ORIGINAL RESEARCH

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Tandem Stance Test Performance is Independently Associated with Overall Mortality Risk in Middle-Aged and Older Adults

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Abstract

Objective: The tandem stance test (TST) is a simple, non-invasive measure of static balance, but its independent prognostic value for all-cause mortality in the general population remains unclear. This study aimed to evaluate the prospective association between TST performance and all-cause mortality.

Materials and Methods: We analyzed data from 11973 participants aged ≥45 years (51.8% female; mean age 59.0 ± 9.2 years) enrolled in the China Health and Retirement Longitudinal Study (CHARLS) at baseline in 2011, with follow-up through 2020. TST was categorized as "success" or "failure". Cox proportional hazards (PHs) models assessed the association between TST outcomes and mortality, adjusting for age, sex, smoking, comorbidities, and income. Sensitivity analyses employed semiparametric PHs models for interval-censored data due to incomplete death dates in some waves.

Results: Overall, 22.9% failed the TST; failure was associated with older age, female sex, greater comorbidity burden, and higher mortality (17.8% vs. 11.0%; $p < 0.001$). In fully adjusted Cox models, TST failure predicted increased mortality risk (hazard ratio (HR): 1.261, 95% confidence interval (CI): 1.128-1.410; $p < 0.001$). Subgroup analyses showed consistent associations across sex, smoking, comorbidity, and most income strata, but not among participants ≥70 years or with high income. Semiparametric models confirmed the robustness of the results (adjusted HR: 1.329, 95% CI: 1.157-1.527; $p < 0.001$).

Conclusion: TST failure is associated with all-cause mortality in middle-aged and older adults. As a quick, scalable tool, TST holds promise for early risk stratification in clinical and public health settings, warranting validation in diverse populations.

Keywords: Tandem stance test, mortality, CHARLS, balance, semiparametric models

Introduction

Balance plays a key role in maintaining overall physical vitality and functional autonomy,drawing from a blend of vision, inner ear, and body-sense signals processed by the central nervous system (1-4). A rapid decline in balance ability after age 50 is one of the main causes of falls; approximately 30%-60% of community-dwelling older adults experience falls yearly, accounting for two-thirds of accidental deaths (5-7).

Although balance assessments, such as posturography tests (8), were not routinely conducted in the physical examination of older adults, recent evidence indicates their potential association with mortality; for example, was associated with an 84% increased risk of all-cause mortality in middle-aged and older adults (9). Nevertheless, the single-leg stance is more demanding than the semi-tandem or tandem positions, requiring greater neuromuscular control. Patients with vestibular dysfunction or diminished muscle strength frequently exhibit compromised postural control, rendering the single-leg stance maneuver difficult to perform and thereby limiting its applicability in these populations.

The tandem stance test (TST) involves aligning one foot directly anterior to the other. Similar to the single-leg stance, this posture significantly reduces the body's base of support, thereby increasing the challenge of maintaining balance. TST can be used independently or as an integral component of commonly used balance assessment tools, such as the short physical performance battery (SPPB) balance scale and the clinical gait

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and balance scale (10-13). Previous studies have shown that TST duration is positively correlated with gait speed (14) and is a predictor of falls within six months in older adults (8).

Recent studies have demonstrated that inability to complete the TST is associated with prevalent cardiovascular disease, cognitive impairment, and frailty (15-17). Thus, TST may offer a rapid, low-cost means of detecting multisystem dysfunctions that themselves are established predictors of mortality (18-21). Nonetheless, to our knowledge, whether TST performance is independently associated with all-cause death remains elusive. To address this gap, we aim to evaluate the association between TST failure and subsequent all-cause mortality in middle-aged and older adults.

Material and Methods

Study Population

The China Health and Retirement Longitudinal Study (CHARLS), coordinated by Peking University, is a nationwide prospective survey targeting Chinese adults aged 45 and above (22). Using a multistage, stratified design, CHARLS enrolled participants from 150 counties across 28 provinces at baseline in 2011. Follow-up waves were completed in 2013, 2015, 2018, and 2020 to capture longitudinal changes in health status, socioeconomic status, and demographic characteristics. Approval for the study was granted by the Biomedical Ethics Review Committee of Peking University (IRB approval number: IRB00001052-11015, date: 05.06.2011), and written informed consent was obtained from all participants before enrollment.

A total of 17705 participants were initially enrolled at baseline, of whom 5732 were excluded due to: 1) missing TST data (n = 4913); 2) age less than 45 years at enrollment (n = 263); and 3) loss to follow-up immediately after baseline survey (n = 556). Missing data were handled using listwise deletion. Consequently, 11973 participants were included in our prospective longitudinal analyses (Figure 1).

Assessment of TST

To date, no universally standardized cutoffs for TST have been established. Prior investigations have variously proposed 10-, 30-, or 60-second thresholds for this balance assessment (8,10,11,14,23). In CHARLS survey, TST performance was classified using predefined age-stratified criteria according to sponsor's protocol: participants aged ≥70 years who sustained the stance for less than 30 seconds and those aged <70 years who held it for less than 60 seconds were classified as "Fail" (Questionnaire PE001: determines which of the following tests the subject should perform based on the subject's age? 1) 30-second tandem stance balance test (subjects 70 years or older); 2) 60-second tandem stance balance test (subjects under 70 years old).

Statistics

Baseline demographic, lifestyle, clinical, and socioeconomic variables were obtained from the CHARLS 2011 wave. Vital status and mortality data were collected during follow-up waves (2013, 2015, 2018, and 2020) through standardized exit interviews. While mortality status was confirmed in all waves, exact dates of death were only documented in the 2013 wave and in a subset of the 2020 wave. For deaths reported in 2015 and 2018, the precise dates were unavailable. For participants who died, the survival time was calculated as the interval from the 2011 wave date to either the known date of death or, if the exact date was unknown, the median interview date of the wave in which their death was recorded.

In summarizing descriptive data, continuous measures were reported as means with standard deviations (SD) (mean ± SD), whereas discrete factors were detailed through frequencies and proportions. Survival curves for participants with TST "success" and "fail" outcomes were estimated using the Kaplan-Meier method. Additionally, the associations between variables and mortality risk were evaluated using Cox proportional hazards (PHs) regression. R software (4.1.1) was used for statistical analysis, with significance assessed at the 0.05 level (two-tailed).

Sensitivity Analyses

Given that the exact death dates in some waves were unknown, we reanalyzed the data using an interval-censored method. Survival times were treated as interval-censored, bounded between the date of the last interview confirming the participant was alive and the date of the subsequent interview confirming death. Interval-censored survival times were analyzed using semiparametric PH models implemented in the icenReg package (24). The hazard function was modeled as $h(t|X_i) = h_o(t) \exp(\beta^T \cdot X_i)$, where $h(t|X_i)$ denotes the hazard rate at time t, h0(t) is the unspecified baseline hazard, X_i is the covariate vector, and β is the vector of log hazard ratios (HR) estimated from the data. Bootstrap resampling (B = 100 samples) was employed to compute robust standard errors and confidence intervals (CI).

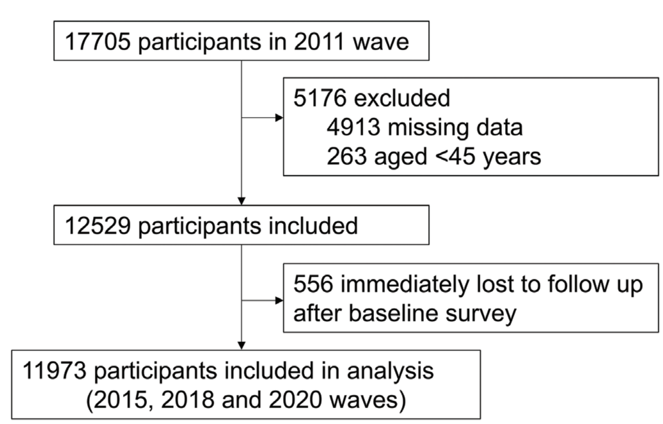

Figure 1. Study diagram.

This approach avoids biases inherent to methods assuming exact or right-censored event times, ensuring valid inference for interval-censored data (24).

Results

A total of 17705 participants were interviewed between 2011 and 2020, of whom 11973 were included in our analyses (Figure 1). The mean ± SD age of the participants was 59.0 ± 9.2 years, and 51.8% were female. No adverse events occurred during TST testing, and 2746 (22.9%) participants failed to complete the TST (Table 1). The proportion of TST failure responders increased with age, was 14.9% among those 45-49 years, and almost half (48.8%) at ≥80 years (Supplementary Figure 1). Specifically, individuals who failed the TST were, on average, older (61.8 years vs. 58.2 years, $p < 0.001$), more likely to be female (63.3% vs. 48.3%, $p < 0.001$), and had a higher prevalence of comorbidities (74.8% vs. 66.0%, $p < 0.001$), including hypertension, diabetes, and heart disease. Additionally, the TST "fail" group included a greater proportion of non-smokers (65.5% vs. 57.8%, $p < 0.001$) and individuals with "poor" income (14.6% vs. 11.8%, $p = 0.001$). Notably, the higher proportion of non-smokers in the TST "fail" group may be attributed to the significantly greater prevalence of smoking among males than females (74.9% vs. 8.3%, $p < 0.001$). Furthermore, the mortality rate was significantly higher among those who failed the TST (17.8% vs. 11.0%, $p < 0.001$). These findings indicate a robust association between TST performance and key sociodemographic and health-related factors.

During the nine-year follow-up (2011–2020), 1507 (12.6%) participants died (Table 1). The Kaplan-Meier survival curves demonstrate a significant difference in all-cause mortality between the TST "success" and "failure" groups (Figure 2). Over the follow-up period, individuals in the TST "fail" group exhibited a consistently lower survival probability than individuals in the TST "success" group ($p < 0.001$), suggesting that impaired TST performance is associated with an increased risk of mortality. The Cox PHs analysis demonstrated a significant association between TST failure and elevated all-cause mortality risk (unadjusted HR: 1.503, 95% CI: 1.348-1.674, $p < 0.001$; Table 2). This relationship persisted in an age- and gender-adjusted model (HR: 1.267, 95% CI: 1.133-1.417, $p < 0.001$) and in a fully adjusted model incorporating age, gender, smoking status, comorbidities, and income (HR: 1.261, 95% CI: 1.128-1.410, $p < 0.001$).

Table 1. Demographic and clinical characteristics of study participants according to tandem stance test.

Variable	Total (n = 11973)	Tandem stance test: Success (n = 9227)	Tandem stance test: Fail (n = 2746)	p-value
Age, years, mean (SD)	59.0 (9.2)	58.2 (8.9)	61.8 (9.6)	<0.001
Gender, n (%)				
Female	6198 (51.8%)	4460 (48.3%)	1738 (63.3%)	<0.001
Male	5775 (48.2%)	4767 (51.7%)	1008 (36.7%)	
Smoking, n (%)				<0.001
No	7132 (59.6%)	5332 (57.8%)	1800 (65.5%)	
Yes	4841 (40.4%)	3895 (42.2%)	946 (34.5%)	
*Comorbidity, n (%)				
No	3824 (31.9%)	3133 (34.0%)	691 (25.2%)	<0.001
Yes	8149 (68.1%)	6094 (66.0%)	2055 (74.8%)	
Income, n (%)				
Poor	1486 (12.4%)	1085 (11.8%)	401 (14.6%)	0.001
Relatively poor	3841 (32.1%)	3011 (32.6%)	830 (30.2%)	
Average	6342 (53.0%)	4901 (53.1%)	1441 (52.5%)	
Relatively high	281 (2.3%)	213 (2.3%)	68 (2.5%)	
Very high	23 (0.2%)	17 (0.2%)	6 (0.2%)	
Death, n (%)				
No	10466 (87.4%)	8208 (89.0%)	2258 (82.2%)	<0.001
Yes	1507 (12.6%)	1019 (11.0%)	488 (17.8%)	

*Comorbidity includes hypertension, dyslipidemia, diabetes or high blood sugar, cancer or malignant tumor, chronic lung diseases, liver disease, heart disease, stroke, kidney disease, digestive disease, emotional, nervous, or psychiatric problems, memory-related disease, arthritis or rheumatism, and asthma.
p-values were calculated by Student's t test, or χ^2 test, as appropriate.
SD: Standard deviation.

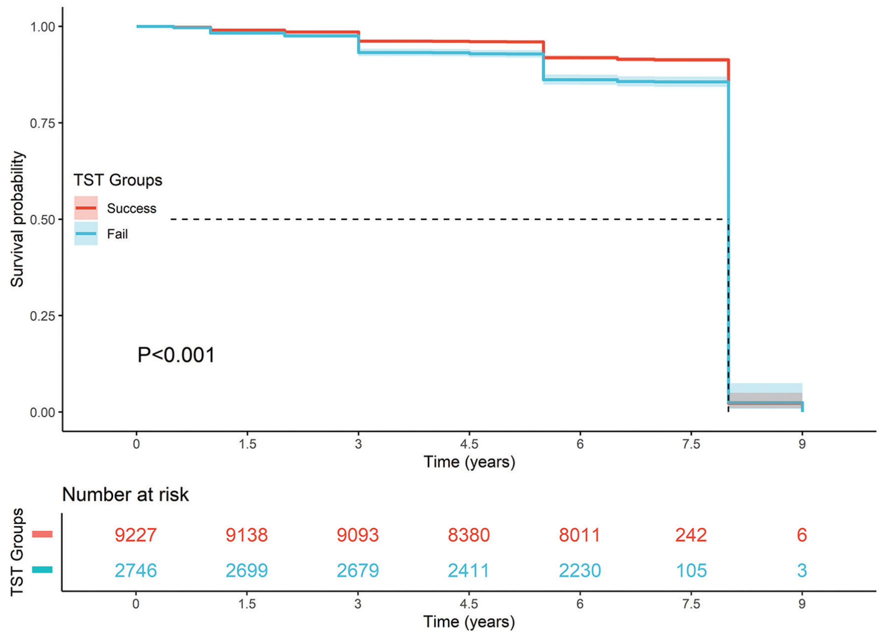

Figure 2. Kaplan-Meier survival curves for participants aged ≥45 years, stratified by TST performance. The log-rank p-value is shown. The dotted horizontal line denotes a survival probability of 0.5. TST. The number at risk decreases sharply toward the end of follow-up, due to cohort attrition and conservative imputation of event times (using the median interval between follow-up waves), resulting in few participants being retained in the final 2020 survey wave.

TST: The tandem stance test.

Table 2. Associations of TST with all-cause mortality in middle-aged and older adults.

TST Outcome	Events/participants (%)	Mortality HR (95% CI)	p-value*
Model 1 - unadjusted			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.503 (1.348-1.674)	<0.001
Model 2 - adjusted for age and gender			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.267 (1.133-1.417)	<0.001
Model 3 - adjusted for age, gender, smoking, comorbidity and income			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.261 (1.128-1.410)	<0.001

*Cox proportional hazards modelling.
HR: Hazard ratio, CI: Confidence interval.

Subgroup analyses revealed that TST failure was associated with increased all-cause mortality across most strata (Figure 3). The association was significant among participants aged <70 years (HR: 1.450, 95% CI: 1.248-1.685), but not among those ≥70 years (HR: 1.153, 95% CI: 0.985-1.349). Both females and males exhibited elevated risks. Similar patterns were observed among non-smokers (HR: 1.498), smokers (HR: 1.658), those with comorbidities (HR: 1.394), and those without comorbidities (HR: 1.737).The association remained significant across most income levels, including “poor”, “relatively poor”, and “average”, except for the highest income categories. These results support the robustness of TST performance as a mortality predictor across diverse populations.

Due to imprecise documentation of the timing of death for selected participants, a sensitivity analysis was performed using an interval-censoring technique, consistent with the prior protocol (24). The semiparametric PHs model showed a significant association between TST failure and an increased risk of all-cause mortality (unadjusted HR: 1.708, 95% CI: 1.506-1.938, p < 0.001) (Table 3). This association was significant after adjustment for age and gender (HR: 1.354, 95% CI: 1.178-1.555, p < 0.001) and remained significant in the fully adjusted model incorporating age, gender, smoking status, comorbidity, and income(HR: 1.329, 95% CI: 1.157-1.527, p <0.001).

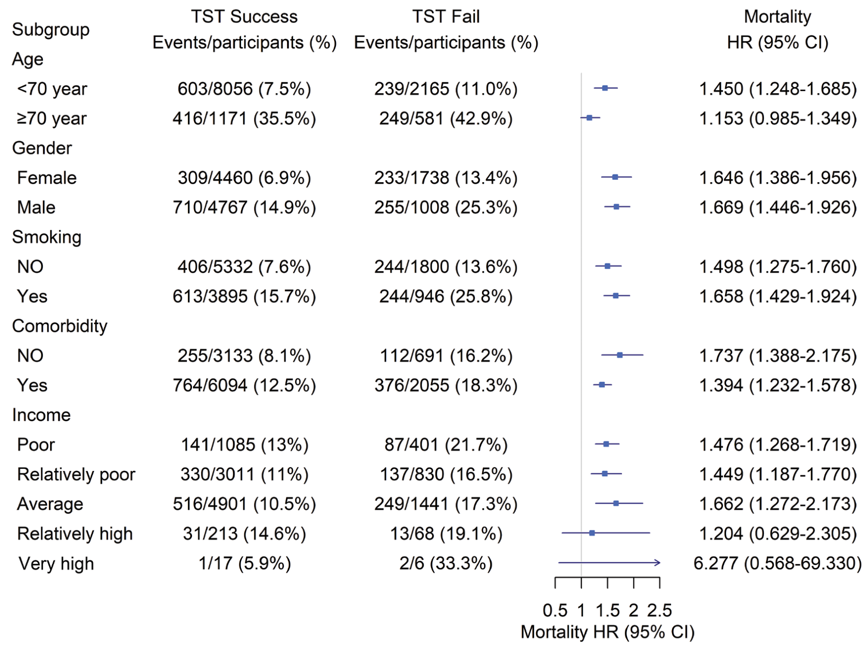

Figure 3. Subgroup analysis of the association between TST failure and all-cause mortality. Hazard ratios (HRs) and 95% confidence intervals (CIs) were estimated using unadjusted Cox proportional hazards models. TST, tandem stance test.

TST: The tandem stance test.

Table 3. Associations of TST with all-cause mortality in middle-aged and older adults in interval-censored regression models.

TST Outcome	Events/participants (%)	Mortality HR (95% CI)	p-value*
Model 1 - unadjusted			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.708 (1.506-1.938)	<0.001
Model 2 - adjusted for age and gender			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.354 (1.178-1.555)	<0.001
Model 3 - adjusted for age, gender, smoking, comorbidity and income			
Success	1019/9227 (11.0%)	1 (reference)	
Fail	488/2746 (17.8%)	1.329 (1.157-1.527)	<0.001

*Semiparametric proportional hazards modelling.
HR: Hazard ratio, CI: Confidence interval.

Discussion

In this large, prospective cohort study, we observed a significant association between TST failure and increased all-cause mortality over a nine-year follow-up (HR: 1.503, 95% CI: 1.348-1.674; Table 2). This association remained robust after adjusting for key confounders, including age, gender, smoking status, comorbidities, and income (HR: 1.261, 95% CI: 1.128-1.410). Our findings were consistent across most subgroups, except among participants aged 70 years or older and participants in the highest income categories. Our results build on prior evidence linking physical performance measures, such as the SPPB (including side-by-side stance, semi-tandem stance, and TST) and the 10-second single-leg stance to mortality risk (9,11). As a core component of the SPPB, the TST demonstrated comparable predictive value, suggesting that it may serve as an effective surrogate. Compared to the SPPB, TST is simpler, quicker, and elicits higher participant compliance, making it well-suited for large-scale screening. In contrast, the 10-second single-leg stance is more challenging; previous studies indicate that most individuals older than 70 years cannot perform it (9). In the CHARLS cohort, nearly half of the participants under 80 years of age successfully completed TST (Figure S1), highlighting its greater feasibility and acceptability among older adults. Recent findings suggest a relationship between poor performance on the semi-TST and greater mortality risk in middle-aged and older adults (25). Our findings provide compelling additional evidence underscoring the relationship between balance and mortality. In summary, our study demonstrated that TST is a simple, non-invasive measure of balance, offering a practical and valuable tool for assessing mortality risk in middle-aged and older adults.

An intriguing observation from our subgroup analyses was the lack of a notable correlation between TST failure and mortality among participants aged 70 years or older (Figure 3). Notably, an age-stratified definition of TST failure was employed in the CHARLS protocol: inability to sustain the stance for ≥60 seconds among those aged <70 years versus ≥30 seconds among those ≥70 years. This approach, while pragmatically tailored to age-related declines in neuromuscular capacity, introduces measurement heterogeneity that may attenuate the observed association in the older subgroup (HR: 1.153, 95% CI: 0.985-1.349; Figure 3). Specifically, the lower threshold for older adults could classify a subset of individuals with moderate impairments as "successful", thereby diluting the contrast between groups and reducing statistical power to detect differences in mortality risk. Our findings suggest that adopting a uniform criterion, such as a 60-second threshold for all ages, may improve the predictive utility of TST, which merits further investigation.

The link between TST failure and increased mortality risk likely involves multisystem physiological decline. Impaired balance, as reflected by TST failure, may serve as a sentinel marker of age-related pathologies, including sarcopenia, neurodegenerative changes, and peripheral neuropathy (26-29). Such deficits elevate the risk of falls (30,31), accelerate frailty progression (26,32),and compromise functional independence (33,34) -all pathways that may culminate in premature mortality. The rapid age-dependent increase in TST failure (48.8% among participants ≥80 years, Figure S1) may mirror the trajectory of neuromuscular aging, suggesting that balance impairment is a sensitive indicator of cumulative health deterioration.

Our investigation is characterized by several advantages, including the incorporation of a large, nationally representative panel drawn from CHARLS and followed for nine years, providing robust evidence of a temporal relationship between TST performance and mortality. Standardized data collection protocols and comprehensive adjustment for confounders enhance the reliability of our findings. Additionally, the consistency of results across Cox PHs models and sensitivity analyses using interval-censored methods underscores the robustness of the association.

Study Limitations

Despite the strengths of this study, several limitations must be acknowledged. First, the absence of exact death dates for some participants may introduce imprecision in survival estimates. However, a sensitivity analysis using interval-censored methods addressed this issue and corroborated the primary findings. Second, unmeasured or inadequately measured factors, e.g., history of falls, physical activity levels, education, body mass index, cognitive function, and nutritional status, may have influenced our results. Higher education and healthier lifestyles are typically associated with better balance and lower mortality risk, whereas poor nutrition, obesity, or cognitive impairment may impair balance and increase mortality risk. Furthermore, the lack of correction for multiple comparisons in our subgroup analyses may increase the risk of Type I error. Future studies should incorporate interaction tests to confirm subgroup-specific effects. Finally, the study's reliance on a cohort from mainland China may limit the transferability of its findings to other demographic or geographic contexts. Validation in diverse cohorts is required to evaluate the broader applicability.

Our studies indicate that TST complements established frailty indices and fall risk assessments by providing an additional dimension of functional evaluation. Owing to its simplicity and scalability, TST is particularly suited to primary care and resource-limited settings where comprehensive performance batteries are impractical. Future research should examine its integration into multidimensional geriatric assessments and its potential to enhance risk stratification when combined with existing screening tools.

Overall, our analysis demonstrates an independent association between TST failure and increased all-cause mortality in middle-aged and older populations in China. This simple balance test offers a practical means of identifying at-risk individuals, with potential applications in clinical and public health settings. Although additional studies are required to validate these results across varied populations and clarify the underlying mechanisms, our findings highlight the value of TST as an indicator of general health and survival.

Ethics

Ethics Committee Approval: The study was approved by the Biomedical Ethics Review Committee of Peking University (approval number: IRB00001052–11015, date: 05.06.2011).

Informed Consent: Written informed consent was obtained from all participants before their inclusion in the study.

Footnotes

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

Supplementary Figure. https://d2v96fxpocvxx.cloudfront.net/beb8919b-f013-4ea1-b1c8-40332e840fe1/content-images/6b065a03-f1c8-4d16-804a-00ccdf67b67f.pdf

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