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Elevated BMI Impairs Balance among Older Adults with Vestibular Disorders

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ABSTRACT

King AC, West-Sell SA, VanNess M, Oliver TJ, Jensen CD. Elevated BMI Impairs Balance among Older Adults with Vestibular Disorders. **JEM**online 2023;8(1):1-12. Each year, more than 3 million older adults are admitted to emergency departments for fall-related injuries. Identifying variables that predict fall risk may help manage this problem. The purpose of this study was to evaluate the effect of body mass index (BMI) on balance in older adults with fall risk. We enrolled 25 older adults (12 men, 13 women) with vestibular disorders to complete balance assessments before and after a treadmill exercise session. A linear regression model was used to test the effects of age, sex, BMI, and group assignment on the change in balance percent explained 78% of the variance ($P<0.001$). Performing a fatigue protocol was associated with a greater loss of balance ($P=0.044$). Furthermore, when evaluating obesity as a binary variable, a BMI >30 was associated with a loss in balance of 5 percentage points ($P=0.011$). Therefore, weight-management strategies such as exercise prescribed by an exercise physiologist, when performed in a safe and controlled environment, may elicit improved balance.

Key Words: Aging, BMI, Exercise, Fall Risk, Obesity

INTRODUCTION

Each year, one in four adults aged 65 and older experience a fall of which many of the adults suffer an injury. In total, more than 3 million older adult patients are annually admitted to U.S. emergency departments for the injures (6). Unfortunately, the problem is seldom resolved upon discharge since patients commonly develop a fear of and susceptibility to subsequent falls (1,8,15). Also, among the older adults, the injuries sustained often associate with an ongoing loss of physical functioning, deterioration in quality of life, and shortened lifespan (13).

A major cause of falls in this population is weak lower extremity muscles. Reduced strength results in poor balance, and impaired balance creates opportunity for more falls (24). However, strength is not the sole culprit. When older adults report the reason for their falls, it is often attributed to a feeling of “dizziness” (17). This dizzy sensation may be indicative of an underlying health condition and can contribute to the early diagnosis of a vestibular disorder.

The vestibular system is located within the inner ear. It is responsible for sensing spatial orientation, movement, and postural equilibrium that involves the central and peripheral nervous systems. The central nervous system (CNS) resides in the brain and brainstem while the peripheral nervous system (PNS) bridges the pathways between the inner ear and the brainstem through the vestibulocochlear nerve (23). Once the CNS receives somatosensory information from the PNS, the body recognizes its orientation in space. With degeneration of the vestibular system, this orientation along with the capacity for controlled movement is compromised (20). While vestibular degeneration occurs gradually with aging, it is exacerbated by damage and poor health, owing to the removal or reduction of labyrinthine hair cells and vestibular receptor ganglion cells (25). If this occurs, it is difficult for the CNS to perceive, organize, and execute the sensorial information being relayed from the eyes and ears. The end result is a dizzy sensation.

It is important to recognize the interaction effect between biological aging and physical fitness on vestibular health and function. If we can elucidate the relationship between fitness and balance in the at-risk population, we may be able to implement exercise prescriptions and improve patient outcomes in the clinical setting. As a result, it is possible to reduce the annual occurrence of fall-related injuries. A piece of this puzzle that currently lacks comprehensive investigation is how anthropometric characteristics affect the relationship between exercise and postural stability. Thus, the purpose of this study was to explore the influence of body shape and size on exercise and indices of balance in patients who were at risk of falls owing to diagnosis of a vestibular disorder

METHODS

Study Design

This study used a randomized controlled, one-day pre-test and post-test design that involved 25 older adults with a diagnosed vestibular disorder. The effects of age, sex, body mass index (BMI), and a treadmill exercise protocol on post-exercise balance were evaluated. The study was approved by the Institutional Review Board at University of the Pacific Stockton, CA.

Participants

All participants resided in California's Central Valley. They had a diagnosed vestibular disorder, and they participated in physical therapy treatment for that condition. A licensed physical therapist identified eligible participants based on the inclusionary criterion that they were at least 65 years of age. Potential participants were excluded if they had: (a) undergone a previous surgery to the lower extremity, head, eyes, or brain; (b) a history of injury precluding participation or affecting performance; or (c) participated in an exercise program outside of their physical therapy sessions.

All participants who met the criteria for enrollment and provided consent participated in an introductory session to be familiarized with the equipment, thus reducing learning effects during data collection. All study recruitment and testing were completed at an out-patient physical therapy clinic under the supervision of a licensed physical therapist specializing in older adults and advanced vestibular disorders (DPT, GCS, and VeDA). If the participants did not comply with the informed consent or wanted to withdraw from the study, all data collected on the participant were voided and shredded.

Safety

Physical risks were accounted for by providing care to avoid situations where fatigue led to dizziness or loss of balance. A licensed physical therapist was present during the data collection. The participants were required to wear a gait belt during the postural assessments and treadmill activities to prevent injuries from falls. Also, the participants were instructed to notify the physical therapist if they felt dizzy or nauseas during any of the procedures at which time the protocol would be stopped. No participants lost their balance or reported feeling dizzy or nauseas during the study.

Randomization

Upon completion of baseline measurements, the participants were randomized into 1 of 2 groups using a software application (research randomizer). The participants were assigned to complete either a light intensity walk protocol on a treadmill and represented the intensity of their activities of daily living without causing fatigue (ADL Group) or a moderate-vigorous exercise protocol on a treadmill that represented an intensity above their activities of daily living and induced fatigue (Fatigue Group).

Procedures

Baseline Testing

The participant's sex and age were recorded, and their height and weight were measured using standard techniques. Body mass index (BMI) was calculated, and maximum heart rate was estimated by subtracting each participant's age from 220. After recording these data, the participants completed a Dizziness Handicap Index (DHI). The DHI is a 25-item self-assessment inventory designed to evaluate the self-perceived handicaps imposed by dizziness. Following completion, a Polar T31 heart rate transmitter (Polar Electro Oy, Kemeple, Finland) was fastened below each participant's chest to measure heart rate response during the treadmill protocol.

Then, a balance assessment was administered using a HUMAC Balance System developed by Computer Sports Medicine Inc. (CSMi). The CSMi balance board was calibrated prior to each use and the computerized program assessed center of pressure, weight shifting, and limits of stability. The method of testing has been previously validated (18) and was consistent across all the participants to minimize researcher error and to ensure accuracy in the data collected. To remove barriers that might affect performance, the participants completed a balance test without wearing shoes and socks.

Baseline assessment required the participants to stand on the board with their feet at shoulders' width and their eyes open for 30 seconds, which determined center of pressure and body weight. After 30 seconds, the CSMi software produced a score (0 to 100) and a percentage (0 to100), both representing the participants' center of pressure that was calculated in 4 quadrants. A high score is associated with increased postural sway and decreased postural stability while a high percentage is associated with a greater proportion of time the participant spent on target indicating a decrease in postural sway and an increase in stability.

Treadmill Protocols

During the treadmill activity, heart rate (using the Polar heart rate monitor) and rating of perceived exertion (RPE) were collected every 2 minutes. RPE was assessed using the Borg RPE scale (3), which ranks the participants' self-reported level of effort on a scale of 6 (minimum intensity) to 20 (maximum intensity).

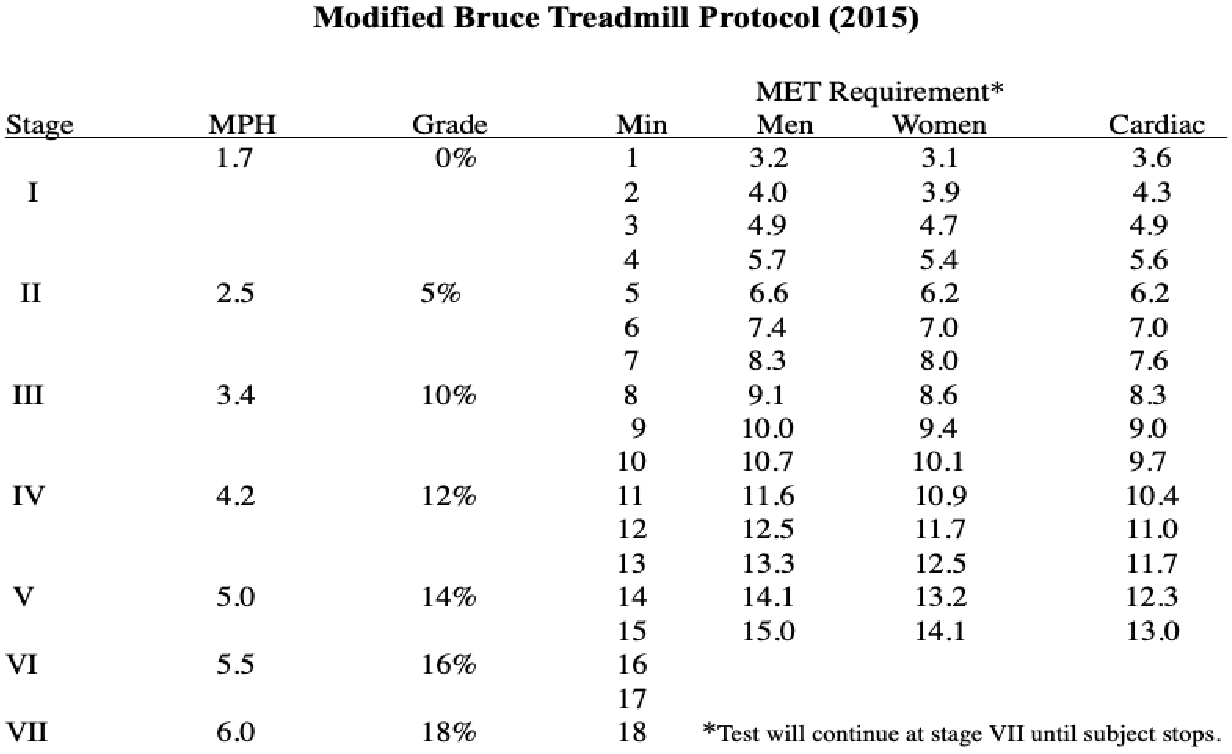
ADL Group

The participants assigned to the ADL Group were asked to complete Stage I only of the modified Bruce treadmill protocol (22) that involved walking at a speed of 1.7 mph at a 0% grade for 4 minutes. The protocol was designed to be consistent with the participants' ADLs while not inducing fatigue. Upon completion of the walk, the participants returned to the CSMi balance board for further testing.

Fatigue Group

The participants assigned to the Fatigue Group performed the modified Bruce treadmill protocol (22) that consisted of 7 stages, each with a progressively higher grade and faster speed (Figure 1). The participants were asked to complete all stages to the best of their ability or until they reached a state of fatigue that was defined as 85% of maximum heart rate, an RPE of 17 (signifying perception of the exercise to be very hard), or voluntary cessation based on expressed participant need. Upon completion of the treadmill session, the participants completed a 30-second cool-down walk at 0.5 mph at a 0% grade and then returned to the CSMi balance board for further testing.

Figure 1. Modified Bruce Treadmill Protocol (2015).



Modified Bruce Treadmill Protocol (2015)

				MET Requirement*		
Stage	MPH	Grade	Min	Men	Women	Cardiac
	1.7	0%	1	3.2	3.1	3.6
I			2	4.0	3.9	4.3
			3	4.9	4.7	4.9
			4	5.7	5.4	5.6
II	2.5	5%	5	6.6	6.2	6.2
			6	7.4	7.0	7.0
			7	8.3	8.0	7.6
III	3.4	10%	8	9.1	8.6	8.3
			9	10.0	9.4	9.0
			10	10.7	10.1	9.7
IV	4.2	12%	11	11.6	10.9	10.4
			12	12.5	11.7	11.0
			13	13.3	12.5	11.7
V	5.0	14%	14	14.1	13.2	12.3
			15	15.0	14.1	13.0
VI	5.5	16%	16			
			17			
VII	6.0	18%	18			

*Test will continue at stage VII until subject stops.

Post-Intervention Testing

Following the treadmill protocol, each participant returned to the CSMi balance board and completed the same baseline 30-second center of gravity and postural stability assessment. During this post-intervention testing period, the assessment was repeated in 30-second intervals (30-second test, 30 seconds of seated rest, repeat) until their measurements returned to their baseline scores within a 5% margin of error. Once the participant’s score was within the 5% margin of their baseline score, their participation in the study was complete.

Statistical Analyses

All statistical tests were conducted using SPSS version 24 (IBM SPSS Statistics, IBM Corporation, Chicago, IL, USA). Descriptive statistics of the entire sample (percentages, means, and standard deviations) were conducted to determine baseline characteristics. Mean differences between the Control Group and the Experimental Group were determined with independent-samples *t*-tests and Chi Squared Tests. Multiple linear regression models tested the effect of BMI and obesity classification on the change in balance score, holding constant baseline balance and all significant confounders (age, sex, and group assignment). Statistical significance was set at P<0.05.

RESULTS

We enrolled 25 participants in the study. One participant failed to complete all testing and was excluded from analysis. The remaining 24 participants with complete data were analyzed. All measured variables (demographic and anthropometric data) are presented in Table 1. There were no differences between the Groups (i.e., Fatigue or ADL) in sex, age, BMI, or submax heart rate (85% Max HR).

Table 1. Participant Demographics.

	Total Mean	Fatigue Group Mean	ADL Group Mean	Significance
N	24	12	12	
Sex	50% male	58.3% male	41.7% male	P=0.414
Age (years)	74.7 ± 6.5	74.8 ± 5.8	74.6 ± 6.7	P=0.923
BMI	28.3 ± 3.2	29.0 ± 2.3	27.7 ± 3.8	P=0.335
Max HR 85%	123.6 ± 5.0	123.6 ± 4.4	123.7 ± 5.7	P=0.968
DHI Score	38.3 ± 18.6	32.7 ± 18.1	44.0 ± 18.0	P=0.138

Baseline and post-intervention balance data (Table 2) reveal, on average, across the total sample, participants had a higher balance score (mean increase of 3.3 ± 8.3; P=0.061) indicating greater postural sway and a lower balance percent (mean decrease of 6.3 ± 7.0 percentage points; P<0.001) indicating decreased postural stability immediately post-exercise. The Fatigue Group increased balance score (5.8 ± 10.0) more than the ADL Group (0.0 ± 5.6), but this difference was not significant (P=0.154). When evaluating balance percent, the difference was significant with the fatigue group demonstrating a greater decrease (-9.7 ± 8.0) when compared to the ADL Group (-2.8 ± 3.7; P=0.013). There was no difference between men and women in change in balance score from pre-test to initial post-test. Men increased their balance score by 3.0 ± 9.4 while women increased their balance score by 3.7 ± 7.4 (P=0.852). Change in balance percent from baseline to initial post-test was also similar between men (-8.1 ± 7.4) and women (-4.4 ± 6.4; P=0.208). From baseline to final post-test (final balance test in which balance had returned to within 5% of baseline values), there was no difference in duration between sexes (P=0.383), but there was a difference between treatment groups. The Fatigue Group took 375.0 ± 97.8 seconds to return to baseline while the ADL Group took only 137.5 ± 53.5 seconds (P<0.001).

Table 2. Baseline and Post-Intervention Balance Data.

	Total Mean	Fatigue Group Mean	ADL Group Mean	Significance
Baseline Balance Score	17.6 ± 10.0	18.9 ± 9.1	16.2 ± 11.1	p = 0.527
Baseline Balance %	90.8 ± 2.7	91.3 ± 2.0	90.4 ± 3.4	p = 0.467
Initial Post-Test Score	20.9 ± 13.4	24.7 ± 10.8	17.1 ± 15.1	p = 0.174
Initial Post-Test %	91.3 ± 2.4	81.6 ± 8.3	87.6 ± 4.1	p = 0.036
Change from Baseline to Initial Post-Test Balance Score	3.3 ± 8.3	5.8 ± 10.0	0.0 ± 5.6	P = 0.154
Change from Baseline to Initial Post-Test Balance %	6.3 ± 7.0	–9.7 ± 8.0	–2.8 ± 3.7	P = 0.013
Final Post-Balance Score	18.5 ± 9.2	21.4 ± 9.8	15.5 ± 7.7	p = 0.115
Final Post-Balance %	91.3 ± 2.4	91.7 ± 1.6	91.0 ± 3.0	p = 0.507

Results from the regression analyses illustrating the change in balance following the exercise protocol and demonstrating a significant effect of body size on balance are presented in Table 3. The collection of predictors explained 78% of the variance of the change in balance percentage ($P<0.001$). Holding constant age, sex, baseline balance score, baseline balance percent, and whether participants were in the ADL Group or the Fatigue Group, each additional point of BMI predicted a worsening of balance by 0.7 percentage points ($P=0.024$). In this same model, holding all other variables constant, performing the modified Bruce treadmill protocol at Stage 2 or higher was associated with a worsening of balance by 3.9 percentage points ($P=0.044$). In Table 4, BMI (a continuous variable) has been replaced by obesity status (a binary classification). In this model, holding all other variables constant, obesity associated with a worsening of balance by 5 percentage points ($P=0.011$) while the overall model explains 80% of the variance in the change in balance percent ($P<0.001$).

Table 3. Multiple Linear Regression Predicting Change in Balance %.

Variable	Coefficient	Standard Error	*t*	Significance	95% Confidence Interval
Predicting Change					
BMI	-0.707	0.283	-2.501	P=0.024	-1.307 to -0.108
Baseline Balance Score	-0.730	0.129	-5.683	P=0.000	-1.003 to -0.458
Baseline Balance Percent	-1.263	0.413	-3.060	P=0.007	-2.138 to -0.388
ADL or Fatigue Group	-3.909	1.788	-2.186	P=0.044	-7.699 to -0.119
Constant	106.436	45.118	2.359	P=0.31	10.790 to 202.082
Model Summary	**Observations**	**F**	**Significance**	**R^2**	**Mean Square**
	24	8.085	P<0.001	0.780	126.350

Dependent variable: change in balance percentage from baseline to immediate post-test. Predictors: BMI, baseline balance score, baseline balance percentage, ADL or Fatigue condition.

Table 4. Multiple Linear Regression Explaining Change in Balance %.

Variable	Coefficient	Standard Error	*t*	Significance	95% Confidence Interval
Obesity	-5.018	1.737	-2.889	P=0.011	-8.700 to -1.336
Baseline Balance Score	-0.755	0.124	-6.079	P=0.000	-1.019 to -0.492
Baseline Balance Percent	-1.210	0.393	-3.079	P=0.007	-2.042 to -0.377
ADL or Fatigue Group	-4.745	1.682	-2.821	P=0.012	-8.310 to -1.180
Constant	82.070	41.392	1.983	P=0.065	-5.678 to 169.817
Model Summary	**Observations**	**F**	**Significance**	**R^2**	**Mean Square**
	24	9.060	P<0.001	0.799	129.420

As shown in Table 5, change in balance score from baseline to initial post-test was unaffected by sex (P=0.852), age (P=0.604), BMI (P=0.801), obesity classification (P=0.829), or baseline balance score (P=0.749). However, sex (P=0.017), baseline balance score (P<0.001), and group assignment (P=0.074) were significant predictors of the initial post-test balance score (Table 5). This collection of predictors accounted for 83% of the variance (P<0.001); in this model, holding all other variables constant, women in our sample were 4.4 points lower than men (P=0.017). Table 6 illustrates the importance of participant performance within the fatigue group. By comparison, for participants assigned to the fatigue group, it took 128 additional seconds to recover (return to baseline values when compared to participants in the ADL Group (P=0.001).

Table 5. Multiple Linear Regression Explaining Initial Post-Test Balance Score.

Variable	Coefficient	Standard Error	*t*	Significance	95% Confidence Interval
Constant	6.079	2.119	2.868	P=0.010	1.658 to 10.500
Baseline Balance Score	0.739	0.086	8.545	P=0.000	0.559 to 0.919
ADL or Fatigue Group	3.224	1.710	1.885	P=0.074	-0.344 to 6.792
Model Summary	**Observations**	**F**	**Significance**	**R^2**	**Mean Square**
	24	31.593	P<0.001	0.826	530.569

Dependent variable: post-test balance score. Predictors: baseline balance score, ADL, or Fatigue Group assignment.

Table 5. Multiple Linear Regression Explaining Duration Until Baseline Balance Score.

Variable	Coefficient	Standard Error	*t*	Significance	95% Confidence Interval
Constant	73.094	23.140	3.159	P=0.005	24.826 to 121.363
ADL or Fatigue Group	127.622	32.545	3.921	P=0.001	59.734 to 195.510
Duration on TM (sec)	0.169	0.071	2.378	P=0.028	0.021 to 0.317
Change Immediate Balance Percent	-8.409	1.810	-4.647	P=0.000	-12.184 to -4.634
Model Summary	**Observations**	**F**	**Significance**	**R^2**	**Mean Square**
	24	50.301	P<0.001	0.883	139852.149

Dependent variable: duration until baseline in seconds. Predictors: ADL or Fatigue Group assignment, duration on treadmill in seconds, change in baseline balance percentage.

DISCUSSION

Our results suggest that an elevation in BMI, especially when classified as obese (>30), leads to poorer control over balance among patients with vestibular disorders. In turn, poorer balance control associates with an elevated risk in falls (11). Because our participants did not have widely discrepant exercise histories, differences in BMI are unlikely to be attributable to exercise, and thus physical conditioning per se could not explain our observed differences in balance. BMI seems to be an independent predictor of balance control following physical exertion.

This study has several limitations. First, we did not include a true control group and all enrolled participants completed treadmill activities. Second, the total sample size was relatively limited and does not provide a full representation of all older adults with a diagnosed vestibular disorder. Thus, the impact of balance on exercise stress response was not adequately powered to examine as confounding variables. Lastly, the study did not collect measurements during multiple timepoints. All enrolled participants were recruited from one out-patient physical therapy clinic and completed pre-post testing during one study visit. Had the study included a longer intervention with additional exercise training, the results may provide a more accurate representation of exercise effects on postural stability among older adults with vestibular disorders.

Nevertheless, the combination of validated measurements such as HR monitors and the CSMi HUMAC Balance Board reliably measured the participants cardiac responses of treadmill exercise and postural stability (14,18). Therefore, our data indicate that older adults with a high BMI and a vestibular diagnosis may experience a lower postural stability, thus an increase in fall risk. Blood pressure pre-post measurements and prescribed medications should be considered for postural stability changes during exercise in future studies.

There are several possible explanations for the observed relationship between BMI and balance in older adults are linked to the known effects of physical function and postural control that is known to deteriorate with age (5). First, we must consider the inverse association of BMI and physical performance. Research has shown low levels of physical activity can lead to a higher BMI (21) Furthermore, a review of several studies has indicated that a sedentary lifestyle can decrease physical function, specifically muscular strength associated with the lower extremities that may contribute to an increase in fall risk (4). Therefore, weak lower muscular strength provides stronger indications of postural instability that predisposes to a greater body sway found in both obese young and older adults (12,19).

While it may be reasonable for patients who are at risk of falling to incorporate exercise into their daily routines, focusing on the improvement of BMI, exercise avoidance is a common behavior in this population due to the fear of falling. When this fear restricts participation in activities of daily living, quality of life can be affected. Over time, these sedentary habits can compromise health and physical functioning in several ways (2,9), Although some physicians recommend that vestibular patients restrict their engagement in physical activity (10), it is important that they do not exclude exercise entirely. Cessation of physical activity associates with an increase in BMI (16) and, in fact, the present study found that participants with a higher BMI had impaired control over their posture following physical activity, independent of exercise. While this was apparent in both the Control and Experimental Groups, the loss of postural stability was exacerbated in the presence of higher intensity activity. Interestingly, we found balance adults aged 65 and older need at least 150 minutes a week of moderate intensity activity or 75 minutes a week of vigorous intensity activity. Additionally, they recommend at least 2 days dedicated to strength training and 3 days of participation in balance exercises per week. With recognition that chronic conditions may affect an individual's ability to meet these recommendations, the CDC advocates that those individuals remain percent (i.e., the amount of time participants spends on target) to be more sensitive to fatigue – and that fatigue was more sensitive to differences in BMI – than balance score (which indicated a steadiness of posture).

CONCLUSIONS

In consideration of our findings, it is prudent advice for patients at risk of falls to maintain a healthy BMI. An effective method is to remain active and incorporate controlled and safe exercise into one's daily routine (e.g., aquatics or stationary bike). A sedentary lifestyle is a known risk factor for cardiovascular and metabolic conditions. It may also be an indirect risk factor for fall-related injuries. The Center for Disease Control and Prevention (CDC) recommends active as one's ability allows in a safe environment (7). The fear of falling that often accompanies movement is a barrier for successful fall prevention. Further investigation of strategies to overcome this barrier is warranted.

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