

ORIGINAL RESEARCH

THE VALIDITY OF PLANTARFLEXOR STRENGTH MEASURES OBTAINED THROUGH HAND-HELD DYNAMOMETRY MEASUREMENTS OF FORCE

Adam R. Marmon, PhD¹
Federico Pozzi, PT, MA¹
Ali H. Alnahdi, PT, PhD²
Joseph A. Zeni, PT, PhD¹

ABSTRACT

Purpose/Background: Hand-held dynamometers are commonly used to assess plantarflexor strength during rehabilitation. The purpose of this study was to determine the concurrent validity of measuring plantarflexion force using a hand-held dynamometer (HHD) as compared to an electromechanical dynamometer as the gold standard. The hypothesis was that plantarflexor forces obtained using a hand-held dynamometer would not show absolute agreement with a criterion standard.

Design: Concurrent validity assessment for a diagnostic strength testing device.

Setting: Institutional clinic and research laboratory

Participants: Volunteer sample of healthy university students (N=20, 10 women, 10 men; 25.9 ± 4.1 years).

Main Outcome Measure(s): Maximal plantarflexion strength was measured using both a HHD and an electromechanical dynamometer (EMD) as a criterion measure.

Results: Plantarflexor force measures with the HHD were significantly different ($p < 0.01$) and not correlated with plantarflexor forces measured using the EMD for either limb ($R^2 \leq 0.09$).

Conclusions: Plantarflexor strength measurements acquired using HHD are different from those acquired using an EMD and are likely influenced by the strength of the examiner.

Key words: Diagnostic strength, triceps surae, concurrent validity

Level of Evidence: Prospective cohort study, level II

¹ University of Delaware, Newark, DE, USA

² King Saud University, Riyadh, Saudi Arabia

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CORRESPONDING AUTHOR

Adam R. Marmon

INTRODUCTION

Measurements of muscle strength, often assessed clinically as force produced, are a standard and important component of any clinical evaluation. Accurate and reliable measures are essential to gauge the effectiveness of treatment and monitor patient progress over time. The gold standard for objective strength assessments in the research and clinical environments are commercially available electromechanical dynamometers (EMD) that measure force production. However, these devices are large, expensive and time-intensive. Clinicians need to fit the machine to each subject and must learn to navigate the machine's software. Alternatively, hand-held dynamometers (HHD) are frequently employed in a clinical setting to measure strength. HHDs are less expensive, require less time to set up and do not require that the user have knowledge of machine-specific software.

Despite the benefit of using the HHD to quantify muscle strength, the reliability of these devices can be influenced by numerous factors, including technique¹ and experience of the clinician.^{2,3} Methodological descriptions for the use of these devices vary, but range from the patient applying force against a form of non-elastic resistance⁴ or, more commonly, applying force against manual resistance exerted by the tester.^{3,5-11} When manual resistance is used to counter the motion produced by the muscle, it is assumed that the tester can produce resistance that is equal to or exceeds the force produced by the patient. Thus, this device is suitable to test strength in weaker populations¹²⁻¹⁴ or in small muscle groups.^{15,16} However, the validity of using HHD for measuring larger and more powerful muscles, such as the plantarflexors, has not been thoroughly examined, despite the use of HHD to measure these muscles in the clinical and research environments.^{9,17,18}

Previous reports examining the use of HHD for testing the elbow flexors and knee extensors have shown that the clinician can be overpowered by the torques produced by the subject, ranging from more than 50 Nm and 100 Nm respectively.¹⁹ It is therefore realistic that a subject's plantarflexor torque, which has been reported to be more than 50 Nm in elderly participants²⁰ can overpower the resistance provided by the clinician. Therefore, the HHD measures may be

more reflective of the strength of the tester than the absolute force production ability of the patient. This concern has been raised during the testing of upper extremity strength in which the strength of the tester was found to affect the reliability and magnitude of force measurements produced by the subjects.²¹

The plantar flexors are one of the strongest muscle groups in the lower extremity. These muscles are responsible for forward propulsion during walking,²² support and propulsion during running,²³ controlling ankle motion during stair descent²⁴ and attenuating impact forces during jump landings.²⁵ These muscles are impaired in a variety of orthopaedic and neurological conditions and are often the target of strengthening interventions.²⁶⁻³⁰ Accurate methods of quantifying plantarflexion force output in the clinic are required. To date, there is no record of a systematic examination of the validity of using HHD for measuring plantarflexor strength. Therefore, the purpose of this study was to determine the concurrent validity of measuring plantarflexion force with a HHD as compared to an EMD as the gold standard. The hypothesis was that that the plantarflexor forces obtained using a HHD would not show absolute agreement with those obtained using an EMD.

METHODS

Participants

Healthy adult subjects were recruited from the student body of the University of Delaware. The study was approved by the Institution Review Board of the University and each subject gave informed consent before participation. Subjects were excluded from the study if they had diabetes, heart disease, high blood pressure not controlled by medication, neurologic problems, respiratory conditions, cancer, surgery in either lower limbs, pain in either lower limbs, or if they were older than 35 or younger than 18.

Procedures

Subjects attended one testing session at the Muscle Performance Lab at the University of Delaware. They were asked to wear gym clothes and sneakers. The strength (force production) of the plantarflexor muscles was assessed bilaterally using a HHD (Manual Muscle Tester, model 01163, Lafayette Instruments Company, Lafayette, IN, USA) and an EMD

(Kin-Com 500 H, Chattex Corporation, Chattanooga, TN, USA). A coin-flip was used to decide both the starting condition (HHD vs EMD) and side (right vs. left). The moment arm of the resistance (distance between the ankle center of rotation and resistance pad) was measured for both limbs during the first condition and kept consistent in the second one. The same investigator, who had both clinical and research related experience using both the HHD and EMD, tested all subjects.

For testing on the EMD, subjects were positioned on the Kin-Com according to manufacturer recommendation for plantarflexion testing. Subjects were positioned supine and the axis of rotation for the test foot was aligned with the axis of rotation of the dynamometer arm. To avoid sliding of the subjects during testing, a restraint was positioned above the shoulder and secured to the dynamometer. The lower leg was also secured to the dynamometer using a Velcro strap in order to avoid unnecessary movements. The test foot was then secured to the EMD's ankle attachment using Velcro straps. The foot was positioned with the ankle in the neutral position, (e.g. the talocrural joint flexed at a 90° angle; Figure 1A). Two submaximal (approximately 50 and 75% of the subject's perceived maximal strength) and one maximal (100%) isometric contractions were executed to familiarize subjects with the testing protocol and warm-up. The test consisted of three maximal isometric contractions. Verbal encouragement was given by the tester and a minute rest was provided between contractions. A custom-made LabView (version 5.1, National Instruments Corporation, Austin, TX, USA) program was used to collect the data. The program was also used to correct for the stiffness of the plantarflexor muscles by subtracting the force generated by the plantarflexors during rest from the values produced during the contraction. The peak value (Newtons) of the three trials was recorded and used for further analysis.

For testing with the HHD, subjects were positioned supine on a height-adjustable, physical therapy mat, with both feet resting off the end of the mat. The height of the mat was consistently set such that the tester could provide maximal resistance. Subjects were instructed to grasp the side of the bed with their hands to avoid sliding. Subjects were advised not to

use their hands and arms to push themselves down during the test. The HHD was positioned under the ball of the foot and held in place by the tester (Figure 1B). Moment arm during both tests was kept constant by placing both measuring devices in the same place during the test, under the metatarsal heads. Subjects were then instructed to perform one submaximal contraction to familiarize with the test and to warm-up. After one minute rest, subjects performed three maximal contractions with the tester providing maximal resistance against the dynamometer. Verbal encouragement was given by the tester and a minute rest was provided between contractions. Data obtained with the hand-held dynamometer were recorded in kilograms and converted to Newtons (1N = 9.81 Kg); the peak value of the three trials was used for analysis.

Statistical Methods

The peak plantarflexion values from the right and left limbs were compared between HHD and EMD

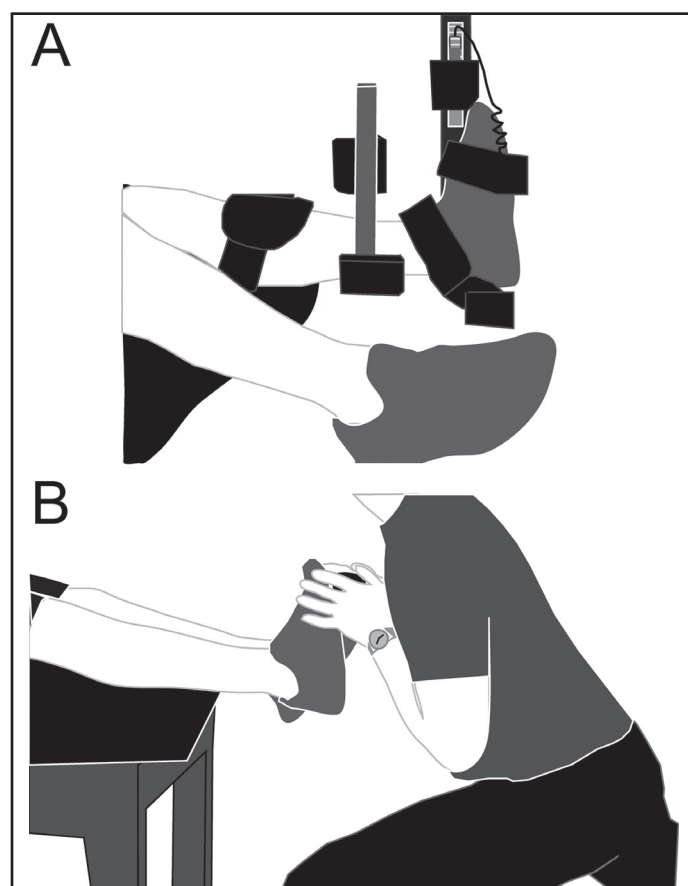


Figure 1. Position of the ankle for plantarflexion strength testing with the KinCOM electromechanical dynamometer (A) and the Handheld Manual Muscle Tester device (B).

using a paired-sample t-test. Intraclass correlation coefficient (ICC) model 3,1 and 95% confidence intervals (CI) were used to quantify concurrent validity between measurements obtained with HHD and EMD. Coefficient of determination (R^2) was also used to examine concurrent validity by quantifying the amount variance in EMD measurement that is explained by HHD measurement. Agreement between HHD measurement and EMD was examined using 95% limits of agreement. Additionally, Bland-Altman plots were created to examine the spread of error and difference between the two measurements in order to determine if the error was random or biased.³¹ Correlations between subject's mass and both EMD and HHD measurements were performed using linear regression. All analyses were performed with IBM SPSS, Version 19. Significance level was set at 0.05.

RESULTS

A total of 23 potential subjects were prescreened for eligibility. Three interested participants were excluded; one had diabetes and two had prior anterior cruciate ligament reconstruction surgeries. Therefore, a total of 20 active and healthy subjects were tested; subject characteristics are reported in Table 1. Plantarflexion force measures were significantly greater when using the EMD (735.1 ± 232.8 N) as compared to the HHD (620.2 ± 54.7 N) ($p < 0.01$;

Table 2). Using EMD as a criterion standard, ICC for the right side was $ICC_{3,1} = 0.141$, 95% CI (-0.31, 0.541) and $ICC_{3,1} = 0.139$, 95% CI (-0.313, 0.539) for the left side. HHD measurements were not related to EMD measurements for the right ($R^2 = 0.09$, $p = 0.19$) (Figure 2A) or left side ($R^2 = 0.088$, $p = 0.20$) (Figure 2B).

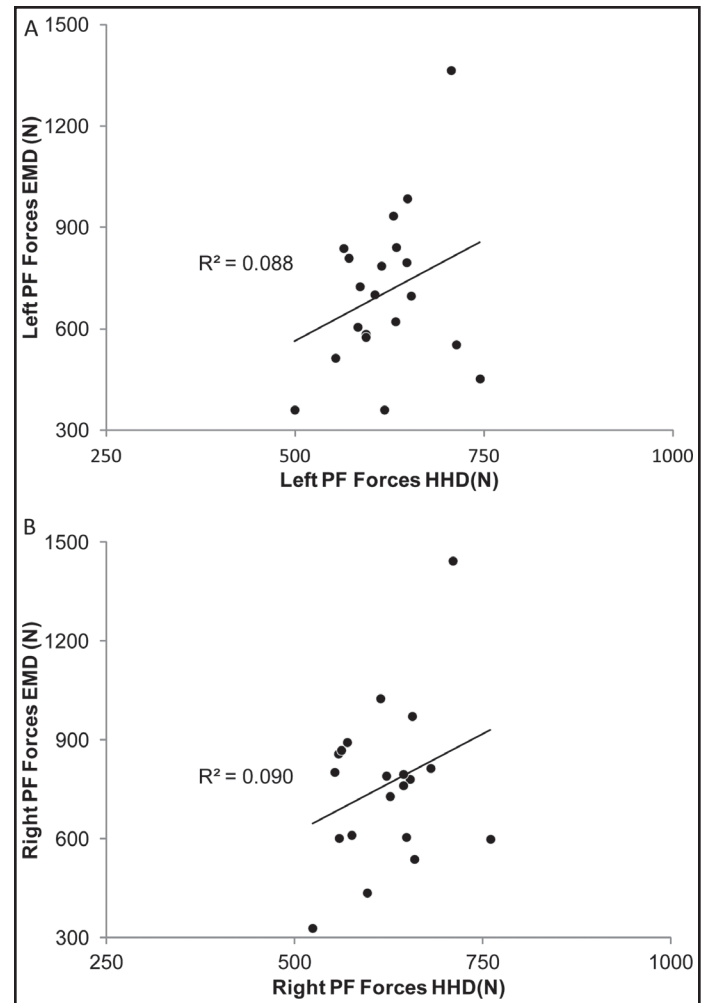


Figure 2. Scatter plot illustrating the relationship between the plantarflexion (PF) forces measured with the hand-held dynamometer (HHD) and electromechanical dynamometer (EMD) for the right (A) and left (B) legs.

Table 1. Subject Demographics.

Age (years)	25.9 ± 4.1
Sex (men/women)	10 / 10
Height (m)	1.7 ± 0.1
Mass (kg)	67.7 ± 12.3
Body Mass Index (Kg/m ²)	23.2 ± 3.1

Table 2. Force Production of Subjects, reported as Means ± Standard Deviations.

Measurement Method	Right Leg	Left Leg	Average
EMD (N)	763.5 ± 236.9	706.6 ± 233.7	735.1 ± 232.8*
HHD (N)	620.9 ± 59.4	619.5 ± 57.8	620.2 ± 54.7
Abbreviation: EMD= electromechanical dynamometer; HHD= handheld dynamometer.			
* Significant difference between EMD and HHD; $p < 0.05$			

The difference in plantarflexion force obtained using the HHD and EMD varied substantially with 95% limits of agreement between -301.17 N and 586.18 N. Bland-Altman plots revealed that the difference between HHD and EMD was influenced by the magnitude of the measure itself for the right (Figure 3A) and left (Figure 3B) sides. At low plantarflexion force measurements, HHD measures were consistently greater than forces measured on the EMD. At high plantarflexion force measurements, HHD was consistently less than force recorded on the EMD.

Plantarflexion force obtained using HHD was not related to body mass for either the right (Figure 4A; $R^2 = 0.024$, $P = 0.515$) or left (Figure 4B; $R^2 = 0.023$,

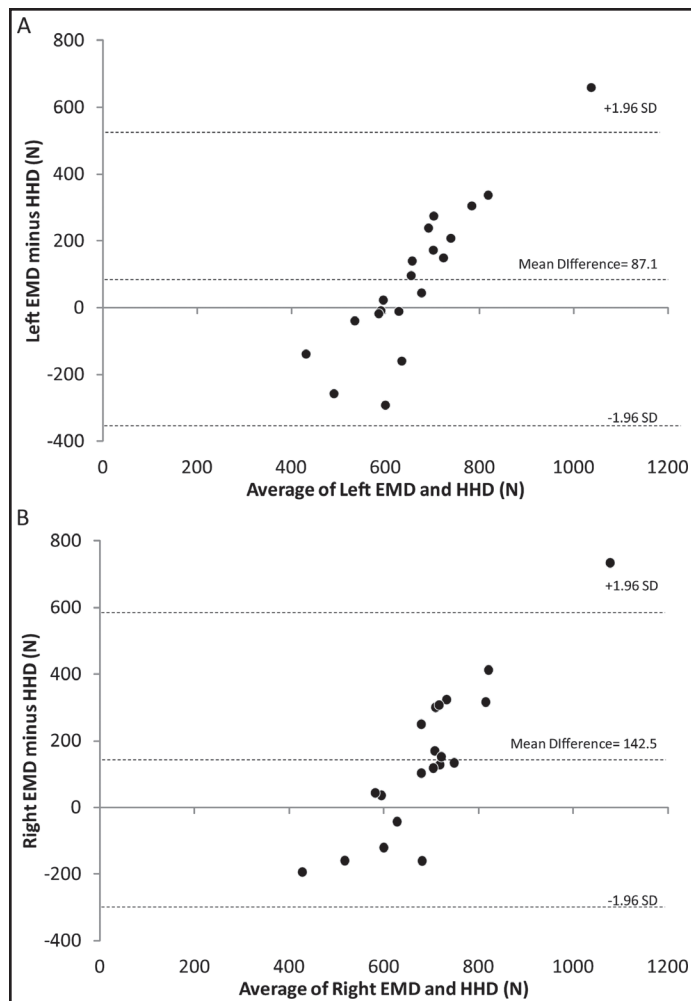


Figure 3. Bland-Altman plots of the difference (vertical axis) versus mean (horizontal axis) of measurements using hand-held dynamometer (HHD) and electromechanical dynamometer (EMD) for the right (A) and left (B) legs. The middle dashed line represents mean difference between HHD and EMD. The upper and lower dashed lines represent the 95% limits of agreement.

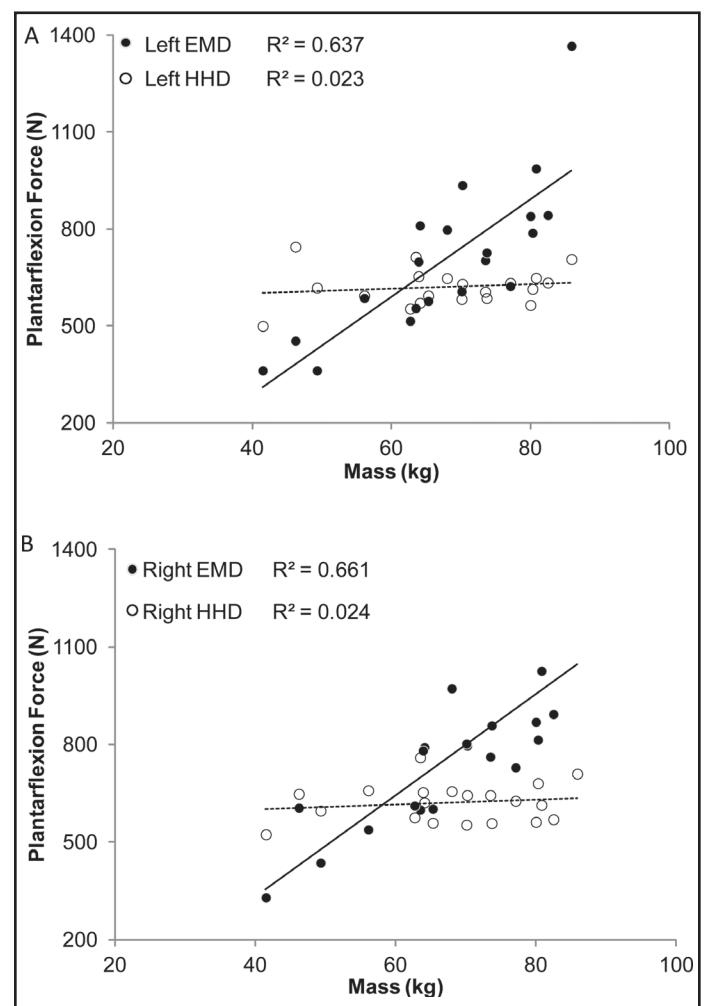


Figure 4. Scatter plot illustrating the relationship between the plantarflexion forces measured using hand-held dynamometer (HHD) and electromechanical dynamometer (EMD) and subject's body mass for the right (A) and left (B) legs.

$P = 0.527$) legs. Plantarflexion force obtained using EMD was significantly related to body mass in both the right (Figure 4A; $R^2 = 0.661$, $P < 0.001$) and left (Figure 4B; $R^2 = 0.637$, $P < 0.001$) legs.

DISCUSSION

The purpose of this study was to determine the concurrent validity of measuring plantarflexion force with a HHD as compared to an EMD as the gold standard. The significant difference between measurements performed using the HHD and EMD, the low ICC values and absence of correlation between measurements, support the authors' hypothesis that plantarflexor forces obtained using a HHD do not show absolute agreement with those obtained using an EMD. Compared to the EMD, forces measured

via HHD were significantly less and had a smaller total range of force values. The magnitude of the measure also influenced the discrepancy between EMD and HHD. Stronger subjects had less force on the HHD and weaker subjects had more force values on the HHD when compared to EMD. This biased shift in force measurement and lack of correlation between the two measures suggests that HHD method described in this study is not valid for quantifying muscle force from the plantarflexors in younger, non-impaired individuals.

Measures of strength are commonly normalized to body mass, as strength and body mass are correlated,³² particularly for plantarflexor strength.³³ In the current data, significant correlations between plantarflexor strength and body mass were only observed for the strength measures obtained using EMD and not when using the HHD. While standardizing strength allometrically can be achieved with more precision using different anthropometric and imaging techniques,^{34,35} normalizing strength to body mass is used frequently to account for body size in homogenous populations.³⁶ The lack of association between body mass and plantarflexion strength assessed using HHD, suggests that HHD does not provide a valid measure of plantarflexion strength.

Repeatability and consistency of joint angle is essential when evaluating strength of the plantarflexor muscle group. Changes in ankle joint angle of 10 degrees can result in a change in torque output of up to 40 Nm when the knee is extended.³⁷ In this study, attempts were made to standardize the ankle position in both the HHD and EMD conditions. Although the straps and shoulder pads reduced subject motion and ensured standard positioning during the EMD testing, controlling for subject motion on the mat during the HHD test was difficult. The researchers instructed all subjects to resist sliding by using their upper extremities to hold the mat; however, this in itself may introduce bias into the force measurement. It was anticipated that excessive use of the upper extremity during HHD testing would increase muscle force output, which was not what was observed during this study.

The range of plantarflexion forces recorded using the HHD was compressed (max = 760.3 N; min = 511.9 n) compared those recorded using the EMD (max = 1444.2 N; min = 329.8 N). The compressed

range for the HHD data compared to the EMD data suggests that the resistance provided by the examiner may have influenced the magnitude of the outcome. The results in the Bland-Altman plot also show that for the weaker subjects, the tester applied more force and the HHD measures were larger than the EMD. Conversely, for the stronger subjects, the tester recorded less plantarflexion strength with the HHD, suggesting the tester was unable to provide sufficient resistance to measure the subject's true maximal force. In an unrelated study, Bohannon⁷ went as far as to provide information on the strength of the tester, such as body weight and grip strength, to justify that the single tester used for collecting strength measures from upper and lower extremity muscles, was in fact strong enough to manually resist the forces produced by the subjects. However, for a measure of strength to be considered valid, the tester's strength should not factor into the recorded outcomes, especially in clinical practices where patients are not always treated by the same clinician. Others have suggested that once forces approach 300N, the average tester is either unable to resist³⁸ or can be "clumsy or impossible for the average examiner".¹⁷ The plantarflexion forces measured in the current study were substantially larger than 300N. Thus, the current findings further support the belief that tester strength influences plantarflexion measures obtained with a HHD.^{21,39} Clinicians should consider alternative strategies for assessing plantarflexion strength, such as using the heel rise test^{40,41} or utilizing hand-held devices that are placed under assistive straps or against a wall to provide an immovable form of resistance.

STUDY LIMITATIONS

This study was limited in that the data were only collected from young healthy individuals and the findings may not be necessarily apply to older individuals or those with pathological conditions. Additionally, the only measures of strength obtained here were force outputs from isometric contractions, therefore, the findings may not be generalized to other measures of muscle strength.

CONCLUSIONS

HHDs were introduced as a quick, inexpensive alternative to using EMD for assessing strength. However,

in clinical and research settings it is essential that strength measures are valid. These strength values are used to direct patient care, determine progress towards goals, and make informed decisions about evidence-based practice. While HHD may be suitable for assessing strength of some muscles groups, measurements of plantarflexion strength using a HHD should not be considered valid. HHD measures of plantarflexion strength are likely influenced by tester strength or other factors such as consistent positioning of both subject and tester.

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