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Original Research

Acute Dose-Response of Duration During the Isometric Forearm Plank Exercise on Muscle Thickness, Echo-Intensity, Peak Force, and Perception of Effort in Recreationally-Trained Participants

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ABSTRACT

International Journal of Exercise Science 15(6): 676-685, 2022. The primary purpose of this study was to evaluate the acute effects of different durations of the isometric forearm plank exercise (IFPE) on peak force, echo intensity, muscle thickness, and perception of effort in recreationally-trained participants. Fifteen resistance-trained participants (23±3years, 76.4±6.5kg, 173.3±6.5cm) performed the IFPE with bodyweight in one of three durations in a randomized order: a). 1-min, b). 2-min, and c). 3-min. Muscle thickness (MT), echo intensity (EI), peak force (PF), and rating of perceived exertion (RPE) were measured pre-test and post-test. Two-way repeated-measures ANOVAs (2x3) were used to test differences between tests (pre-test and post-test) and treatment (1-min, 2-min, and 3-min) for PF, MT, and EI. One-way ANOVA was used to compare RPE between treatments (1-min, 2-min, and 3-min). There was a significant increase between pre- and post-test only for 3-min IFPE (p=0.008). For EI, there was a significant increase between pre- and post-test only for 3-min IFPE (p<0.001). For PF, there were observed significant reductions on post-test between 1-min vs. 3-min (p<0.001) and 2-min vs. 3-min IFPE (p<0.001). For RPE, there were statistical differences between 1-min vs. 2-min (p<0.001), 1-min and 3-min (p<0.001), 2-min and 3-min (p=0.001). In conclusion, only 3-min IFPE induced an increase in MT and EI and a reduction in PF when compared to 1-min and 2-min (during the post-test). RPE increased with the increase in the duration of the IFPE.

KEY WORDS: Isometric contraction, strength, performance, muscle pump

INTRODUCTION

The isometric forearm plank exercise (IFPE) is a popular strength exercise that has been recommended for both physical programs (13) and rehabilitation (2, 6). Usually, the plank is a body weight-bearing exercise that applies the external load on the forearms and feet. Isometric core training using IFPE is effective to improve torso stiffness and improved dynamic tasks (17). Improvements in core stiffness allow the spine to bear greater loads and express greater distal limb athleticism (7, 16). Lehman et al., (18) reported that the plank exercise produced 29.5% of the maximum voluntary contraction (MVC) (internal oblique), 26.6%MVC (rectus abdominis), 44.6%MVC (external oblique), and 4.98%MVC (erector spinae) in a group of resistance-trained participants. Additionally, Kim et al., (14) reported that the muscle activation was 38.8% of the maximum voluntary isometric contraction (MVIC) (rectus abdominis), 42.4%MVIC (external oblique), and 29.2%MVIC (internal oblique) in healthy individuals and Park and Park (23) reported 51.8%MVIC (rectus abdominis), 23.4%MVIC (external oblique), and 45.8%MVIC (internal oblique) in physically active female volunteers. However, just choosing the right exercise is not enough to improve the acute muscular response or chronic adaptations such as muscular strength or hypertrophy.

The correct choice of the acute variables is another important component of a resistance training (RT) session (19, 20). The combination of intensity and volume is fundamental to determine the dose-response in a RT session (19) and can induce specific metabolic and mechanical stress in the muscle (24, 25). Schoenfeld et al., (26) described the duration as the total of the concentric, eccentric, and isometric components of repetition; and is predicated on the tempo at which the repetition is performed. For dynamic contractions, scientific literature indicates that hypertrophic outcomes are similar when training with repetition durations ranging from 0.5 to 8-sec to concentric muscular failure. On the other hand, for isometric contractions, the dose-response is not so clear. Several studies present interesting results focusing on dose-response volume and intensity of isometric contractions (3, 15, 27, 30, 34). Tillin and Folland (30) reported a sustained contraction protocol involving 3-sec of isometric contractions at 75%MVC resulted in greater strength improvement than a protocol involving 1-sec of isometric ballistic contraction at 80–90%MVC. Kubo et al., (15) observed a greater total contraction duration than the sustained contraction protocol (150-sec or 80-sec). Schott et al. (27) reported that longer sustained contractions (4x30-sec) presented greater responses in isometric strength and hypertrophy than shorter sustained contractions (4x10x3-sec) with the same intensity. Kubo et al., (15) indicated that when the intensity of training is equalized, the magnitude of strength and hypertrophy gained could more likely be determined by the total contraction duration per training session rather than per repetition. Authors suggested that the higher metabolites concentration and lower muscle pH during the longer sustained contractions might be the reason for muscle hypertrophy in isometric contractions (27). Young et al., (34) compared the effects of rhythmic (100% of maximal voluntary contraction) and sustained isometric contractions (1-min at 30%MVC) on the contractile characteristics of the triceps surae in healthy participants for 8-weeks. The results showed a 5.5% (rhythmic) and 3.3% (sustained) increase in MVC and only sustained contractions improved muscular endurance. Balshaw et al., (3) stated that loading magnitude rather than loading duration accounted for the majority of the strength gain. However, greater strength gain was observed in the sustained contraction protocol because of the greater time under tension despite a similar loading intensity (120-sec at 75%MVC vs. 40-sec at 80–90%MVC).

Finally, for isometric exercises, the combination of body weight (intensity) with the duration of isometric contractions (volume) is an important strategy aimed at muscle adaptations such as strength and hypertrophy. Oranchuck et al., (22) reported a small effect of intensity on chronic adaptations (hypertrophy) and a greater effect of volume (duration) after isometric contractions.

Therefore, based on previous studies, it is necessary to understand the effect of isometric exercise duration on acute responses and chronic muscle adaptations. The appropriate duration of isometric contractions is not as well defined as in dynamic contractions, including parameters required for an appropriate core muscles regimen and with durations varying between 1-sec and 120-sec. To the best of the author's knowledge, no study was been conducted to assess the acute effects of different durations during the IFPE (intensity = bodyweight) in recreationally-trained participants. Therefore, the primary purpose of this study was to evaluate the acute effects of different durations of the IFPE on muscle thickness, echo intensity, peak force, and perception of effort in recreationally-trained participants. It is hypothesized that the exercise duration will induce a greater increase in muscle thickness, changes to echo intensity, a reduction in peak force, and an increase in RPE.

METHODS

Participants

The number of participants was determined by a pilot study conducted previously, based on a significance level of 5% and a power of 80% derived from the muscle thickness of individuals with the same characteristics used in the present study (9). Fifteen resistance-trained participants were recruited to this study [13 males and 2 females; age 23 ± 3 years, total body mass 76.4 ± 6.5 kg, height 173.3 ± 6.5 cm, abdominal skinfold 17.6 ± 6.6 mm]. All participants were regularly engaged in RT program and familiar with the IFPE. They had 3 ± 1 years of RT experience (1-2 sessions/week), with no previous surgery or history of injury with residual symptoms (pain) in the spine within the last year. The participants were informed of the risks and benefits of the study prior to any data collection. All participants provided written informed consent prior to participation and the Institutional Review Board at California State University, Northridge approved the protocol and the study (#FY20-410). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (21).

Protocol

This study used a randomized and counterbalanced design. Participants attended one laboratory session and refrained from performing core exercises other than activities of daily living for at least 48 hours prior to testing. A within-subject approach was used in which each participant performed different exercise durations. First, anthropometric data were evaluated (height, weight, and abdominal skinfold). Next, all participants performed a familiarization and specific warm-up (1 set of the IFPE for 10-sec with bodyweight). To perform the IFPE, the participants assumed a push-up position, elbows were directly under the shoulders and flexed at 90 degrees, kept the body straight (shoulder, hip, and knee aligned), and feet straight back (staying on toes). After the specific warm-up, a pre-test was carried out (peak force, muscle thickness, and echo intensity of the rectus abdominis). Then, all participants performed the IFPE with bodyweight in one of three treatments in a randomized order: a). 1-min, b). 2-min, and c). 3-min. After each treatment, a post-test was obtained (peak force, muscle thickness, and echo intensity of the rectus abdominis). The rating of perceived exertion was evaluated 10-min after each treatment. The same procedure was performed for each treatment separated by 10-min. All treatments were directly supervised by a research assistant (Certified Strength and Conditioning Specialist) to ensure proper performance and technique.

Muscle Thickness (MT): Ultrasound imaging was used to obtain measurements of MT. A trained technician performed all testing using an ultrasound imaging portable unit (Hitachi Noblus; Hitachi Medical Corporation, Tokyo, Japan). Following a generous application of a water-soluble transmission gel (Cskin, Medics Medical Products LLC., NY, USA) to the measured site, a 7.5-MHz linear array probe (L55 Probe) was placed perpendicular to the tissue interface without depressing the skin. Equipment settings were optimized for image quality according to the manufacturer's user manual and held constant among testing sessions. When the quality of the image was deemed to be satisfactory, the image was saved to the hard drive and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per methods used by Abe et al. (1). Measurements were taken on the right side of the body at the second portion of the rectus abdominis. Measurements were taken while the participants were lying on a bench. To avoid variations in probe compression, participants were instructed to perform the Valsalva maneuver during measurements. For rectus abdominis, measurements were taken at 25%, 50%, and 75% of the cross-section area. To maintain consistency between pre- and post-intervention testing, each site was marked with ink. To further ensure the accuracy of measurements, 3 images were obtained in each point (25%, 50%, and 75% of the cross-section area). If measurements were within 1mm of one another the figures were averaged to obtain a final value. If measurements were more than 1mm of one another, a fourth image was obtained and the closest measurement was then averaged. The sum of all 3 measurements (25%, 50%, and 75%) was used to further analysis, and the test-retest ICC from the measurements, for MT, was 0.96-0.98 and the intra-rater reliability was 0.96-0.97.

Echo Intensity (EI): The same images utilized for the determination of changes in muscle thickness were also used for quantifying echo intensity. Echo intensity was assessed using an automated grayscale analysis that ranged from 0 (black) to 255 (white) (arbitrary unit, A.U.). A rectangular region of interest box was drawn as large as possible to encompass the muscle. Care was taken to ensure that fascia along the borders of each muscle, subcutaneous adipose tissue, or the bone region was not included in the analyses. The test-retest ICC from our lab for EI was 0.97.

Peak Force (PF): The PF was measured by a digital load cell acquisition system (FM-204-1000K, Shenzhen Aermanda Technology Co. Ltd., Shenzhen, Guangdong, China / Capacity: 1000Kgf / Resolution: 0.01kgf). All participants were positioned standing in front of the cable pulley machine, with a supinated grip on a handle. All participants lay down in a supine position on an incline bench (at 15 degrees), lower limbs flexed, and arms holding a rope attached to a cable-pulley machine next to the chest. All participants performed an isometric maximal contraction in spine flexion (at 30 degrees). Participants performed 3 maximal voluntary isometric contractions (MVIC) at 30º of spine flexion before and after each treatment. Each MVIC was performed for 5-sec and 10-sec of rest. The average of all MVICs was used for further analysis. The test-retest ICC from our lab for PF was 0.95.

*Rating of Perceived Exertion (*RPE*):* The RPE was assessed with a CR-10 scale using the recommendations of Sweet et al., (29). Participants were asked to use an arbitrary unit (AU) on the scale to rate their overall effort for each treatment. A rating of 0 was associated with no effort and a rating of 10 was associated with maximal effort and the most stressful exercise ever performed. All participants answered the following question based on CR-10 scale: "How was your workout?" The RPE was asked after each treatment after 10-min.

Statistical Analysis

The normality and homogeneity of variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively. The mean, standard deviation (SD), delta percentage (Δ%) were calculated. Two-way repeated-measures ANOVAs (2x3) were used to test differences between tests (pre-test and post-test) and treatments (1-min, 2-min, and 3-min) for MT, EI, and PF. One-way ANOVA was used to compare RPE between treatments (1-min, 2-min, and 3-min). Post-hoc comparisons were performed with the Bonferroni test when necessary. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen's d units using effect sizes (d) (14). The *d* results were qualitatively interpreted using the following thresholds: <0.35 - trivial; 0.35-0.8 - small; 0.8-1.5 - moderate; >1.5 - large for recreationally-trained participants (8). An alpha of 5% was used to determine statistical significance.

RESULTS

For muscle thickness (MT), the main effect of test (pre- vs. post-test) yielded an effect size of 0.57, indicating that 57% of the variance in the IFPE was explained by test (pre- vs. post-test) [F(1, 14) = 18.6, p=0.022]. The interaction effect was non-significant [F(1, 14) = 2.80, p=0.097]. There was a significant difference between pre- and post-test only for 3-min IFPE (p=0.008, d=0.38 [trivial], Δ%=7.1) (Figure 1a).

For echo intensity (EI), the main effect of test (pre- vs. post-test) yielded an effect size of 0.32 indicating that 32% of the variance in the IFPE was explained by test [F(1, 14) = 6.66, p=0.022]. There was a significant interaction between test and treatment (p=0.002). There was a significant difference between pre- and post-test only for 3-min IFPE (75.5±16.9 A.U. vs. 80.8±16.9 A.U., p<0.001, d=0.31 [trivial], Δ%=6.3) with no significant difference for 1-min IFPE (77.1±16.4 A.U. vs. 79.5±17.6 A.U., p=0.337) and 2-min IFPE (76.9±16.5 A.U. vs. 76.6±15.2 A.U., p=0.736) (Figure 1b).

For peak force (PF), the main effect of test yielded an effect size of 0.34 indication that 34% of variance in the IFPE was explained by test [F(1, 14) = 7.16, p=0.018]. The main effect of test (pre- vs. post-test) indicated that the mean change score was significantly greater for 3-min (M = 37.7, SD = 24.1) than for 2-min (M = 9.60, SD = 51.3) and 1-min (M = 7.12, SD = 41.8). The main effect of treatment yielded an effect size of 0.42 indication that 42% of variance in the IFPE was explained by treatment [F(1, 14) = 10.22, p=0.036]. The interaction effect was non-significant [F(1, 14) = 4.56, p=0.089]. There were observed significant differences only for post-tests: 1-min vs. 2-min (403.8±74.1 N vs. 398.8±92.8N, p=0.679), 1-min vs. 3-min (403.8±74.1 N vs. 367.6±74.7 N, p<0.001, d=0.46 [small], Δ%=8.9), 2-min vs. 3-min (398.8±92.8N vs. 367.6±74.7 N, p=0.013, d=0.36 [small], Δ%=7.8) (Figure 1c).

For rating of perceived exertion (RPE), One-way ANOVA showed that the effect of RPE was significant [F(2,44) = 42.1, p<0.001]. There were observed statistical differences between 1-min vs. 2-min (M = 42.2, SD = 2.08, p<0.001, d=2.0 [large], Δ%=34.3), 1-min vs. 3-min (M = 41.6, SD = 2.0, p<0.001, d=3.4 [large], Δ%=47.1), 2-min vs. 3-min (M = 44.7, SD = 2.33, p=0.001, d=1.4 [moderate], Δ%=19.5) (Figure 1d).

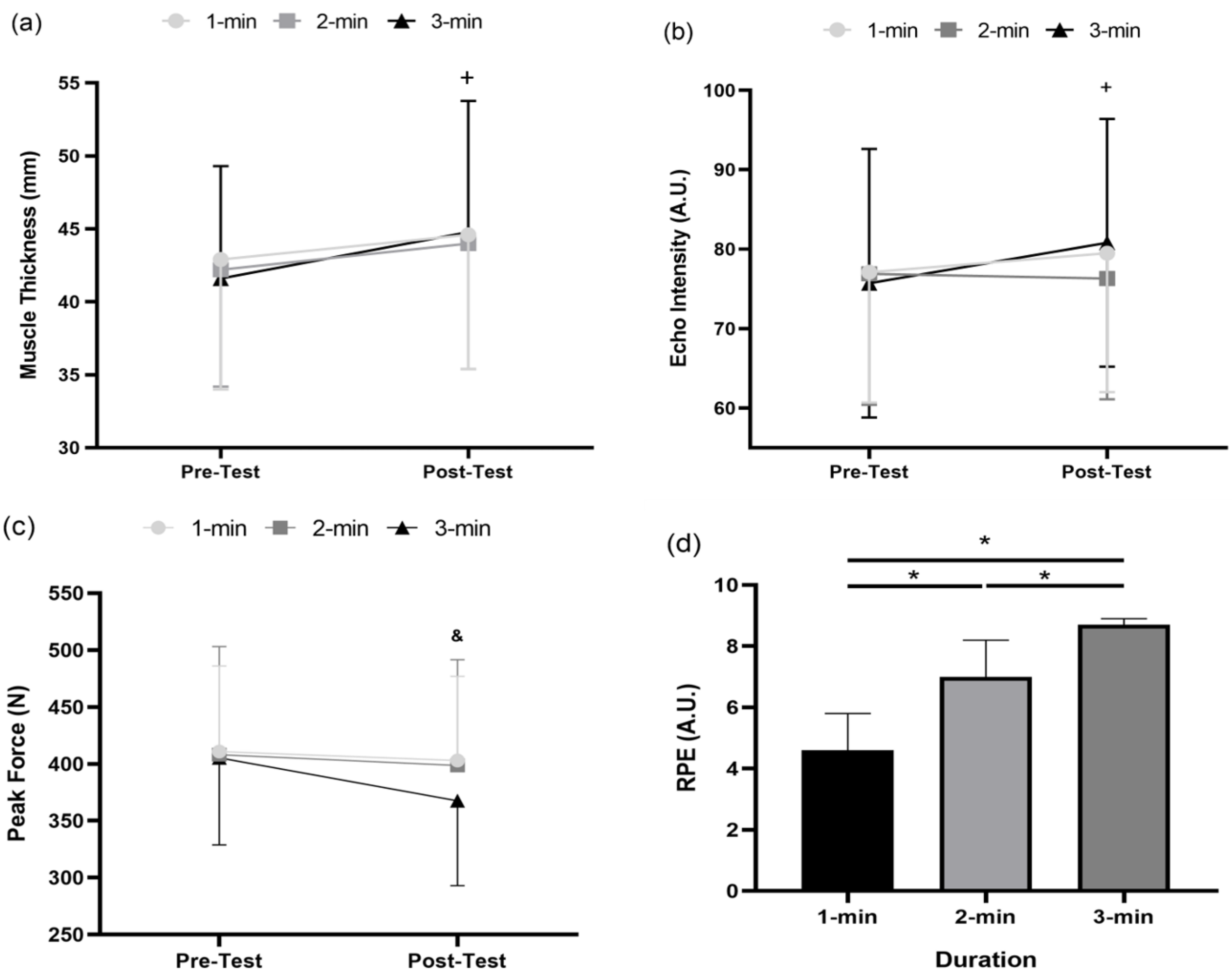

Figure 1. Mean ± standard deviation of (a) muscle thickness, (b) echo intensity, (c) peak force, and (d) RPE between pre- and pos-test. [+]Significant difference between pre- and post-test only for 3-min; [&]Significant difference during post-test between 1-min vs. 3-min and 2-min vs. 3-min. [*]Significant difference between treatments, p<0.01.

DISCUSSION

The aim of this study was to evaluate the acute effects of different durations of the IFPE on muscle thickness, echo intensity, peak force, and perception of effort in recreationally-trained participants. The main findings include 1. There was observed an increase in MT and EI only for 3-min IFPE; 2. Only after 3-min IFPE a reduction in peak force was observed when compared to 1-min and 2-min; and 3. The duration of the IFPE increased the RPE. To the best of the author's knowledge, no study was conducted to measure the acute effects of different durations during the IFPE with the bodyweight in recreationally-trained participants.

Different physical conditions have been shown to induce acute cell swelling, the extent of which relies on the type of exercise, level of fatigue, volume, and intensity (24). RT exercises with momentary muscle failure reduce the intramuscular ATP and CP levels (and Pi, ADP, and AMP accumulation), a high glycolytic flux (production of H+ leads to metabolite accumulation), hypoxia (via muscle contraction), and venous pooling leading to cellular swelling (5, 25, 28, 31). Acute cell swelling can be measured by ultrasound imaging. The ultrasound imaging measures the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone for a specific muscle (1). Muscle thickness (MT) is defined as the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per method used by Abe et al. (1). MT was measured as a sum of all metabolic effects in the muscle after a RT exercise and it was measured before and after each IFPE duration. It was hypothesized that the exercise duration induces a greater increase in MT. The results of this study partially corroborate the main hypothesis. No effects on MT were observed after 1-min (3.9%) and 2-min (4.2%), however, 3-min IFPE presented 7.1% increase in MT. Schoutt et al., (27) suggested that longer isometric contractions promote higher concentrations of metabolites and lower muscle pH. However, in this study, the increase in MT was partially observed as hypothesized. It is well-known that the duration of the exercise can produce higher metabolic and mechanical stress and consequently, might affect cell swelling (24, 25). However, it is assumed that trained participants could be more efficient in removing the by-products from the metabolism with less effect on MT.

Complementing the muscle analysis, the echo-intensity (EI) relates to the pixel density of the image and was initially quantified by visual scoring from ultrasound images (33). The change in EI has also been used to provide insights into the balance between the extracellular and intracellular fluid in studies investigating acute changes in cell swelling (33). It was hypothesized that the exercise duration induces greater changes in EI. The results of this study partially corroborated the main hypothesis, after all, a modification of the echo intensity was observed only after 3-min IFPE (6.3% and trivial effect size). Strenuous exercise/load induces transient muscle edema (10, 33) and has increasing EI values. Based on the authors' knowledge, there are no studies that compared different durations during the IFPE on MT and EI in recreationally-trained participants.

Regarding the acute responses of peak force (PF), it was measured before and after each treatment to understand the effects of neuromuscular fatigue. Neuromuscular fatigue is defined as a reduction in maximal force (or PF) or power production in response to contractile activity (11, 32). It can originate at different levels of the motor pathway and is usually divided into central (at the central nervous system with a reduction in the neural drive to the muscle) and peripheral (changes at or distal to the neuromuscular junction) components (4, 11). It was hypothesized that the exercise duration reduces the PF. The results of this study partially corroborate the main hypothesis, after all, 3-min IFPE showed reductions in PF when compared to 1-min (8.9%) and 2-min (7.8%). Based on the present results, the increase in the exercise duration induced progressive metabolic stress sufficient to affect the level of force produced. However, in this study, the differences between pre- and post-test were similar even with increasing the exercise duration (1-min [1.9%] and 2-min [2.3%], respectively). Possibly, trained participants were able to remove (or buffer) the by-products of metabolism for some time, however, this ability can be affected by the duration of the activity, reducing their physical performance.

The rating of perceived exertion (RPE) is frequently used to quantify, indirectly, the level of effort after sets, exercises, different populations, and workouts (12, 19). RPE presents a relationship with physiological and performance measures and assists in quantifying the general load (12). It was hypothesized that the exercise duration induces an increase in RPE, corroborating the present results. It was observed that with the increase in the exercise duration of the IFPE (with bodyweight) the RPE increased. It is well known that RPE is affected by the level of neuromuscular fatigue after exercise/load for recreationally-trained participants. In this way, the duration of isometric contractions with bodyweight might increase the perception of effort.

In conclusion, only 3-min IFPE induced an increase in MT and EI and a reduction in PF when compared to 1-min and 2-min (during the post-test). RPE increased with the increase in the duration of the IFPE. The main results of this study may benefit recreational athletes, practitioners, and rehabilitation programs. Initially, the results of this study supported the notion that the IFPE durations greater than 3-min might provide strenuous fatigue-induced stimulation and metabolic stress in recreationally-trained participants. Secondly, it is essential to understand that the chronic adaptations of training are due to a succession of acute stimuli.

This study has some limitations that should be considered when interpreting the current results. First, we measured only pre- and post-test. A longer time course could demonstrate the time required for values to return to baseline. Second, we did not measure lactate or by-products from the metabolism. The findings of this study are specific to the young resistance-trained population and, therefore, cannot necessarily be generalized to other exercises, durations, or different populations including adolescents, athletes, women, and the elderly.

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