Location	Duration	End.†	$\dot{V}o_2$max	Strength‡	Lean mass§
(16)	US Special Operations	Submarine	33 d	↓			
(54)	US Infantry	Afghanistan	9 mo		↓	↔	↓
(31)	US Combat Arms	Iraq	13 mo	↓	↓	↑	↑
(64)	US Army National Guard	Afghanistan or Iraq	10–15 mo		↓	↑	↔
(47)	Finnish Defence Forces	Chad	4 mo	↔		↔	
(14)	British Royal Marines	Afghanistan	6 mo		↔	↔	↔
(44)	US Combat Aviation	Afghanistan	12 mo		↔		
(15)	US Special Operations	Afghanistan‖	3–6 mo			↑	↑

*End. = running endurance; ↑ = significant increase compared with predeployment values; ↔ = no significant change compared with predeployment values; ↓ = significant decrease compared with predeployment values.

†Running endurance was assessed using either the 2-mile run or a 12-minute run.

‡Strength was assessed as a one-repetition maximum (using a squat, bench, or incremental box lifting test) or a maximal isometric strength test (using a handgrip, knee extension, or lifting test); for ease of interpretation, results have been collapsed across testing modalities.

§No previous studies have specifically examined changes in muscle size (cross sectional area) in response to deployment; therefore, we instead report changes in lean mass as a surrogate.

‖86% of soldiers in this study deployed to Afghanistan; the remaining soldiers deployed elsewhere.

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endurance training (6 sessions per week, 40 minutes per session, at ~90–100% of HRmax) for 10 weeks; subsequently, subjects were randomly assigned to groups in which either the frequency, volume, or intensity of exercise was reduced by 33% or 66% for the next 15 weeks. Adaptations (i.e., short-term endurance [i.e., time to exhaustion at workloads equal to ~100% of $\dot{V}O_2$max, which generally lasted ~4–8 minutes], long-term endurance [i.e., time to exhaustion at workloads equal to ~80% of $\dot{V}O_2$max, which generally lasted ~1–3 hours], and $\dot{V}O_2$max) were assessed pretraining, post-training, and post-reduced training. The results of Hickson et al. (23–25), as well as the results of Brynteson and Sinning (7) in which the effect of reduced exercise frequency was examined, are summarized in Tables 2 and 3, and discussed in detail below. Importantly, our recommendations regarding the minimal dose of exercise needed to maintain endurance performance are largely based on the single series of experiments conducted by Hickson et al. (23–25). Because no additional research could be found to further substantiate their findings (besides that of Brynteson and Sinning (7)), these recommendations should be treated with caution, because the findings have not been replicated.

Reduced Frequency. After training moderately active subjects 6 sessions per week for 10 weeks, Hickson and Rosenkoetter (25) reduced training frequency to 4 sessions per week or 2 sessions per week for 15 weeks, while exercise volume (40 minutes per session) and intensity (~90–100% of HRmax) were maintained. Short-term endurance and $\dot{V}O_2$max were fully maintained, regardless of the exercise frequency. Because of the study design, Hickson and Rosenkoetter (25) were not able to determine whether a reduced training frequency of less than 2 sessions per week was effective at maintaining short-term endurance and $\dot{V}O_2$max. Brynteson and Sinning (7) trained subjects with an undisclosed previous training status for 5 sessions per week, 30 minutes per session, at 80% of HRmax for 5 weeks. Subsequently, subjects were randomly assigned to receive reduced exercise frequency of either 1, 2, 3, or 4 sessions per week for the next 5 weeks, whereas exercise volume and intensity were maintained. These authors (7) found that $\dot{V}O_2$max was effectively maintained for 5 weeks in all groups, regardless of exercise frequency. That said, after pooling the results across groups, Brynteson and Sinning (7) found that groups performing reduced training for 3–4 sessions per week (mean change of approximately +1% compared with post-training values) were more effective in maintaining their $\dot{V}O_2$max than groups performing reduced training for 1–2 sessions per week (mean change of approximately −3% compared with post-training values). Overall, because Hickson and Rosenkoetter (25) identified 2 session per week as sufficient for maintaining

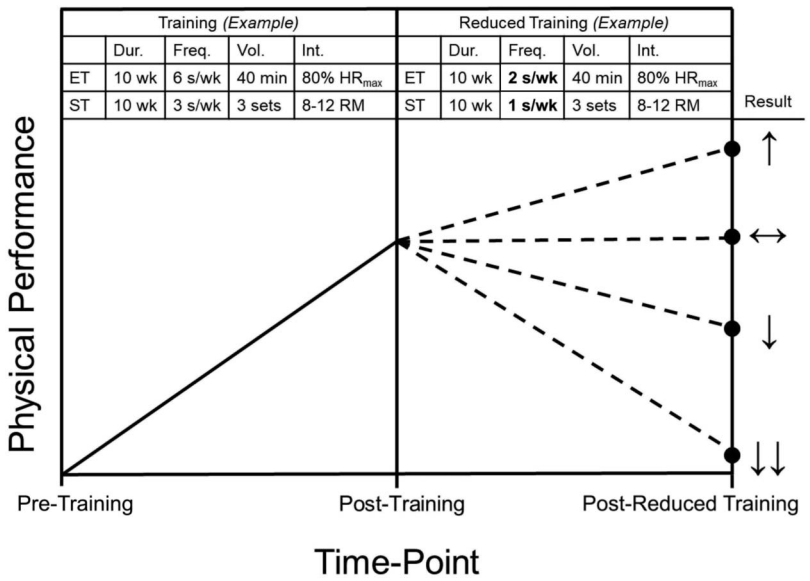

Figure 1. Generalized experimental design and potential performance outcomes. The studies examining the effects of reduced training on performance all followed very similar experimental designs. In these studies, subjects performed a standardized training regimen for several weeks. Subsequently, subjects performed a period of "reduced training" for several weeks. Physical performance (endurance, $\dot{V}O_2$max, strength, or muscle size) was measured pre-training, post-training, and post-reduced training. In this review paper, we categorized the physical performance outcomes as having one of 4 potential outcomes: ↑ = physical performance further increased (i.e., significantly greater than post-training values); ↔ = physical performance was fully maintained (i.e., not significantly different compared to post-training values); ↓ = physical performance was partially maintained (i.e., significantly reduced compared to post-training values, but significantly greater than pre-training values); or ↓↓ = physical performance was not maintained (i.e., significantly reduced compared to post-training values and not significantly different compared to pre-training values). The training and reduced training exercise prescriptions provided in this figure are for illustrative purposes only. The exact exercise prescriptions used in the relevant studies are provided elsewhere in the manuscript. The gray shaded boxes are used to draw the reader's attention to the exercise variable that was changed compared to normal training values. ET = endurance training; Freq. = frequency; HRmax = maximum heart rate; Int. = intensity; RM = repetition maximum; s = sessions; ST = strength training; Vol. = volume.

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Table 2

Effect of reduced training on endurance performance.*†‡

		Training				Reduced training				
Ref.	Test	Dur. (wk)	Freq. (s·wk^{-1})	Vol. (min)	Int.	Dur.	Freq. (s·wk^{-1})	Vol. (min)	Int.	Result
(25)	ST End.§	10	6	40	90–100% HRmax	15	**4**	40	90–100% HRmax	↔
(25)	ST End.§	10	6	40	90–100% HRmax	15	**2**	40	90–100% HRmax	↔
(24)	ST End.§	10	6	40	90–100% HRmax	15	6	**26**	90–100% HRmax	↔
(24)	ST End.§	10	6	40	90–100% HRmax	15	6	**13**	90–100% HRmax	↔
(23)	ST End.§	10	6	40	90–100% HRmax	15	6	40	**82-87% HRmax**	↔
(23)	ST End.§	10	6	40	90–100% HRmax	15	6	40	**61-67% HRmax**	↓
(24)	LT End.‖	10	6	40	90–100% HRmax	15	6	**26**	90–100% HRmax	↔
(24)	LT End.‖	10	6	40	90–100% HRmax	15	6	**13**	90–100% HRmax	↓
(23)	LT End.‖	10	6	40	90–100% HRmax	15	6	40	**82-87% HRmax**	↓
(23)	LT End.‖	10	6	40	90–100% HRmax	15	6	40	**61-67% HRmax**	↓

*Dur. = duration; End. = endurance; HRmax = maximum heart rate; LT = long-term; Ref. = reference; s = sessions; ST = short-term; ↑ = physical performance further increased (i.e., significantly greater than post-training values); ↔ = physical performance was fully maintained (i.e., not significantly different compared with post-training values); ↓ = physical performance was partially maintained (i.e., significantly reduced compared with post-training values, but significantly greater than pretraining values); ↓↓ = physical performance was not maintained (i.e., significantly reduced compared with post-training values and not significantly different compared with pretraining values).

†Bolded values are used to draw the reader's attention to the exercise variable that was changed compared with normal training values.

‡The endurance tests were measured using treadmill and cycling tests; the effects of reduced training on endurance was similar, regardless of the modality of testing (treadmill vs. cycling); therefore, for ease of comparison, the treadmill and cycling results have been pooled.

§The short-term endurance test was the time-to-exhaustion at work rates requiring ~100% of maximal aerobic capacity (which generally lasted 4–8 min).

‖The long-term endurance test was the time-to-exhaustion at work rates requiring ~80% of maximal aerobic capacity (which generally lasted 1–3 h).

endurance performance, and because Brynteson and Sinning (7) were unable to identify clear differences between reduced training of 1, 2, 3, or 4 sessions per week, we conclude that short-term endurance and $\dot{V}O_2$max can be fully maintained for up to 15 weeks when exercising as little as 2 sessions per week, as long as exercise volume and intensity are maintained. The minimal exercise frequency necessary to maintain long-term endurance has not been identified.

Two caveats must be mentioned with respect to the effect of reduced frequency on endurance adaptations. First, although as little as 2 sessions per week seems to maintain endurance performance in general populations, short-term (≤4 weeks) research indicates that a more conservative approach may be required for highly trained individuals. More specifically, other researchers (26,34,42) have recommended reducing training frequency by no more than ~20% to maintain athletic performance. Second, one additional study by Slettalokken and Rønnestad (56) examined the effects of supplementary high-intensity interval training (HIIT) performed at different frequencies during the off-season on endurance performance. However, the participants also performed other running and soccer training during the intervention period, which may have affected the results. Therefore, this study (56) has not been included in the analysis.

Reduced Volume. After training moderately active subjects for 40 minutes per session for 10 weeks, Hickson et al. (24) reduced training volume by 33% (26 minutes per session) or 66% (13 minutes per session) for 15 weeks, whereas exercise frequency (6 sessions per week) and intensity (~90–100% of HRmax) were maintained. Short-term endurance and $\dot{V}O_2$max were fully maintained, regardless of the exercise volume. Long-term endurance was fully maintained when volume was reduced by 33%;

Table 3

Effect of reduced training on maximal aerobic capacity ($\dot{V}O_2$max).*†

		Training				Reduced training				
Ref.	Test	Dur. (wk)	Freq. (s·wk^{-1})	Vol. (min)	Int.	Dur.	Freq. (s·wk^{-1})	Vol. (min)	Int.	Result
(7)	$\dot{V}O_2$max	5	5	30	80% HRmax	5	**4**	30	80% HRmax	↔
(7)	$\dot{V}O_2$max	5	5	30	80% HRmax	5	**3**	30	80% HRmax	↔
(7)	$\dot{V}O_2$max	5	5	30	80% HRmax	5	**2**	30	80% HRmax	↔
(7)	$\dot{V}O_2$max	5	5	30	80% HRmax	5	**1**	30	80% HRmax	↔
(25)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	**0**	**N/A**	**N/A**	↓
(25)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	**4**	40	90–100% HRmax	↔
(25)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	**2**	40	90–100% HRmax	↔
(24)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	6	**26**	90–100% HRmax	↔
(24)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	6	**13**	90–100% HRmax	↔
(23)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	6	40	**82-87% HRmax**	↓
(23)	$\dot{V}O_2$max‡	10	6	40	90–100% HRmax	15	6	40	**61-67% HRmax**	$\downarrow^c$, $\downarrow\downarrow^t$

*Bolded values are used to draw the reader's attention to the exercise variable that was changed compared to normal training values.

†Dur. = duration; HRmax = maximum heart rate; N/A = not applicable; s = sessions; ↑ = physical performance further increased (i.e., significantly greater than post-training values); ↔ = physical performance was fully maintained (i.e., not significantly different compared to post-training values); ↓ = physical performance was partially maintained (i.e., significantly reduced compared to post-training values, but significantly greater than pre-training values); ↓↓ = physical performance was not maintained (i.e., significantly reduced compared to post-training values and not significantly different compared to pre-training values).

‡$\dot{V}O_2$max was measured using treadmill and cycling tests; the effects of reduced training on $\dot{V}O_2$max was similar, regardless of the modality of testing (treadmill vs. cycling); therefore, for ease of comparison, the treadmill and cycling results have been pooled; the only exception has been noted with^c = results for the cycling $\dot{V}O_2$max test and^t = results for the treadmill $\dot{V}O_2$max test.

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Table 4
Effect of reduced training on maximal strength.*†

		Training				Reduced training				
Ref.	Test	Dur. (wk)	Freq.	Vol.	Int.	Dur. (wk)	Freq.	Vol.	Int.	Result
(2)	KE 1RM	16	3 s·wk^{-1}	3 sets	8–12RM	32	**0 s·wk^{-1}**	**N/A**	**N/A**	↓
(2)	KE 1RM	16	3 s·wk^{-1}	3 sets	8–12RM	32	**1 s·wk^{-1}**	3 sets	8–12RM	↑
(2)	KE 1RM	16	3 s·wk^{-1}	3 sets	8–12RM	32	**1 s·wk^{-1}**	**1 set**	8–12RM	↑
(49)	SQ 1RM	10	2 s·wk^{-1}	3 sets	4–10RM	12	**1 s·wk^{-1}**	3 sets	4RM	↔
(49)	SQ 1RM	10	2 s·wk^{-1}	3 sets	4–10RM	12	**1 s·2 wk^{-1}**	3 sets	4RM	↓
(58)	SQ 1RM	8	2–3 s·wk^{-1}	3–4 sets	6–12RM	8	**0 s·wk^{-1}**	**N/A**	**N/A**	↓↓
(58)	SQ 1RM	8	2–3 s·wk^{-1}	3–4 sets	6–12RM	8	**2 s·wk^{-1}**	**2 sets**	6–8RM	↔
(58)	SQ 1RM	8	2–3 s·wk^{-1}	3–4 sets	6–12RM	8	**1 s·wk^{-1}**	4 sets	6–8RM	↔
(59)	KE 1RM	12	3 s·wk^{-1}	3 sets	80% 1RM	24	**0 s·wk^{-1}**	**N/A**	**N/A**	↓
(59)	KE 1RM	12	3 s·wk^{-1}	3 sets	80% 1RM	24	**1 s·wk^{-1}**	3 sets	80% 1RM	↔
(63)	LP 1RM	12	2 s·wk^{-1}	2–5 sets	~50–60% 1RM	24	2 s·wk^{-1}	2–5 sets	30–90% 1RM	↑
(63)	LP 1RM	12	2 s·wk^{-1}	2–5 sets	~50–60% 1RM	24	**1 s·wk^{-1}**	2–5 sets	30–90% 1RM	↑
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**2 s·wk^{-1}**	**1 contr.**	100% MVC	↔
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**1 s·wk^{-1}**	**1 contr.**	100% MVC	↔
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**1 s·2 wk^{-1}**	**1 contr.**	100% MVC	↔
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**2 s·wk^{-1}**	**1 contr.**	**50% MVC**	↓
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**1 s·wk^{-1}**	**1 contr.**	**50% MVC**	↓
(32)	EF MIS	9	4 s·wk^{-1}	1, 3, 5, or 10 MVCs	100% MVC	8	**1 s·2 wk^{-1}**	**1 contr.**	**50% MVC**	↓
(20)	KE MIS	10–18	2–3 s·wk^{-1}	1 set	7–10RM	12	**0 s·wk^{-1}**	**N/A**	**N/A**	↓
(20)	KE MIS	10–18	3 s·wk^{-1}	1 set	7–10RM	12	**2 s·wk^{-1}**	1 set	7–10RM	↔
(20)	KE MIS	10–18	3 s·wk^{-1}	1 set	7–10RM	12	**1 s·wk^{-1}**	1 set	7–10RM	↔
(20)	KE MIS	10–18	2 s·wk^{-1}	1 set	7–10RM	12	**1 s·wk^{-1}**	1 set	7–10RM	↔
(59)	KE MIS	12	3 s·wk^{-1}	3 sets	80% 1RM	24	**0 s·wk^{-1}**	**N/A**	**N/A**	↓
(59)	KE MIS	12	3 s·wk^{-1}	3 sets	80% 1RM	24	**1 s·wk^{-1}**	3 sets	80% 1RM	↔
(61)	LE MIS	10–12	1–3 s·wk^{-1}	1–2 sets	8–12RM	12	**0 s·wk^{-1}**	**N/A**	**N/A**	↓, ↓↓‡
(61)	LE MIS	10–12	1–3 s·wk^{-1}	1–2 sets	8–12RM	12	**1 s·2 wk^{-1}**	1–2 sets	8–12RM	↔
(61)	LE MIS	10–12	1–3 s·wk^{-1}	1–2 sets	8–12RM	12	**1 s·4 wk^{-1}**	1–2 sets	8–12RM	↔

*1RM = one-repetition maximum; Dur. = duration; EF = elbow flexion; KE = knee extension; LP = leg press; MIS = maximal isometric strength; MF = mean fiber; N/A = not applicable; Ref. = reference; RM = repetition maximum; s = sessions; SQ = squat; ↑ = physical performance further increased (i.e., significantly greater than post-training values); ↔ = physical performance was fully maintained (i.e., not significantly different compared with post-training values); ↓ = physical performance was partially maintained (i.e., significantly reduced compared with post-training values, but significantly greater than pretraining values); ↓↓ = physical performance was not maintained (i.e., significantly reduced compared to post-training values and not significantly different compared with pretraining values).
†Bolded values are used to draw the reader's attention to the exercise variable that was changed compared with normal training values.
‡The results depended on the joint angle tested; for some joint angles, adaptations were partially maintained, whereas for other joint angles, adaptations were not maintained (i.e., they were not significantly different than pretraining values).

however, long-term endurance was only partially maintained when volume was reduced by 66%. Therefore, we conclude that short-term endurance and $\dot{V}O_2$max can be fully maintained for up to 15 weeks when exercise volume is reduced by 66% (as little as 13 minutes per session), as long as exercise frequency and intensity are maintained. For exercise performances lasting 1–3

Table 5
Effect of reduced training on muscle size.*†

		Training				Reduced training				
Ref.	Test	Dur. (wk)	Freq. (s·wk^{-1})	Vol.	Int.	Dur. (wk)	Freq. (s·wk^{-1})	Vol.	Int.	Result
(2)	MF CSA‡	16	3	3 sets	8–12RM	32	**0**	**N/A**	**N/A**	↓↓
(2)	MF CSA‡	16	3	3 sets	8–12RM	32	**1**	3 sets	8–12RM	↔^{y}, ↓↓^{o}
(2)	MF CSA‡	16	3	3 sets	8–12RM	32	**1**	**1 set**	8–12RM	↔^{y}, ↓↓^{o}
(58)	Qd CSA	8	2–3	3–4 sets	6–12RM	8	**0**	**N/A**	**N/A**	↓↓
(58)	Qd CSA	8	2–3	3–4 sets	6–12RM	8	**2**	**2 sets**	6–8RM	↔
(58)	Qd CSA	8	2–3	3–4 sets	6–12RM	8	**1**	4 sets	6–8RM	↔
(59)	Th CSA	12	3	3 sets	80% 1RM	24	**0**	**N/A**	**N/A**	↓↓
(59)	Th CSA	12	3	3 sets	80% 1RM	24	**1**	3 sets	80% 1RM	↔
(63)	Qd CSA	12	2	2–5 sets	~50–60% 1RM	24	2	2–5 sets	30–90% 1RM	↔
(63)	Qd CSA	12	2	2–5 sets	~50–60% 1RM	24	**1**	2–5 sets	30–90% 1RM	↓↓

*CSA = cross sectional area; Dur. = duration; MF = mean fiber; N/A = not applicable; Qd = quadriceps; Ref. = reference; RM = repetition maximum; s = sessions; Th = thigh; ↑ = physical performance further increased (i.e., significantly greater than post-training values); ↔ = physical performance was fully maintained (i.e., not significantly different compared with post-training values); ↓ = physical performance was partially maintained (i.e., significantly reduced compared with post-training values, but significantly greater than pretraining values); ↓↓ = physical performance was not maintained (i.e., significantly reduced compared with post-training values and not significantly different compared with pretraining values).
†Bolded values are used to draw the reader's attention to the exercise variable that was changed compared with normal training values.
‡Distinct groups of younger (20–35 years old) and older (60–75 years old) participants were evaluated. The results are collapsed across groups, except when a group by time interaction occurred. In these instances, results for the younger (^{y}) and older (^{o}) groups are separated.

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hours, it seems that volume can be reduced by 33% (as little as 26 minutes of exercise per session).

Reduced Intensity. Whereas endurance adaptations are well-maintained despite prominent reductions in exercise frequency or volume, reductions in exercise intensity have drastic implications for physical performance. After training moderately active subjects at ~90–100% of HRmax (equal to heart rates of ~180–185 beats per minute) for 10 weeks, Hickson et al. (23) reduced training intensity by 33% (82–87% of HRmax; equal to heart rates of ~150–155 beats per minute) or by 66% (61–67% of HRmax; equal to heart rates of ~114–124 beats per minute) for 15 weeks, while exercise frequency (6 sessions per week) and volume (40 minutes per session) were maintained. Whereas short-term endurance was maintained in the group training at 82–87% of HRmax, it was not maintained in the group training at 61–67% of HRmax. $\dot{V}O_2$max and long-term endurance were not maintained in either group when exercise intensity was reduced by any amount. In fact, in the group training at 61–67% HRmax, their treadmill $\dot{V}O_2$max was not significantly different than pre-training values. From a practical perspective, it is especially alarming that endurance adaptations were poorly maintained despite training 6 sessions per week and 40 minutes per session. This underscores the importance of exercise intensity for maintaining endurance performance.

Maintaining Adaptations to Strength Training (i.e., Strength and Muscle Size)

As with the studies by Hickson et al. (23–25) mentioned above, the studies examining the effects of reduced training on strength and muscle size have followed similar designs. That said, to reach conclusions on the minimal dose of exercise necessary to maintain strength training adaptations, we rely on multiple studies by multiple authors using different exercise prescriptions, as summarized in Tables 4 and 5 and discussed below. Noteworthy, some of these studies have simultaneously altered exercise frequency and volume, which is highlighted below. Also, these studies quantified maximal strength using multiple methods (specifically, using 1RM strength and using maximal isometric strength [MIS]) and it is possible that the minimal dose of exercise needed to maintain 1RM is different than the dose needed to maintain MIS (discussed below).

Reduced Frequency. Reduced exercise frequency has received considerable attention in the strength training research. For 1RM strength, reducing exercise frequency from 2-3 sessions per week to 1 session per week was sufficient to fully maintain or even further increase strength, as long as volume and intensity were maintained (2,49,58,59,63), whereas reducing exercise frequency to 1 session per every 2 weeks only partially maintained 1RM strength (49). These findings indicate that a minimal frequency of 1 session per week is required to maintain 1RM strength for 8–32 weeks. Conversely, for MIS, it appears that as little as 1 session of training every 4 weeks is sufficient to maintain performance for up to 12 weeks, as long as volume and intensity are maintained (61). Based on these findings, it appears that the minimal exercise frequency needed to maintain 1RM strength (1 session per week) is different than the minimal dose needed to maintain MIS (1 session per every 4 weeks). This discrepancy could lead exercise and sport practitioners to wonder what the target frequency should be to maintain performance. To help rectify this discrepancy, we rely on the study of Rønnestad et al. (49), who found that athletes (i.e., professional soccer players) receiving 1 session of strength training per week maintained their squat 1RM (and maintained sprint speed) for 12 weeks, whereas athletes receiving 1 session of strength training per every 2 weeks experienced a significant decline in squat 1RM (and slower sprint speed) after 12 weeks. Because an exercise frequency of 1 session per week was sufficient to maintain functional performance (in this case, sprint speed), whereas exercise frequency of less than 1 session per week was insufficient to maintain functional performance, we recommend a minimum dose of 1 session per week of training to maintain strength. In other words, our recommendation is to focus on the minimal exercise frequency needed to maintain 1RM strength, not MIS.

For muscle size, the minimal frequency of exercise necessary to maintain adaptations may depend on the age of participants. In younger participants (~20–35 year old), as little as 1 session of strength training per week seems sufficient to maintain muscle size (2,58), whereas in older participants (~60–75 year old), 1 session of strength training is occasionally (2,63), but not always (59), insufficient to maintain muscle size. Therefore, for older participants, we conservatively recommend performing resistance training on 2 sessions per week to maintain muscle size, as this frequency has previously been shown to be effective (63).

Reduced Volume. To our knowledge, no research has isolated the independent effects of reduced exercise volume (number of sets) on the maintenance of strength and muscle size. That said, two studies have simultaneously reduced exercise frequency and volume (2,58), which will be discussed below.

Reduced Frequency & Volume. To investigate the combined effect of reduced exercise frequency and volume on strength and muscle size, Bickel et al. (2) reduced exercise frequency from 3 sessions per week to 1 session per week, and exercise volume from 3 sets per exercise to 1 set per exercise for 32 weeks, whereas exercise intensity remained the same (8–12RM). These researchers (2) found further improvements in 1RM strength during the reduced training period; in addition, muscle size was fully maintained (at least in the younger [~20–35 year old], but not older [~60–75 year old] subjects). Similarly, Tavares et al. (58) reduced exercise frequency from 2-3 sessions per week to 2 sessions per week, and exercise volume from 3-4 sets per exercise to 2 sets per exercise, whereas exercise intensity remained relatively similar (6–12RM vs. 6–8RM). These authors (58) found that strength and muscle size were fully maintained for 8 weeks. Therefore, we conclude that as little as 1 set per exercise performed on as little as 1 session per week can maintain strength (in younger and older subjects) and muscle size (in younger subjects) for up to 32 weeks. To maintain muscle size in older subjects, we conservatively recommend performing strength training on 2 sessions per week (63) with a minimal volume of 2–3 sets per exercise, because this volume has been shown to be effective in other studies (59,63).

Reduced Intensity. To our knowledge, only one study has investigated the effects of reduced intensity on the maintenance of muscle strength. Morehouse (32) published a report in which participants trained isometrically for 9 weeks at 100% of maximal voluntary contraction (MVC) and then reduced the frequency, volume, and intensity of isometric contractions for a further 8 weeks. The author (32) concluded that repetitions performed at 100% of MVC effectively maintained strength, whereas repetitions

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performed at 50% of MVC were insufficient to maintain strength. Therefore, we conservatively recommend that intensity must remain at near-maximal intensities (or at least at the individual's typical training level) to maintain isometric muscle strength.

Maintaining Performance vs. Improving Performance

Before transitioning to the concluding sections of this paper, it is important to highlight an insight shared by Hickson and Rosenkoetter (25): after reading their results, one could wonder whether intense training for 6 sessions per week followed by intense training for 2 sessions per week may result in similar final $\dot{V}O_2$max values as subjects who simply trained intensely for 2 sessions per week. However, Hickson and Rosenkoetter (25) found (in a small, unpublished observation) that the optimal dose of exercise for maintaining performance is different than the optimal dose of exercise for improving performance. More specifically, when subjects trained intensely for 6 sessions per week for 10 weeks and then performed a reduced training period for 2 sessions per week for 15 weeks, subjects maintained a higher $\dot{V}O_2$max than the subjects who simply trained intensely for 2 sessions per week for 10 weeks. Similarly, although strength and muscle size can be maintained by performing just one set per exercise and just one session per week (2), research indicates that greater volumes/frequencies of resistance training are more effective for improving strength and muscle size (21,52). Noteworthy, though, conflicting evidence exists in the literature, indicating that increasing the frequency of endurance and resistance training is not always associated with greater gains in performance in all situations and for all populations (18,27,28). Overall, these findings underscore that the recommendations made in this review paper are specific to the minimal dose of exercise necessary to maintain physical performance and not on the optimal dose of exercise recommended to improve physical performance.

Future Directions

The research cited herein provides an initial evidence-base for making recommendations about the minimal dose of exercise needed to maintain performance. That said, future research should consider investigating:

- The use of special populations, namely athletes and military personnel.
- Longer periods of reduced training (e.g., ~1 year); such information would be highly relevant for military personnel.
- The minimal frequency of endurance exercise necessary to maintain long-term endurance (i.e., lasting ~1–3 hours); such information would be useful for marathoners, triathletes, and soldiers expected to carry heavy loads for long distances, for example.
- The effectiveness of HIIT to maintain performance during prolonged periods of reduced training. Previous research has already established the impressive effectiveness of HIIT for improving endurance performance (19); and preliminary research indicates HIIT is also effective supplementary training for maintaining endurance performance (48,56). Noteworthy, in addition to helping maintain physical performance during short-term (3 weeks) reduced training, incorporating a weekly HIIT session does not seem to negatively affect psychological indicators of "burnout" compared with performing only low-intensity training (1).
- The effects of reduced frequency plus reduced volume on endurance performance. For example, can performance be maintained when frequency is reduced to 2 sessions per week and volume is simultaneously reduced by ≥33%?
- The independent effects of exercise load/intensity on maintaining strength and muscle size. This is especially important considering that, during some military deployments, it is possible that available resistance exercise equipment may provide limited maximal loading capacity. Similarly, there are times when the general population does not have access to exercise facilities and equipment (e.g., during the 2020 coronavirus pandemic). Regarding this topic, future research should also investigate whether increases in strength training frequency/volume can compensate for reductions in load/intensity (21,51,52). Finally, future research should also investigate the effectiveness of equipment-free or minimal-equipment methods for maintaining strength adaptations (e.g., calisthenics (22) or partner-assisted exercises (12)).
- The independent effects of reduced strength training volume (number of sets) on maintenance of strength and muscle size.
- The minimal dose of exercise necessary to maintain muscle size in older populations (2,11,59,63).

Conclusions

Overall, exercise intensity seems to be the key variable for maintaining physical performance over time. Performance adaptations to endurance training and strength training seem to be relatively well-maintained in general populations despite relatively large reductions in exercise frequency (up to 66%) and volume (33–66%), as long as exercise intensity is maintained. Although insufficient studies using trained/athletic populations met the inclusion criteria of this paper (i.e., reduced training periods lasting >4 weeks), several review papers from the "tapering" research realm clearly indicate that athletes can maintain (or even enhance) their endurance performance for up to 4 weeks by reducing training frequency by up to ~20%, reducing training volume by 60–90%, and by maintaining (or even increasing) exercise intensity (4,26,34,43,45). Similarly, "tapering" research indicates that athletes can maintain (or even enhance) their strength performance for up to 4 weeks by reducing training volume by 30–70% (through reduced training frequency or reduced training session volume) and maintaining (or even increasing) exercise intensity (46,60). Finally, although tempting to speculate, the recommendations made herein may not apply to models of extreme disuse (e.g., spaceflight, casting, unloading). For example, a recently published study (13) found that 6 sessions per week of endurance training (which included 3 sessions per week of interval training) was insufficient to maintain $\dot{V}O_2$max in astronauts following ~6 months of spaceflight. This finding (13) indicates that the severity/duration of disuse during spaceflight may require a greater dose of exercise training to fully maintain performance adaptations.

Practical Applications

Based on the research reviewed herein, the following recommendations are made to exercise and sport practitioners who strive to maintain the endurance and strength of their athletes and clients. With respect to our recommendations, in the event of uncertainty in the minimal dose needed to maintain performance, we have chosen the more conservative approach. Finally, as noted above, these recommendations should be

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treated with the utmost caution because of the limited number of studies available, limitations in interpreting the existing studies, and the primary population studied (i.e., mostly the general population).

To maintain short-term endurance (i.e., maximal bouts of exercise lasting ~4–8 minutes) in general populations:

- Exercise frequency can be reduced to 2 sessions per week, as long as exercise volume and intensity are maintained; or:
- Exercise volume can be reduced by 66% (as little as 13 minutes per session), as long as exercise frequency and intensity are maintained; or:
- Exercise intensity can be reduced to ~82–87% of HRmax, as long as exercise frequency and volume are maintained.

To maintain long-term endurance (i.e., maximal bouts of exercise lasting ~1–3 hours) in general populations:

- The minimal exercise frequency is not known. Therefore, we conservatively recommend maintaining exercise frequency at or near the individual's typical training level.
- Exercise volume can be reduced by 33% (as little as 26 minutes per session), as long as exercise frequency and intensity are maintained.
- Exercise intensity must be maintained as high as reasonably possible (at least as high as the individual's typical training intensity).

To maintain $\dot{V}O_2$max in general populations:

- Exercise frequency can be reduced to 2 sessions per week, as long as exercise volume and intensity are maintained; or:
- Exercise volume can be reduced by 66% (as little as 13 minutes per session), as long as exercise frequency and intensity are maintained.
- Exercise intensity must be maintained as high as reasonably possible (at least as high as the individual's typical training intensity).

To maintain 1RM strength in general populations:

- Exercise frequency can be reduced to 1 session per week.
- Exercise volume can be reduced to 1 set per exercise.
- We conservatively recommend an exercise intensity that results in maximal effort during the final repetition of each set (or maintaining the exercise load at least as high as the individual's typical training level).

To maintain muscle size in younger (~20–35 year old) general populations:

- Exercise frequency can be reduced to 1 session per week.
- Exercise volume can be reduced to 1 set per exercise.
- We conservatively recommend an exercise intensity that results in maximal effort during the final repetition of each set (or maintaining the exercise load at least as high as the individual's typical training level).

To maintain muscle size in older (~60–75 year old) general populations:

- We conservatively recommend an exercise frequency of 2 sessions per week.
- We conservatively recommend 2–3 sets per exercise.
- We conservatively recommend an exercise intensity that results in maximal effort during the final repetition of each set (or maintaining the exercise load at least as high as the individual's typical training level).

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