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EVALUATION OF MECHANICAL AND FUNCTIONAL VERTEBRAL JOINT STABILITY BY ISOKINETIC DYNAMOMETRY

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ABSTRACT

Introduction: joint stability is a prerequisite for the functional activities and has being extensively studied. However, the existing assessment methods do not cover information on all stabilizer system components. **Purpose:** to evaluate the vertebral joint stability by isokinetic dynamometry and to correlate the findings with clinical tests. **Method**: fifty-seven asymptomatic individuals from both sexes with age between 18 and 30 years had vertebral joint stability evaluated by the isokinetic variables: passive stiffness curve, potentially elastic energy and trunk extensor strength, and by Schober Index and finger-floor distance. The relationship between these parameters were statistically analyzed with significance level of 5%. **Results:** there was significative difference in Schober Index between the groups that had presence and absence of passive stiffness curve (p=0,001) **Conclusion:** the present study provided information on the participation of passive variables in the context of vertebral stability. The protocol developed for data collection on passive stiffness also allows measuring the anatomical and structural components responsible for mechanical stability.

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INTRODUCTION

Joint stability is an essential prerequisite for functional activities, because executing an appropriate biomechanical movement does depend on a good stabilization of body segments. The spine stability has been widely studied and theories have been proposed (Aquino *et al.,* 2004; Oliveira *et al.,* 2009; Alencar *et al.,* 2016), but the mechanisms for control and interaction between the subsystems to achieve joint stability are still controversial (Cholewicki and McGill, 1996; McGill *et al.,* 2003; Oliveira *et al.,* 2009). Moreover, studies suggest that muscle or joint stiffness have fundamental importance in the ability of dynamic adjustments to increased resistance to disturbances imposed by the daily functional activities (Fonseca *et al.,* 2004).

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Regarding to the spine, segmental instability or loss of stiffness (Pope *et al.,* 1992) has been studied through joint motion parameters with a concept developed by Panjabi (1992), who named "neutral zone" the region of movement around the intervertebral joint, where little resistance is offered to passive movements, and "elastic zone" is the region where the joint structures, particularly the muscles, offer greater resistance to movement. Thus, the increased neutral zone may be an indicator of greater complacency of elastic and non-elastic components of the joint and they can influence on the resistance to the destabilization posed, favoring instability. In this case, a measure of spinal stability may be related to the stiffness levels of active and passive components of the spine, contributing to make available more than one way for assessing vertebral stability. For purposes of the present study, the local stabilization of the spine was considered as an adjustment made from the intersegmental movement. A global stabilization refers to the muscles directly linked to the spine such as multifidus, intertransversal, intervertebral, as well as the muscles indirectly linked to the anterior and posterior groups. The stability can not be measured solely by one or another component, it does not depend only of the segmental's range of motion.It should be included in a broader system, a global system of control and passive and active adjustments (Oliveira *et al.,* 2009). Thus, an stability measurement of the spine should contemplate the level of stiffness that are represented by the passive and active components. Therefore, there is great difficulty to reach consensus on the assessment of stability, especially with regard to the spine and the validation of diagnostic methods is also a theme under discussion (Posner *et al.,* 1982; Dvorák *et al.,* 1991; Jang *et al.,* 2009; Eduardo *et al.,* 2011).

Other clinical evidence is more closely related to flexibility and range of motion or the mobility degree, such as joint range tests and the Schober index (Macrae and Wright, 1969), used in the clinical practice as parameters for treatment evolution.
Both the mechanical and functional stability depend on passive and active muscle properties, since the former reflects passive stability or joint laxity degree and the second reflects the active capacity of generating force exclusively by means of passive stability mechanisms (Aquino *et al.,* 2006). Stiffness is a poorly studied variable and when it is analyzed, this usually occurs from the active point of view of increased tension during muscle contraction (Lee *et al.,* 2006) and current evidence does not point out a method which assesses joint stability considering all its complexity, i.e. anchored in a technology that addresses its properties. The isokinetic dynamometer is an instrument which enables obtaining objective measures, such as: muscle power, fatigue and work, increasing the reliability of assessment. Passive variables, such as stiffness, have been investigated by means of this device (Araújo *et al.,* 2011), and they are obtained from a curve related to resistance of the tendon-muscle unit to the passive motion (Blackburn *et al.,* 2004).

Considering this property and its components, such as stored elastic potential energy, have been related to the stability of a segment (Alencar *et al.,* 2006; Abrantes, 2006, 2009), and they are derived from forces emanating from muscle action, this study aimed to evaluate the vertebral joint stability by isokinetic dynamometry and to correlate the findings with clinical tests. The variables obtained by the dynamometer refer to the components of the stabilization system, which is the union of the passive and active forces acting on a joint. The results may contribute to define reliable stability parameters and, also, establish a relationship between these parameters and clinical tests used in the daily practice, in order to increase confidence for establishing diagnostic, therapeutic, and evaluative practices with regard to the spine.

METHODS

The study was approved by the Research Ethics Committee of Pontifical Catholic University of Paraná (PUCPR), Brazil, under the number 0005831/12. Sixty four subjects agreed to voluntary participate in the research and signed written consent form, but 7 of them were not included, because they did not meet the inclusion criteria: asymptomatic individuals aged between 18 and 30 years; non-regular practitioners of stretching; and absence of back surgeries. The exclusion criteria were: pregnancy; congenital pathologies in the spine compromising mobility; severe deviations in alignment; ligament hyperlacing; use of medicines which influence on muscle activity; and osteoporosis or osteopenia. Procedures are shown in Figure 1. The 57 subjects included underwent functional assessment, including anamnesis, postural inspection, weight and height measurement, and clinical tests: Schober index was used to assess lumbar mobility, and it is also used to provide stiffness parameters in progressive diseases, such as ankylosing spondylitis (Macrae and Wright, 1982) and finger-floor distance test to assess flexibility in the posterior chain (Rosen *et al.,* 2000). Ligamentous hyperlaxity parameters were analyzed according to the Beighton score. The equipment used was the isokinetic dynamometer (*Cybex*®, model NORM 7000) in the trunk module. A pilot study was previously performed with 14 subjects to establish the best positioning in the trunk module of the isokinetic dynamometer for passive stiffness data collection. The pilot study subjects underwent to the same inclusion and exclusion criteria of the subjects of the present study. The individuals were tested in 4 positions, in order to observe the curve behavior with regard to the increased posterior chain tension and the posterior muscle contraction during the tests. These subjects were tested firstly in the position recommended by the equipment owner's manual, with the motion axis was set at L4-L5, full relaxation of the spine and with relaxation and flexion of the cervical to observe the curves of passive stiffness produced (Wimpenny, 2000) (Figure 2). The second, the one with cervical rectification, and the third the one with cervical rectification and knee extension. Finally, the fourth position repeated with the first co-contraction of the muscles of the lower trunk. Of the 14 subjects tested, 57% presented a curve in the first position, against 35.7% in the second position, 29% in the third position, and 42,8% in the fourth position. This showed that position 1 was the most curve generator, in addition the curves generated in position 1 followed the same patterns already described in the literature (Aquino *et al.,* 2005), as shown in figure 3, because of this, this position was chosen to be that of data collection.

After the positioning and fixation of the subject in the latch module of the dynamometer (Figure 2), the weight measurement was conducted at 45 angle degree and the dynamometer operating mode was set on passive continuous mobilization (PCM), in order to assess the trunk extensor muscles. The speed was 5 degrees/s from the neutral position (0 degree) to minimize the activation of reflexes triggered by sudden stretching, and, also, because it is slow enough to simulate a passive stretching. The final range was defined through the maximum voluntary flexion of each subject, who was asked to move her/his trunk forward up to the extent to which she/he felt a discomfort sensation due to stretching. The testing protocol consisted of a single passive flexion of the trunk up to the maximum range allowed by the subject. This number was set through the behavior of mechanical and dynamic properties of soft tissues. The room temperature was kept at 21 Celsius degrees in all tests. The familiarization was provided through a complete movement and the length between familiarization repetition and the test was 10 seconds, long enough to enable the examiner to reinforce the test guidelines. The volunteers were instructed to keep the trunk and spine muscles as relaxed as possible to ensure passivity during the test. After the acquisition of passive stiffness data, was evaluated the peak torque of trunk muscles using the same position as the previous test (Figure 2), except of relaxation of the spine and with relaxation and flexion of the cervical spine flexion.

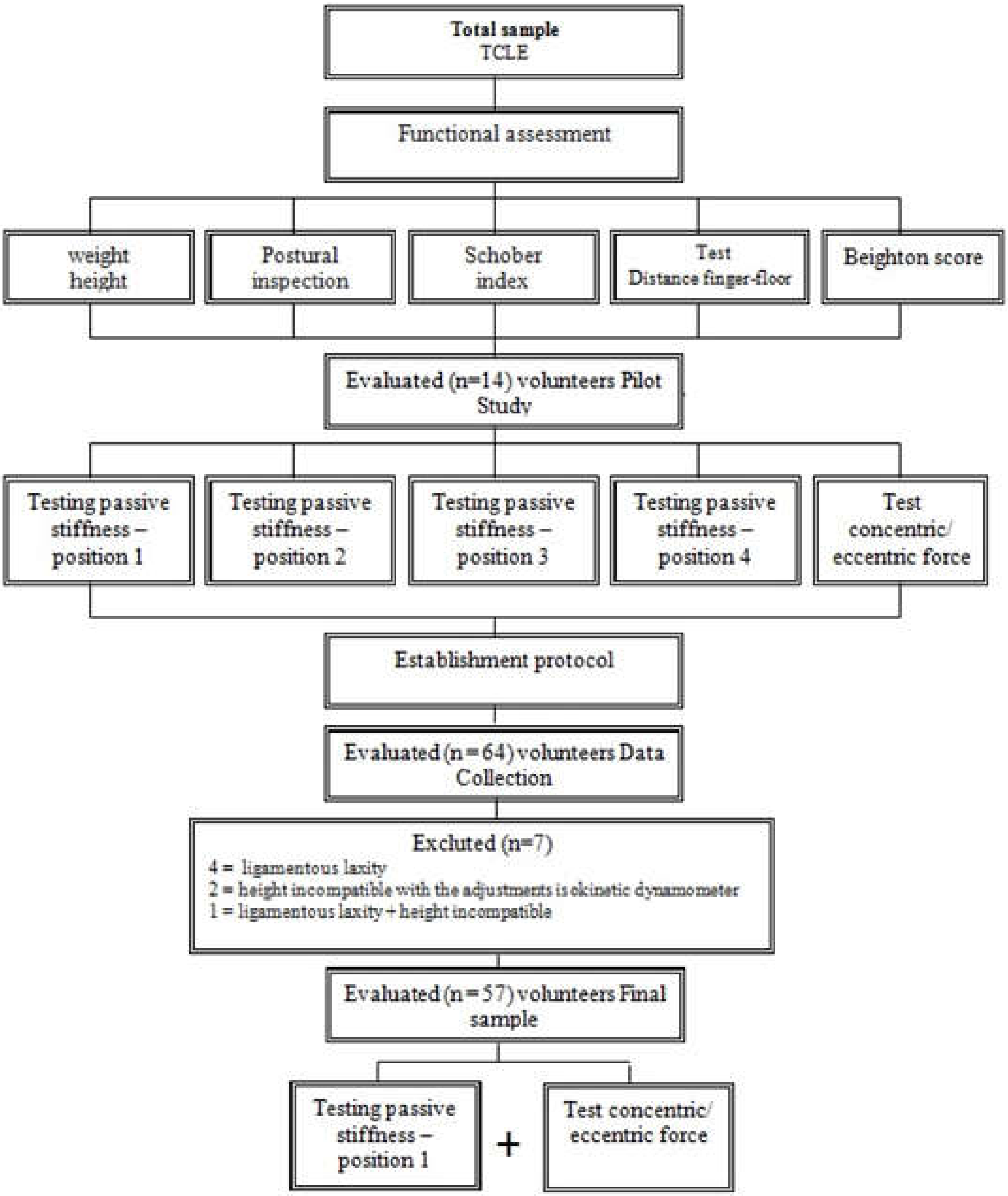

Figure 1. Flow diagram – Data collection procedures

Table 1 . General descriptive statistical data on the sample is displayed

Variable	n	Average ± SD	Median (Min-Max)
Age (years)	57	22,9 ± 3,9	22,0 (18-30)
BMI (Kg/m^2)	57	23,3 ± 3,7	22,8 (17,7-34,2)
Schober index (cm)	57	15,0 ± 0,9	15,0 (12,5-18)
Finger-floor distance test (cm)	57	12,4 ± 8,1	12,5 (0-31)
Concentric peak torque (N/m)	57	117,5 ± 53,3	99,0 (18-239)
Eccentric peak torque (N/m)	57	191,1 ± 77,2	180,0 (59-396)
ROM (º)	57	96,7 ± 5,9	100,0 (73-100)
Potencial energy (Nm/º) *	28	44,5 ± 31,9	33,5 (1-121)
		n (%) of No	n (%) of Yes
Presentation curve passive stiffness	57	25(43,9)	32(56,1)

*Restricted to those who had potential energy evaluated by the instrument.
Source: the author

Table 2. Variables variation for presence and absence of the passive stiffness curve

Variables	passive stiffness curve	n	Average ± SD	Median (Min-Max)	*p* value
Finger-floor distance test (cm)	No	25	12,0 ± 7,1	13 (0-26)	0,733*
	Yes	32	12,7 ± 7,1	11,5 (0-31)	
Schober Index (cm)	No	25	15,4 ± 1,0	15,5 (13,5-18)	0,001*
	Yes	32	14,7 ± 0,8	14,5 (12,5-16)	
ROM (º)	No	25	97,5 ± 6,0	100 (73-100)	0,259**
	Yes	32	96,1 ± 5,9	100 (76-100)	
Concentric peak torque (N/m)	No	25	126,7 ± 50,6	110 (73-239)	0,252*
	Yes	32	110,3 ± 55,0	95 (18-232)	
Eccentric peak torque (N/m)	No	25	208,0 ± 79,1	190 (59-396)	0,144*
	Yes	32	177,8 ± 74,1	161 (83-334)	

*Teste t de Student t test for independent sample, p<0,05
** Mann-Whitney non-parametric test, p<0,05
Source: the author

The operating mode was set on concentric/eccentric (CON/ECC) and speed was set at 60 degrees/s from the spine extension position, i.e. -15 degrees, in order to simulate demands posed by the functional activities of the segment. Therefore, it was set up the final angle of the test at 50 degrees of flexion, for joint protection. It was performed three concentric and eccentric isokinetic repetitions, in addition to three repetitions for familiarization. The time elapsed between the familiarization repetition and the test was 1 minute, to provide muscle recovery.It was instructed the individual to move with all the force that could produce, and auditory and visual stimuli were used to promote maximum contraction at each repetition.

Figure 2. Positioning recommended (Cybex ® model NORM 7000; Wimpenny, 2000) with relaxation of the cervical spine and hands

RESULTS

The crossing of variables was done in order to think through the protocol developed and also the stability parameters and individual characteristics with regard to the passive stiffness curve and stored elastic potential energy.

The group was divided in terms of presence or absence of the passive stiffness curve and stored elastic potential energy.The general descriptive statistical data on the sample is displayed in table 1. Table 2 displays data on the variables variation for presence or absence of the passive stiffness curve. The descriptive statistical data of the variables are presented according to the groups defined by the curve and the *p* values obtained from the statistical tests. For assessing the association between potential energy and force (concentric and eccentric), we tested the correlation hypothesis. Table 3 displays the correlation between concentric and eccentric peak torque and the potential energy stored and the *p* values obtained from the statistical tests.

DISCUSSION

For the active test of concentric and eccentric force, we used parameters already described in the literature (Gómez *et al.,* 2005), however, studies describing normative data for eccentric tests, especially addressing the trunk were not found. According to Dvir (2002), the issue of eccentric moment versus concentric moment of the trunk muscles has received little attention. The stiffness was regarded in this study as an indicator of passive stability, as well as the capacity to generate active stability forces (Abrantes, 2009). From then on, were chosen the crossing of individual characteristics regarded as predictors of joint stability, such as flexibility, mobility, age, and body mass index (BMI), in order to establish a relationship between them and the passive stiffness curve, since the geometry or the articular congruence, mechanical properties of the biological tissues involved, body mass, and forces acting on the joints are related to stability (McGill and Cholewicki, 2001; Alencar et al.,2006; Aquino *et al.,* 2006). Tirrell et al. (2012) claim that molecular components are, to a great extent, responsible for muscle functions, such as tension, both passive and active. By studying the molecular distribution of proteins (collagen, titin, and myosin) belonging to muscles, it was likely to find these proteins in distal muscles and there was rapid muscle contraction. Thus, we suggest that the distal muscles must have higher passive tension than the proximal muscles. Through the present study, we may infer that absence of the curve in all participating subjects can be related to its location with regard to the axial skeleton. The trunk muscles are proximal and, also, the vast majority of them are postural muscles with slow recruitment, therefore, they are not biologically favored with large amounts of the proteins collagen, titin, and myosin, which would increase passive tension.

The shortening level of the posterior chain, which was measured by means of the finger-floor distance test, did not influence the presence of the curve, as displayed in Table 2. Gadjoski (2001), who worked with stretching techniques and variable passive stiffness in other joints reported decreased passive stiffness after stretching exercises and they associated this decrease to increased elasticity of constituent structures of elastic components, parallel to muscle wrappers. Blackburn et al. (2004), in turn, showed that high extensibility does not seem to be a predisposing factor for decreased muscle stiffness. Musculotendinous extensibility in the present study was moderately related to passive muscle stiffness and weakly related to active muscle stiffness.The results of the present study were more congruent with the findings of Blackburn et al. (2004) perhaps because stiffness is not influenced only by the elastic components, but also by the cross-sectional area of muscles, capsules, joints ligaments, skin, and connective tissue may constitute determinant factors for stiffness (Aquino *et al.,* 2006). Aquino et al. (2006) obtained was a significant association between flexibility and stiffness in the hamstrings, however, the authors conclude that only a small percentage of the variability in stiffness measurement may be explained by flexibility, because these properties are not synonymous and they must be analyzed independently. According to Araújo et al. (2011), contrary to passive stiffness, flexibility measurement is not determined only by mechanical properties, it is also influenced by individual levels of tolerance to stretching. Several clinical and scientific reports on joint mobility and stability demonstrate that there is some kind of association between these two variables. Most researches on spine stability, for instance, take into account the joint mobility degrees (Leone *et al.,* 2007; Jang *et al.,* 2009).

The results of the present study corroborate with evidences (Leone *et al.,* 2007; Jang *et al.,* 2009) and the Schober index influenced on the passive stiffness curve behavior, as displayed in Table 2. The passive stiffness curve showed a statistically significant relation to the mobility parameters of this clinical test, and we may suggest its use as a complementary measure to other methods for assessing stability. This may be relevant for the current stage of research on the topic, however, there is a need for establishing normative data on the assessment of passive properties of the trunk extensor muscles, and this study may be pointed out as pioneering in this regard. The relationship between mobility measured by means of the Schober index and passive stiffness measured by means of the dynamometer may be explained through Hooke‘s Law and its material deformation diagrams, showing a higher incidence of resistance in the elastic limit zone (Aquino *et al.,* 2005). In practice, this may be demonstrated by means of the isokinetic test, in which the final range of trunk flexion takes place on the lumbar segment, where the motion axis is positioned for the test, i.e. the same area with the greatest resistance torque in the passive trunk flexion movement shown by all subjects. Other methods for assessing segmental mobility, such as functional radiographs, may not constitute a strong evidence because does not consider stability in all its complexity. Jang et al. (2009) used this method and found out that there is a need for supplementing with other assessment ways, since, according to these authors, radiographic criteria does not address all aspects of instability, there are discrepancies between clinical and radiological findings. Alencar et al. (2006) claim that the mechanical properties of ligaments are regarded as the most important in terms of constraints to passive movements, highlighting the importance to analyze stability from this point of view. However, according to Araújo et al. (2011), there is an interdependence between mechanical properties and the resistance torque that a joint needs to generate. Thus, passive mechanisms may be enough or act along with muscle activation to resist unwanted movements. In the present study, the relationship between concentric and eccentric force of the trunk extensor muscles and the presence of the passive stiffness curve in the same muscle group of the subjects participating in the study (Table 2) had no statistical significance. The statistical correlation between the stored elastic potential energy values and the concentric and eccentric force values was not significant with regard to the linear relationship between these variables (Table 3). These weak correlations could indicate that these variables are important with regard to stability components, however, the evaluation of these components is so complex that it requires an approach which considers the various stability predictors and the interaction between them. These arguments are corroborated by Alencar et al. (2006) with regard to the existence of two stability mechanisms, i.e. mechanical and functional. However, they do not corroborate the hypotheses of Kubo et al. (2001), Fukashiro et al. (2006), and Stafilidis and Arampatzis (2007), who infer that the higher the potential energy stored by the muscle group, the greater the force capacity, due to the tendon elastic capacity. Passive structures, according to these researches, may be closely related to the dynamic muscle performance, providing elastic energy in high speed contractions, needed to neutralize imbalances posed during functional activities. In the present study, stiffness or accumulation of stored elastic potential energy was not predictive of the ability to generate force, either concentric or eccentric. As the concentric contraction tension generated by coupling of cross-bridges and the tension produced by an eccentric contraction related to the passive resistance of non-contractile components, the dynamic stiffness resulting from these forces is related to functional stability. Thus, in order to consider the stability component, in all its complexity, there is a need to take into account a whole and not only an isolated assessment of passive and active muscle variables. This hypothesis is congruent with Gajdosik (2001), when the author claims that it is possible to calculate the magnitude of active forces indirectly, by subtracting the passive forces from the total force produced throughout the entire muscle length. By adding passive to active stiffness stability from the static and dynamic points of views is assessed, obtaining information on stability throughout its range. This proposition corroborates, even indirectly, the results of Silva et al. (2009), who studied the adjustment of dynamic stiffness through eccentric contractions and co-contraction; they concluded that these two forms of muscle activation are not the only mechanisms for adjusting stiffness, indicating passive properties as contributors, too. According to these authors, the mechanisms vary according to individuals and with regard to the proposed activities. The assessment mode may strengthen the hypothesis that even with great contributions of factors related to mechanical stability for performing various functional activities, the passive stiffness of joints seems to be not enough to ensure joint stability (McGill and Cholewicki, 2001).

Conclusion

The present study provided information on the participation of passive variables in the context of stability. Among the variables correlations, only the

Schober test presented statistically significant relationship with the presence of passive stiffness curve and consequently with joint stability. This finding demonstrates that the protocol developed for collecting data on passive stiffness allows measuring the anatomical and structural components responsible for mechanical stability, however, it was not able to provide an absolute joint stability parameter. There is a need for further research to apply the tests presented here, checking force values through co-contraction of the muscles involved in the segment focused. Further studies could also establish new tests, expanding the possibilities for assessing joint stability of the spine, in order to validate this protocol and improve it.

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