



## Original research

# External and internal training load relationships in soccer players: the metabolic power approach

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**Abstract:** The aim of the present study was to examine the relationships between internal training loads (TL) (Banister, Edwards Training-Impulse (TRIMP), session RPE (s-RPE)) and external TL (Total distance (TD), high speed distance (HSD), high metabolic distance (HMD)) in amateur soccer players. Nine male amateur soccer players (age = 28.74±5.2 years; height 173.74±8.04 cm; weight 72.73±5.5 kg) voluntarily participated in the study. Individual field-based training sessions were monitored over 8 weeks. The results showed that there were moderate and very large correlations between s-RPE and both Edwards and Banister's TRIMP (respectively,  $r = 0.42-0.86$ ;  $r = 0.45-0.85$ ). Additionally, from large to nearly perfect correlations were observed between the HR-based methods ( $r = 0.58-0.98$ ). We also found moderate to very large correlations between s-RPE and HMD and large to nearly perfect correlations between HR-based TL methods and HMD. Correlations between internal load and external load parameters was weaker in HSD than TD. In the light of the results of the current study, internal and external loads should not be used interchangeable and HMD seems to be appropriate to monitor TL in soccer players because its equations include both speed and acceleration values.

**Keywords:** Total distance, acceleration load, rating of perceived exertion, heart rate, speed zones.

## 1. Introduction

To better understand the demands of soccer, training and match load must be tracked using accurate empirical methods (Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010; Dalen, Jørgen, Gertjan, Havard, & Ulrik, 2016). During a soccer match, players cover 10–14 km, mainly performing low intensity aerobic exercise (Andrzejewski, Chmura, Pluta, & Kasprzak, 2012; Bangsbo, Mohr, & Krstrup, 2006; Stølen, Chamari, Castagna, & Wisløff, 2005). Although aerobic metabolism dominates energy delivery, the large number of distinctive high-intensity actions, such as sprints, which are performed approximately

30 times over distances totaling around 230 m in soccer matches (Andrzejewski, Chmura, Pluta, Strzelczyk, & Kasprzak, 2013; Dellal et al., 2011), have a very important influence on the energy production processes of soccer players (Bangsbo et al., 2006; Mohr, Krstrup, & Bangsbo, 2003; Stølen et al., 2005).

In the terms of the physiological demands of the game, the oxygen consumption of players is approximately 70%-80% of maximal oxygen uptake (Manzi, Impellizzeri, & Castagna, 2014; Reilly, 1997; Reilly, Bangsbo, & Franks, 2000; Stølen et al., 2005), mean and



maximal heart rate (HR) responses of players are around 85% and 98% of maximal values, respectively (Bangsbo et al., 2006; Manzi et al., 2014). The accurate measurement of energy expenditure associated with soccer competition is a very difficult process because of the complex structure of the game. The estimated energy expenditure in a soccer game is about 5-6 MJ (Reilly et al., 2000; Shephard, 1999), although it should be remembered that these demands can be affected by factors such as the opposing team, the stage of the season, playing position, game location (Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Reche-Soto et al., 2019). Thus, the continued monitoring of the effectiveness of different methods in measuring the demands of soccer games helps coaches to select appropriate training strategies and technologies (Andrzejewski et al., 2013).

Training load monitoring methods can be categorized into two main types. The first one, internal load monitoring, includes physiological and psychological values such as heart rate, blood lactate, oxygen consumption, and rating of perceived exertion (RPE). (Soligard et al., 2016). The most common method for determining internal training load and energy expenditure is continuous heart rate (HR) recording (Alexandre et al., 2012). To monitor HR load different training impulse (TRIMP) methods have been used which take account of the time spent in pre-defined HR zones; two most common examples are Edwards' TRIMP and Banister's TRIMP (Clarke, Farthing, Norris, Arnold, & Lanovaz, 2013; Paulson, Mason, Rhodes, & Goosey-Tolfrey, 2015; Scott et al., 2013). However, these methods cannot be used in official games and they are also not suitable for anaerobic actions such as sprints (Osgnach, Poser, Bernardini, Rinaldo, & Di Prampero, 2010). This means that coaches are unable to accurately track match data, which is very important in the weekly load calculation process (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Therefore, an increasing number of studies in the past few years have examined the validity of s-RPE

methods. These studies have found strong correlations between s-RPE and both Edwards' TRIMP (Casamichana, Castellano, Calleja-Gonzalez, RomaN, & Castagna, 2013; Impellizzeri et al., 2004; Scott et al., 2013) and Banister's TRIMP (Impellizzeri et al., 2004; Scott et al., 2013). Previous studies have shown that s-RPE is a valid, reliable, inexpensive and very simple method and can be used as an alternative instead of HR-based methods for monitoring training load (Foster et al., 2001; Singh, Foster, Tod, & McGuigan, 2007; Wallace, Slattery, & Coutts, 2014)

The second, external load monitoring, has become possible thanks to the development of technology over two last decades to allow us to measure values such as power output, speed, acceleration and metabolic power (Bourdon et al., 2017; Scott, Lockie, Knight, Clark, & Janse De Jonge, 2013; Soligard et al., 2016). Although speed values have been most common external load method for the estimation of energy expenditure and training and match loads of soccer players, this approach may not provide accurate results for these values, because some actions cause very high energy expenditure, even if players do not reach high speed. Acceleration has been found to contribute up to 10% of the total player load in soccer (Dalen et al., 2016) and so, acceleration values are very essential elements in measuring metabolic loads, even when speed is low (Gaudino et al., 2014, 2013; Manzi et al., 2014; Osgnach et al., 2010; Polglaze, Dawson, & Peeling, 2016). Some researchers have in fact claimed that acceleration-based actions could be more decisive than the maximal running speed capabilities of team sports players (Carling, Bloomfield, Nelsen, & Reilly, 2008; Vázquez-Guerrero, Suarez-Arrones, Gómez, & Rodas, 2018). On the other hand, both speed-based and acceleration-based methods are very important factors depending on the pitch size and the player's position and they should be used together for accurate training load measurement in soccer.

Previous sentence explains the importance of having an approach that considers the instantaneous interplay of player's running

speed and acceleration (Manzi et al., 2014; Osgnach & Di Prampero, 2018; Osgnach et al., 2010; Polglaze et al., 2016; Reche-Soto et al., 2019). Metabolic power (MP) is a kinematic-based approach and its values have been used over recent decades to determine energy expenditure and training and match loads for soccer players. However, some studies argue that the MP method could be questionable because of the overestimated energy costs of some exercises, such as walking, constant velocity running (Brown, Dwyer, Robertson, & Gastin, 2016; Stevens et al., 2015) or underestimated energy costs of resting phases of drills, shuttle running; intermittent movement patterns etc. (Buchheit, Manouvrier, Cassirame, & Morin, 2015; Stevens et al., 2015; Brown, Dwyer, Robertson, & Gastin, 2016). On the other hand, using oxygen analyzer is the gold standard to measure energy expenditure, obviously this method is useless on the field, therefore MP seems appropriate solution to measure this value. To our knowledge, although MP has been using as a training load tool in soccer, this is the first study examine the relationships between internal load tracking methods and MP, which is an acceleration and speed-based method. The aim of this study, therefore, was to assess the relationships between s-RPE, heart rate-based methods, high metabolic distance (HMD), and speed-based actions in soccer players.

## 2. Materials and Methods

### *Subjects*

Nine amateur male soccer players from Turkish local amateur league (age = 28.74±5.2 years; height 173.74±8.04 cm; weight 72.73±5.5 kg) voluntarily participated in the study. They performed 4 training sessions and played 1 official game per week. Each subject had the risks and benefits explained to him beforehand, signed an informed consent form to participate, and completed a medical history form.

### *Methodology*

Before the data collection procedure, the players performed the Yo-Yo intermittent

recovery test (YIRT) to determine maximal HR ( $HR_{max}$ ) and HR training zones. During the first 8 weeks of the season, a total of 209 individual field-based training sessions (strength and regeneration training sessions were not included) were monitored using portable global positioning system (GPS) technology (GPSports SPI Pro X, Canberra, Australia). This version of the SPI Pro X (size = 48 x 20 x 87mm; mass = 76g) provides raw position, velocity and distance data at 15Hz (15 samples per second). The SPI Pro X devices were worn in a customized padded pouch in the player's jersey and positioned between the shoulder blades, slightly superior to the scapulae (Delaney et al., 2016;). All data were downloaded using SPI Pro X software Team AMS. Players asked to wear the same GPS device for each training sessions in order to avoid inter-unit error (Duffield, Reid, Baker, & Spratford, 2010; Gaudino et al., 2013). All devices were ready 15 min before the data collection to allow acquisition of satellite signals (Duffield et al., 2010; Gaudino et al., 2013; Waldron, Worsfold, Twist, & Lamb, 2011). When the satellite signal was below eight, data was eliminated on these days (Gaudino et al., 2013; Varley, Fairweather, & Aughey, 2012; Waldron et al., 2011). Using the data collected the Edwards' and Banister's TRIMP values, s-RPE, total distance (TD), high speed distance (HSD), and high metabolic power distance (HMD), and were determined. The relationships between external and internal training loads were examined and the strength of the relationship was calculated for each player.

*Yo-Yo Intermittent Recovery Test (YIRT)*. The YIRT was used to determine the maximum heart rate responses of players. This test consists of repeated 20 m runs back and forth between the starting, turning, and finishing lines at a progressively increased speed, which is controlled by audio beeps from a tape recorder. Between each running bout, the subjects have a 10-sec active rest period, consisting of 2 x 5 m of jogging. The test was performed until exhaustion or two failures to reach the next cone before the signal

(Bangsbo, Iaia, & Krstrup, 2008). HR was measured and stored using a Polar chest belt (Polar Electro OY, Kempele, Finland) with GPSports SPI Pro X devices attached throughout the test. Stored data were transferred to the computer and filtered using the SPI Pro X software Team AMS. The highest HR measurement was recorded in the YIRT as HRmax.

*Internal training load.* S-RPE loads were calculated by multiplying the training duration (in minutes) by the RPE for the session (Foster et al., 2001). In the current study, the same coach of the team asked the players how hard their workout was; each athlete's s-RPE was collected about 30 min after the training session to ensure that each subject reported a global RPE for the entire session rather than the most recent exercise (Singh et al., 2007). Each player was confidentially interviewed and not allowed to see the values given by other players. Before the study, the CR-10 scale (Table 1) was explained to players verbally and used for two weeks to ensure that players were familiarized with it.

**Table 1.** The Modified Borg Category Ratio-10 Rating of Perceived Exertion Scale (Foster et al., 2001).

Rating	Descriptor
0	rest
1	very, very easy
2	easy
3	moderate
4	somewhat hard
5	hard
6	
7	very hard
8	
9	
10	maximal

Edwards' and Banister's TRIMP were used to determine HR-based internal load of players in current study. Edwards' TRIMP was obtained by calculating the product of the accumulated training duration (minutes) in 5 HR zones applying a coefficient relative to the following zones and then summing the result (Table2) ( Paulson et al., 2015; Scott et al., 2013).

**Table 2.** The Edwards' TRIMP HR Zones and The Weighing Factor.

HR Zones	the weighing factor	%HRmax
1	1	50-60
2	2	60-70
3	3	70-80
4	4	80-90
5	5	90-100

For Banister's TRIMP, the following equations were used:

$$\text{Banister's TRIMP: [Duration (min)]} \\ (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) / (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}) 0.64^{e^{1.92x}}$$

where  $\text{HR}_{\text{ex}}$  = average HR during exercise,

$$\text{HR}_{\text{rest}} = \text{HR at rest,}$$

$$\text{HR}_{\text{max}} = \text{YIRT maximal HR,}$$

$$e = 2.712,$$

$$x = (\text{HR}_{\text{ex}} - \text{HR}_{\text{rest}}) / (\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}).$$

The resting HR values ( $\text{HR}_{\text{rest}}$ ) were determined for Banister's TRIMP by giving HR monitors to players to take home; they were asked to wear the device for 2 minutes while lying supine on waking, which provided the  $\text{HR}_{\text{rest}}$  value (Scott et al., 2013). For these procedure the RS 810 polar (Polar Electro OY, Kempele, Finland) was used.

*External training load.* Every player's distance covered values were monitored during each session. Above 14.4 km·h<sup>-1</sup> speed was used to calculate high speed distance (HSD). Previous studies have claimed that uphill running at constant speed is biomechanically equivalent to accelerated running on flat terrain (Di Prampero et al., 2005; Stevens et al., 2015). Osgnach et al. (2010) created an equation with a terrain factor for use in team sports and reported that high metabolic power (20 Wkg<sup>-1</sup>) could be considered as corresponding to a VO<sub>2max</sub> of 57 ml·kg<sup>-1</sup>·min<sup>-1</sup> above resting, and they assumed that exercise above this cutoff value is mainly anaerobic (Manzi et al., 2014; Osgnach et al., 2010). HMD covered at more than 20 Wkg<sup>-1</sup> equates to running at 5ms<sup>-1</sup> and accelerating at 2ms<sup>-1</sup> according to Osgnach et al. (2010). HMD was obtained automatically by using SPI Pro X software Team AMS.

### Statistical Analysis

Individual correlations were determined based on data from a minimum of 18 training sessions up to a maximum of 28. All data were analyzed using the Statistical Package for the Social Sciences (SPSS version 21.0, Chicago, Illinois, USA). The mean and SD for each variable were determined to quantify the demands of each training session. Before using parametric tests, the assumption of normality was verified using the Shapiro-Wilk test. Individual Pearson's product-moment correlations between s-RPE, HR-based measures and external TL measures were computed using the number of practice sessions for each player according to the methods of Clarke et al. (2013). Correlations were categorized according to the following scale: trivial ( $r < 0.1$ ), small ( $r = 0.1-0.3$ ), moderate ( $r = 0.3-0.5$ ), large ( $0.5-0.7$ ), very large ( $r = 0.7-0.9$ ), nearly perfect ( $r > 0.9$ ), and perfect ( $r = 1$ ) (Hopkins, Marshall, Batterham, & Hanin, 2009).

### 3. Results

The relationships among internal TL are presented in Tables 3. Moderate to very large individual correlations were found between

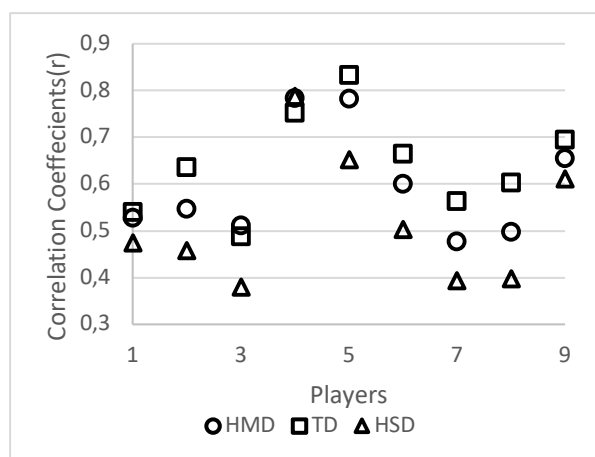
s-RPE scores and both Edwards' TRIMP ( $r = 0.42-0.86$ ) and Banister's TRIMP ( $r = 0.45-0.85$ ) findings. In addition, there were from large to nearly perfect correlations between the HR-based TL methods ( $r = 0.58-0.98$ ) (Table 1) ( $p < 0.01$ ).

The correlations found between s-RPE and HMD in Figure 1. It can be seen that moderate to very large correlations were found between s-RPE and HMD ( $r = 0.47-0.78$ ). While moderate to very large correlations were observed between s-RPE and TD ( $r = 0.48-0.83$ ), for s-RPE and HSD the correlations were  $r = 0.38-0.79$  (Figure 1) ( $p < 0.01$ ).

**Table 3.** Individual correlations between s-RPE and Edwards, Banister training impulse (TRIMP).

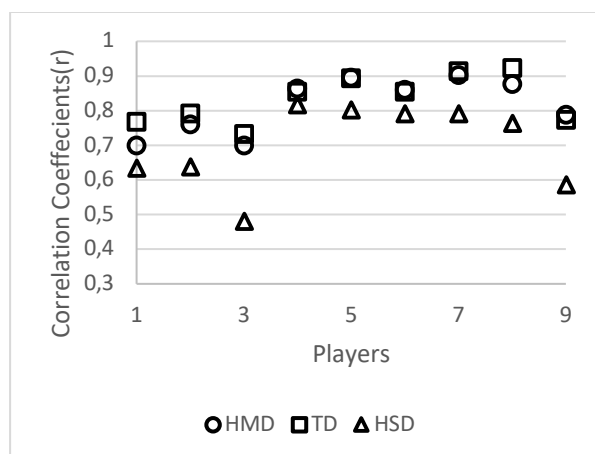
Players	Training No	RPE <sup>*</sup> Edwards	RPE <sup>*</sup> banister	Edwards <sup>*</sup> banister
P1	25	.42*	.61**	.82**
P2	23	.68**	.84**	.58**
P3	23	.79**	.83**	.98**
P4	23	.67**	.62**	.94**
P5	25	.86**	.85**	.98**
P6	21	.55**	.61**	.84**
P7	28	.45*	.45*	.98**
P8	18	.67**	.71**	.93**
P9	23	.76**	.72**	.91**
Mean	23,2	0.66	0.70	0.89
Min	18	0.42	0.45	0.58
Max	28	0.86	0.85	0.98





**Figure 1.** Individual correlations between s-RPE and high metabolic distance (HMD), total distance (TD), high speed distance (HSD)

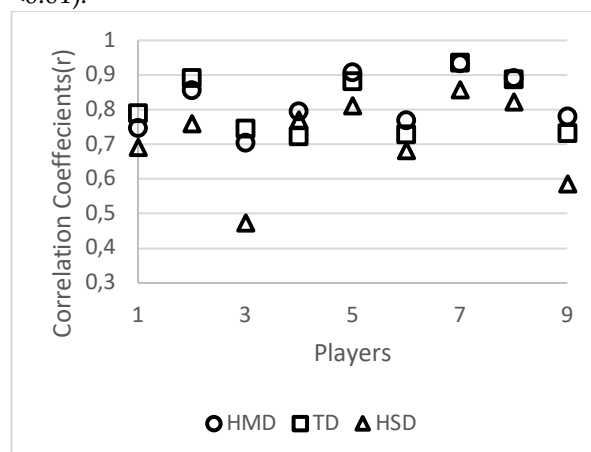
Figure 2 shows the correlations found between Edwards TRIMP values and external TL values. The relationships Edwards TRIMP and HMD ranged from large to very large ( $r = 0.69-0.90$ ). Very large to nearly perfect correlations were found between Edwards TRIMP and TD, ( $r = 0.73-0.92$ ). In addition, there were moderate to very large correlations between Edwards TRIMP and HSD ( $r = 0.48-0.81$ ) (Figure 2) ( $p < 0.01$ ).



**Figure 2.** Individual correlations between Edwards TRIMP and high metabolic distance (HMD), total distance (TD), high speed distance (HSD)

Finally, Correlations of Banister's TRIMP and external TL values are seen in Figure 3. The correlations between Banister's TRIMP and HMD and TD ranged from very large to nearly perfect ( $r = 0.71-0.93$ ;  $r = 0.72-0.93$ , respectively). Moderate to very large

correlations were found between Banister's TRIMP and HSD ( $r = 0.47-0.85$ ) (Figure 3) ( $p < 0.01$ ).



**Figure 3.** Individual correlations between Banister's TRIMP and high metabolic distance (HMD), total distance (TD), high speed distance (HSD)

#### 4. Discussion

The aim of current study was to examine the relationships between internal and external TL in soccer players. The correlations found between s-RPE with both Edwards' TRIMP and Banister's TRIMP ranged from moderate to very large, and there were from large to nearly perfect correlations between HR-based TL methods (Table 3). These results are in line with previous studies that have examined the relationships between internal methods for quantifying training load in soccer players. These studies found large to very large correlations between s-RPE and HR-based methods (Casamichana et al., 2013; Impellizzeri et al., 2004; Scott et al., 2013). Thus, in line with previous studies, we can say that s-RPE is a valid, reliable, viable, inexpensive and accessible method for monitoring TL in team sports (Casamichana et al., 2013; Foster et al., 2001; Singh et al., 2007; Wallace et al., 2014). On the other hand, it should be remembered that different types of training tasks appear to affect the strength of these relations (Casamichana et al., 2013; Impellizzeri et al., 2004). S-RPE should be used carefully to determine TL in intermittent and interval actions required in soccer training, that is, those where players use both aerobic and anaerobic sources for energy provision in the same training session

(Bangsbo, 1994; Halson, 2014). In addition, we should note that players could perceive the same physiological stimuli differently because of variation in individual psychological states (Morgan, 1973), which could cause intra-individual variations while using s-RPE. For these reasons, it is thought that using both s-RPE and HR based TL measures together to monitor internal TL is more advisable in soccer.

Acceleration capabilities and high intensity action qualities of soccer players are vital in decisive activities (Carling et al., 2008; Mohr et al., 2003; Vázquez-Guerrero et al., 2018). Although these values have been most common external load method for the estimation of energy expenditure, using only one of these approach may not provide accurate results for energy expenditure. Therefore, we have examined the relationships between internal loads and HMD, its equation includes both speed and acceleration values. According to the findings of the current study, while there were moderate to very large correlations between s-RPE and HMD, the relations between HR-based methods and these two external TL measures ranged from large to nearly perfect. Previous studies have shown conflicting results concerning the use of MP values in soccer. While some studies support the use of MP (Gaudino et al., 2013; Manzi et al., 2014; Osgnach et al., 2010; Reche-Soto et al., 2019), other studies question this method (Brown et al., 2016; Buchheit et al., 2015; Castagna et al., 2017; Hader, Mendez-Villanueva, Palazzi, Ahmaidi, & Buchheit, 2016; Stevens et al., 2015). Manzi et al. (2014) examine the association between MP responses in official soccer matches and aerobic fitness to determine the ecological validity of the MP approach and argue that MP is a useful method for the assessment of external match load in soccer. MP could provide better information than the speed-based method for understanding the demands of high intensity actions in small-sided soccer games (Gaudino et al., 2014, 2013). On the other hand, Castagna et al. (2017) suggest the use of both speed-based

and MP methods to track external load in match-play. In the light of current study results, HMD seems to be a useful method for monitoring external loads on soccer players since it combines speed and acceleration values in one method.

This study found that the correlation between s-RPE and TD ranged from moderate to very large and correlations of HR based methods with TD were very large to nearly perfect. However, in high-speed and very high speed zones, correlations were found to fluctuate widely across the training sessions assessed. Previous studies have reported similar results (Bartlett, O'Connor, Pitchford, Torres-Ronda, & Robertson, 2017; Casamichana et al., 2013; Paulson et al., 2015; Scott et al., 2013). The low validity of current devices used to measure the actions when it comes to measuring high speed actions (Scott et al., 2013) could be one plausible explanation for these results. Moreover, some kinds of high-intensity activities are performed with very long rest periods intervening, with a resulting reduction in the internal load responses to these actions (Paulson et al., 2015). A further reason could be because the HR responses of players change slowly in short duration high-intensity exercise (Scott et al., 2013) and thus, the HR based TL could underestimate anaerobic actions. In the light of this information, TD seems the most valid speed-based external TL method thanks to the strong correlation of its results with those of internal training load methods. Despite all these points, it is still important to measure high speed actions such as sprints, which have a significant contribution to success in soccer (Mohr et al., 2003).

Our study does have some limitations that should be addressed. One major limitation was that the number of the participant was not enough. The second limitation is the level of players, our participants were from an amateur team and only nine players join training regularly, additionally they had to do their professions before training sections, and

these also may affect results of the current study.

In conclusion, although strong correlations were found among internal load methods, these methods should be used together. We have also provided further evidence that s-RPE is a valid and inexpensive training load monitoring method because there are strong correlations between s-RPE and some external load methods such as, HMD and TD. Our study is also in line with previous research in showing that the MP approach provides more detailed data about match and training load in soccer players (Gaudino et al., 2014; Manzi et al., 2014; Osgnach & Di Prampero, 2018; Reche-Soto et al., 2019). Therefore, MP seems to be more appropriate for soccer players because its equation includes both speed and acceleration values.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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