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Isometric exercise training lowers resting blood pressure

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ABSTRACT

WILEY, R. L., C. L. DUNN, R. H. COX, N. A. HUEPPCHEN, and M. S. SCOTT. Isometric exercise training lowers resting blood pressure. *Med. Sci. Sports Exerc.*, Vol. 24, No. 7, pp. 749–754, 1992. Both rhythmic and "resistive" (weight lifting) exercise training can produce modest decreases in resting blood pressure. The next logical point along an exercise continuum consisting of different proportions of rhythmic and isometric efforts is a strictly isometric effort. The purpose of these studies was to assess the effects of isometric, handgrip exercise training on resting blood pressure. To avoid the extreme pressor responses elicited by fatiguing isometric efforts, the isometric exercise training used in this study consisted of brief handgrip contractions separated by rest periods. Modest repeated rises in systolic and diastolic pressures therefore served as the putative stimuli for training adaptations in resting blood pressures. Human subjects in study 1 trained with four, 2-min isometric handgrip contractions with 3-min rests between contractions. The intensity of the contractions was equal to 30% of their maximal effort for each day. The bouts of isometric exercise were performed three times per week for 8 wk. Study 2 training consisted of four contractions of 50% of maximum effort held for a duration of 45 s with 1-min rests. These were performed 5 $\text{d}\cdot\text{wk}^{-1}$ for 5 wk. In Study 1, all eight trained subjects had a significant decline in both systolic and diastolic resting blood pressures, with group averages of 12.5 and 14.9 mm Hg, respectively. Seven matched control subjects who did not train had no change in resting pressures. In study 2, subjects were trained in their home or workplace and experienced significant mean declines in resting systolic and diastolic pressures of 9.5 and 8.9 mm Hg. In a follow-up period of 5 additional weeks in which no isometric training occurred, resting blood pressures gradually returned to a level not different from pressures preceding training. These results demonstrate a hypotensive effect of isometric exercise training at least as great as other nonpharmacological interventions.

HANDGRIP, HYPOTENSIVE EFFECT,
NONPHARMACOLOGICAL EFFECT

With notable exceptions (4), a modest but consistent decrease in resting systemic blood pressure in response to rhythmic exercise training has been documented in both normotensive and hypertensive individuals (2,5–7). Interestingly, the hypotensive effect is not always associated with a significant training-induced increase in $\dot{V}O_{2max}$ (4). Recently, several studies have shown that resting blood pressure can also be reduced by resistance training (8,9), a form of training consistently shown to have little effect on $\dot{V}O_{2max}$. Moreover, resistance training typically involves both an isometric effort and a rhythmic one. The former is often significant. The next logical point for investigation on the continuum of exercise forms is isometric exercise training. Aside from logic, there is also empirical evidence, though limited, that a training regimen, which has no potential for increasing $\dot{V}O_{2max}$ and involves a strictly isometric effort, could exert a hypotensive adaptation.

Evidence was offered 20 yr ago by Kiveloff and Huber (12), who reported that whole body, isometric efforts lowered the blood pressure in a group of hypertensive patients after 5–8 wk of training. The lack of standardization and quantification of exercise in their study precluded drawing conclusions about the real efficacy of isometric training and probably contributed to the obscurity of their observations in the scientific literature. More recently, Buck and Donner (1) provided observations that a beneficial effect of isometric exercise on resting blood pressure may occur. They found that the incidence of hypertension was lower in occupations classified as moderate to high in isometric activity relative to those classified as low. After allowing for confounding factors such as obesity, alcohol, and smoking, they concluded that daily performance of high levels of isometric activity prevented the occurrence of hypertension. Despite their conviction, controlled experiments are required to clearly document the blood pressure adaptations that result from isometric training. To date, no study has addressed this issue.

The purpose of these studies was to document the effects of isometric exercise training on resting blood pressure. We hypothesized that isometric training with protocols utilizing repeated, brief contractions would effectively lower resting blood pressure. We have completed two related studies. The training stimuli in both were brief, submaximal contractions that avoided the very high arterial blood pressure responses elicited by contractions carried to the point of fatigue. In the first study we compared subjects selected for high-normal resting diastolic blood pressure (DBP) who trained in the laboratory with an isometric handgrip regimen for 8 wk, with a matched nonexercising control group to

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establish the effectiveness of isometric training on lowering DBP. In the second study, the effect of a similar program on the resting blood pressure of subjects with initial blood pressures in the borderline hypertensive range was monitored for a 5-wk training period and a 5-wk detraining period.

MATERIALS AND METHODS

Study 1

Subjects. Healthy volunteers, ages 20–35 were initially screened by measuring their resting seated blood pressures twice a week for 2 wk by standard auscultatory techniques. The four screening measurements were averaged and subjects were selected for resting diastolic blood pressure (DBP) in the 80–90 mm Hg range, then randomly placed into one of two groups. The experimental group (E) began with 10 subjects, of whom eight completed the study. The control group (C) began with 10 subjects, of whom seven completed the study. The reduction in numbers of subjects from those beginning the study were in all cases due to nonattendance. All subjects were informed that the study was designed to examine fluctuations in blood pressure over 8 wk. Subjects were additionally informed that the effect (none specified) of the handgrip contractions on blood pressure were being followed. The emphasis was placed on measuring blood pressure during the contractions so as not to influence the subjects with our interest on the longer term potential effect of the exercise on resting DBP. Subjects were asked to maintain the same exercise, nutritional habits, and general activities during the period of their participation in the study. The importance of not changing habits was specifically discussed with each subject. They were encouraged not to change diet, stop or start smoking or consuming alcohol, or initiate other major lifestyle changes. If this was not possible, they were to inform the investigators and voluntarily withdraw from the study without prejudice. Written explanations of procedures and purposes were provided, and signatures on informed consent forms were obtained from each subject before participation in the exercise study. All protocols were in accordance with policy statements of the American College of Sports Medicine and were approved prior to beginning the studies by the Miami University Committee on the Use of Human Subjects in Research.

Measurements. Subjects came to the laboratory within 1 h of the same time each day for their isometric exercise training or for blood pressure measurements without training (control group). Blood pressure was measured twice in the nondominant arm after at least 10 min seated rest and within 5 min of starting a handgrip exercise. Blood pressure was measured by auscultation using a mercury sphygmomanometer and stethoscope following criteria recommended by the American Heart Association Postgraduate Education Committee (11). A permanent record of blood pressure was also obtained with a cuff microphone and an electrosphygmomanometer preamplifier with a Grass Model 7D Polygraph (Grass Instruments, Quincy, MA). Diastolic blood pressure was taken as Korotkoff phase V (disappearance of sound). In each study all blood pressure measurements were made by the same individual. Heart rate was determined from electrocardiographic recordings, using the Grass polygraph. Counts were made for each appropriate 30-s interval and expressed as beats·min^{-1}.

Handgrip tensions were recorded from a handgrip dynamometer with a linear output related to tension using a low-level DC preamplifier and the Grass Polygraph. The subjects viewed their isometric force production on a direct-reading voltage display meter connected to the dynamometer. This provided the feedback necessary for the individuals to maintain the appropriate percentage of tension. The dynamometer has been previously described in detail (3,13). Each day, a subject would exert a maximal effort for less than 2 s on the dynamometer. After at least 3-min rest, another effort was made. If these differed by no more than 5%, the greater tension was taken as the maximum voluntary contraction (MVC) for the day. If >5% difference occurred, additional grip tensions were measured, with rests between, until a reliable MVC measurement was obtained. The target for tensions that would elicit the appropriate fraction of the maximum (%MVC) then was displayed so that subjects could produce the appropriate tension during the experiments.

Protocol 1. One minute after completion of resting blood pressure measurements for the day, subjects began the first of four 2-min contractions at 30% MVC with the dominant arm. The previously established target tension representing 30% MVC was displayed on a large meter in front of the subject. They were coached to maintain an effort that enabled them to hold a steady tracking on the target meter. Three minutes' rest was allowed between each of the four successive contractions, all with the dominant arm. The choice of this protocol was based on previous studies (19) in which contractions were held to the point of fatigue. We wanted a training effort and duration that would modestly, rather than dramatically, raise blood pressures, and that would allow sufficient recovery time between contractions. To document the magnitude of pressure increases during the interrupted contractions, pressures were measured within the last 20 s of the first and fourth 2-min contractions. Adequate recovery meant that even the fourth 2-min contraction would not result in significant ischemic pain in the arm. The four sets of 2-min contractions and 3-min rests were tested in preliminary trials with a few subjects (not used in these studies) to verify that the above criteria were met. Recovery blood pressures and heart rates were monitored for 5 min, within which time all returned to baseline levels.

This exercise regime was scheduled for 3 d·wk^{-1} for 8 wk. Any subject who missed three consecutive appointments or a total of four for the study was discontinued from the study. The criterion resulted in discontinuing two of 10 original subjects in the E group and three of 10 in the C group.

Statistics. For each subject, means of the two resting measurements taken prior to handgrip were calculated for each day's systolic and diastolic pressures. Heart rates were also measured during each resting period. Since the resting measurements on the first experimental day had not been preceded by any handgrip exercise, these measurements were used to compute the initial averages for each group. The data were then prepared for statistical analysis by computing weekly averages for each subject. The statistical treatment of this data consisted of a two-way repeated measures analysis of variance (16), followed by a Tukey's multiple comparisons procedure. Primary factors in the analysis of variance were groups (two levels) and weeks (eight levels) with subjects nested within groups. A significant group by week interaction measured at the 0.05 level of significance established that the two groups have different effects over the weeks of the study. The Tukey procedure identified which weekly means were significantly different within each group and which weekly means were significantly different when comparing the two groups.

Study 2

Subjects. Procedures were followed as described for study 1, for 10 volunteers, ages 29–52. All subjects completed the protocol. To test our hypothesis in situations closer to "normal" everyday experience, rather than a research laboratory, the investigator either met the subjects in his or her workplace or, if no routine workplace existed, in an unoccupied room near our laboratory. All subjects in this study group participated in the isometric exercise training. The lack of a control group of subjects makes this different from study 1 and limits the comparison of effect of the training with the response during the detraining period in those same subjects, rather than with a matched control group.

Measurements. A portable dynamometer system was used for this study, which precluded obtaining a permanent recording of data as in study 1. The investigator visually observed dynamometer tensions and recorded them. Blood pressures were recorded from auscultatory measurements using a Hawksley Random Zero Sphygmomanometer (Hawksley and Sons Ltd., Lancing, Sussex, England), and heart rate was determined by palpation of the radial artery between blood pressure recordings.

Protocol 2. Procedures followed were like those of protocol 1 with the following exceptions. Beginning with the right arm, four isometric contractions of 50% MVC were held for 45 s, alternating arms, with 1-min rests between sets, thereby considerably shortening the time for each exercise session. Exercise sessions were performed 5 d·wk^{-1} over 5 wk until 24 sessions were completed, matching the total number in protocol 1. During weeks 6–10, no isometric exercise training was performed ("detraining phase"). Resting blood pressures and heart rate recordings were continued once per week after 10 min sitting at rest in the same location that the experiments had been performed.

Statistics. The data for each subject were prepared for analysis in the same manner as in study 1. As there was no control group for study 2, a one-way repeated measures analysis of variance (week as the primary factor crossed with subjects) established a significant difference among the weekly means. Tukey's multiple comparisons procedure then showed which means differed from those of the first and last (fifth) weeks of the isometric training period.

RESULTS

Study 1

Resting blood pressure responses. The initial systolic and diastolic blood pressures as well as the weekly mean blood pressures for each group are displayed in Figure 1. Systolic measurements declined over the 8-wk period in the exercise trained subjects from a group initial average of 134.1 ± 0.95 (SE) mm Hg to 121.4 ± 1.34 mm Hg, and diastolic measurements declined from 86.5 ± 2.01 mm Hg to 71.6 ± 3.50 mm Hg. For the control group, systolic pressures on the initial measurements and the last week were 134.0 ± 3.30 mm Hg and 136.6 ± 2.78 mm Hg, respectively, while diastolic pressures were 83.4 ± 1.67 mm Hg and 85.0 ± 2.43 mm Hg. As exhibited (Fig. 1) by the nonparallel nature of the weekly means for the two groups, there was a significantly different effect of the groups on systolic ($F = 11.77$; $P < 0.0001$) and diastolic pressures ($F = 8.78$; $P < 0.0001$). The multiple comparisons procedure revealed further that, as compared with the means for the first week, both blood pressure measurements for the treatment group had become significantly lower in the fourth week. It was further determined that systolic pressure in the eighth week was significantly lower than that of the fourth week.

Exercise blood pressure responses. Blood pressures in the final 30 s of the first 2-min contraction for the 10 subjects who started in the trained group were compared with their resting pressures. Mean increases

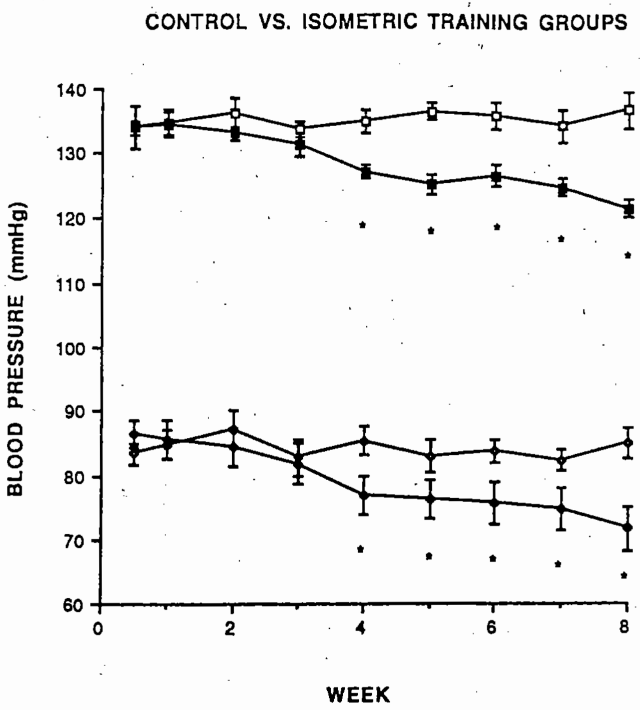

Figure 1—Blood pressure responses by control (C) subjects ($N = 7$) and by isometric exercise trained (X) subjects ($N = 8$) in study 1. Control systolic (SBPC,□) and diastolic (DBPC,◇) blood pressures and isometric exercise trained subjects' systolic (SBPX,■) and diastolic (DBPX,♦) blood pressure responses are shown as the means (± SE) from the initial measurements (week 0) and the 8 wk of training. Trained subjects' systolic and diastolic pressures significantly ($P < 0.05$) declined while control subjects' pressures did not. Asterisks (*) denote weekly averages significantly different from week zero for that group.

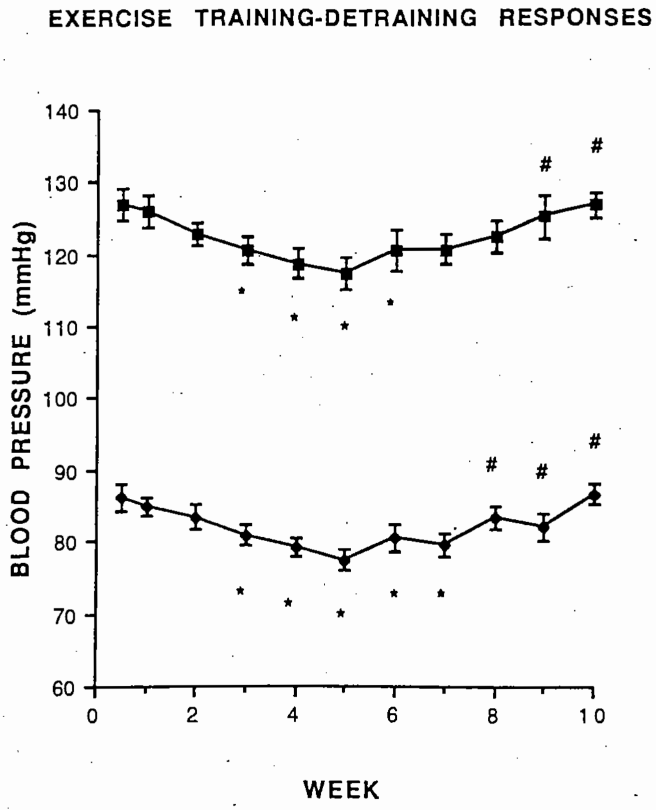

Figure 2—Resting blood pressures of subjects ($N = 10$) from study 2 with 5 wk of isometric exercise training and 5 wk of detraining. Systolic (SBP, ■) and diastolic (DBP, ●) mean blood pressures (±SE) are shown for the group from initial measurements (week 0), isometric training (weeks 1–5), and detraining (weeks 6–10). Both SBP and DBP means declined significantly by week 3 compared with initial measurements (*). Both rose during detraining, and by week 8 were significantly higher than in week 5 ($P < 0.05$). Weekly averages that are significantly different from week 5 are denoted by #.

were systolic pressures of 16.8 ± 1.01 mm Hg (SE) and diastolic pressures of 15.9 ± 0.90 mm Hg.

Resting heart rate responses. Initial and final week mean sitting heart rate measurements were 78 ± 7.87 (SE) bpm and 76 ± 6.52 bpm, respectively, for the experimental group and 77 ± 4.57 bpm and 82 ± 8.26 for control group. These changes were not significantly different for either group ($P > 0.05$).

Study 2

Systolic pressures declined during the isometric training period of 5 wk from 127.0 ± 2.28 (SE) to 117.5 ± 2.23, then returned during the 5-wk detraining period to 126.8 ± 1.84 (Fig. 2). Diastolic pressures showed a similar pattern, declining from 86.2 ± 1.85 to 77.4 ± 1.49 and returning to 86.6 ± 1.34. The changes in weekly means were statistically significant (systolic: $F = 5.73$, $P < 0.0001$; diastolic: $F = 13.06$, $P < 0.0001$). The multiple comparisons procedure determined that the systolic means were significantly lower for weeks 3–6 as compared with week 1. Diastolic means were significantly lower for weeks 3–7 as compared with week 1. As compared with the means of week 5, the systolic measurements became significantly higher in weeks 8, 9, and 10. Heart rates showed no significant changes at any point during the study ($F = 1.09$; $P = 0.377$).

DISCUSSION

These two studies clearly suggest that isometric exercise training can decrease resting blood pressure. The magnitude of these changes compares favorably with those reported for other nonpharmacological approaches to blood pressure reduction. Such reduction has been shown to reduce the risk of mortality (10). For example, Seals and Hagberg in 1984 (17) reviewed 12 investigations of the effects of rhythmic exercise training on resting blood pressure. Eight of the studies reported modest reductions in systolic and diastolic blood pressure of 9 and 7 mm Hg, respectively. The maximum reported hypotensive effect of rhythmic exercise, in a study with carefully maintained body weight and salt intake has been a reduction of 16/11 mm Hg with seven times per week bicycling for 45 min at 60–70% maximum work capacity (15).

The two studies reported here were planned in sequence, with the first in a laboratory setting, comparing selected subjects with resting diastolic blood pressures in the upper range of normal. The purpose of this design was to determine whether the general protocol could be effective in lowering blood pressure. The selection of subjects with resting blood pressures in the high normal range enhanced the chances for an effect to be seen while testing the hypothesis with subjects in whom an acute rise in blood pressure during the contractions would present little or no risk, and comparing those subjects with matched controls. Blood pressures recorded near the end of the brief efforts showed that the desired lowering of resting pressures could be achieved without the risk of extremely high pressures during the efforts. The demonstration of a hypotensive effect in these subjects establishes their utility for future investigations of the physiological mechanisms involved in the effects of isometric exercise on blood pressure.

Study 2 extended the findings by meeting subjects for resting measurements and training in their workplace or a "neutral" room other than the laboratory. In addition, the success of a shorter daily protocol (by using a higher %MVC, shorter grip duration, alternating arms, and exercising 5 $d \cdot wk^{-1}$) illustrated that a very brief daily time commitment to a training regime that is not physically demanding can effectively lower resting blood pressure in humans. It is important to note that the hypotensive effect of this exercise is reversible over a time period similar to that in which the effect was achieved.

These results strongly implicate the potential usefulness of an isometric training regime, especially when the desirable hypotensive effect appears possible to accomplish with the interrupted contraction protocol. This protocol avoids potentially dangerous, markedly high systolic and diastolic blood pressures that are experienced at the end of continuously held fatiguing isometric contractions. Brief, interrupted isometric efforts that acutely elicit only modest, low risk elevations in BP achieve a lowering of resting pressures in a remarkably short time. Kiveloff and Huber (12) first observed a relationship between isometric effort and a hypotensive effect on blood pressure. Their subjects performed a series of brief "maximal" isometric contractions by tensing major muscle groups of the body. A parallel decrease in systolic and diastolic resting blood pressures after 5–8 wk of isometric effort was observed with patients that were hypertensive. There was no change in the pulse rates of their subjects. The contractions were not measured in any quantitative way and no measurements were made that would provide any basis for speculation on the physiological mechanisms involved in the pressure changes. Yet, their results were recognized by Buck and Donner (1), who found a lower incidence of hypertension in workers performing tasks high in isometric activity.

Tangential, but related, observations suggesting a beneficial effect of static efforts were provided by Hagberg et al. (7). They showed that weight lifting maintained a reduction in diastolic blood pressure that had been achieved by endurance (rhythmic) training in previously hypertensive adolescents. In addition, weight training alone appeared to lower systolic pressure in one subject who did not participate in the endurance training. These results have been extended (9) with weight training (Nautilus) at an intensity that did not change $\dot{V}O_{2max}$. The weight training produced favorable modifications of several coronary artery disease risk factors, including lipid profile and blood pressure. While weight training usually has both rhythmic and isometric components, the isometric component is typically a significant, if not greater one.

The cumulative evidence of a potential hypotensive effect of isometric exercise from these previous studies prompted Tipton (18) in a current review to suggest that guidelines for exercise programs for hypertensive persons should be reconsidered. A reevaluation of the utility of isometric exercise can begin by recognizing that the mechanisms by which rhythmic or aerobic exercise training lowers systemic pressure (2,5,6) are not elucidated, though obviously this must involve adjustments in one or more of the components determining cardiac output or total peripheral resistance (TPR). Because no measurements were made in these studies that would permit identification of the specific components responsible, only general and speculative consideration of mediating processes can be offered. The search for mechanisms can begin with a comparison of isometric and rhythmic exercise. Neither an increase in exercising $\dot{V}O_{2max}$ nor a decrease in diastolic blood pressure during rhythmic exercise has been conclusively linked to the beneficial effects of this form of exercise on blood pressure. Thus, the absence of increased $\dot{V}O_2$ and the contrasting rise in diastolic blood pressure in isometric exercise is not sufficient justification for ignoring some parallels between the different forms of exercise. Though isometric and rhythmic exercise differ in these and other significant ways, the possibility that they have in common the generation of similar physiological signals that could alter either or both cardiac output or total peripheral resistance is not remote. For example, mean arterial systolic pressure increases in both exercise forms. Although diastolic pressure in rhythmic exercise may decline, remain unchanged, or rise slightly, the rise in systolic pressure is related to exercise intensity and is often great enough that mean arterial pressure increases significantly. With repeated exposures this pressor response might serve as a stimulus for baroreceptor resetting. We emphasize the point that the rise in pressures in isometric training with the brief, repeated contractions in our studies is modest relative to the levels experienced at fatigue, and therefore do not present a high risk. However, the fact that both systolic and diastolic pressures are rising together means that repeated increases in mean pressure occur and could serve as a stimulus sufficient to elicit reflex changes. Sympathetic neural influences on TPR could also be brought about by changes in central integration of muscle afferent information. Moreover, independent or concomitant changes in a host of endocrine and endocrine-like substances, again triggered by the periodic bursts of pressor or muscle stimuli, could also influence vessel diameter, and thus TPR.

While a change in TPR is the most probable mechanism involved in the decline in blood pressure (14), a change in cardiac output cannot be ruled out. Though no reduction in resting heart rate was observed in these studies, stroke volume could have been altered by the training, thus changing cardiac output and blood pressure. Changes in central sympathetic outflow to the venous side could have affected stroke volume by reducing venous return and preload. Whether such changes occur remains to be investigated.

In conclusion, we have demonstrated that training with a simple regimen of interrupted isometric contractions acutely raises blood pressure only modestly, but leads to a gradual and significant reduction in resting blood pressure over time. This exercise model opens the opportunity to investigate its application for potential use in regulating blood pressure nonpharmacologically as well as to investigate the physiological mechanisms involved in blood pressure regulation.

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