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Validation of the Chinese version of the Perceived Stress Scale-10 integrating exploratory graph analysis and confirmatory factor analysis

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A R T I C L E I N F O

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A B S T R A C T

Objective: The study aimed to initially assess the measurement properties of the 10-item simplified Chinese version of the Perceived Stress Scale (PSS-C-10) and as a first, assess a longitudinal measurement invariance (LMI).
Methods: A longitudinal survey was conducted with a convenient sample of healthcare students using the PSS-C-10. We assessed the PSS-C-10 mainly using composite analytical approaches, including exploratory graph analysis (EGA) and confirmatory factor analysis (CFA) to suggest the best-fit factor structure and assess measurement invariance.
Results: The EGA identified a two-factor structural solution with an accuracy of 98.6% at baseline and 100% at a 7-day follow-up. The CFA subsequently confirmed this structure, with a comparative fit index of 0.963 at baseline and 0.987 at follow-up, Tucker-Lewis index of 0.951 at baseline and 0.982 at follow-up, and root mean square error of approximation of 0.111 at baseline and 0.089 at follow-up. The LMI was supported by the goodness-of-fit indices, and their changes fell within the recommended cut-off range. Additionally, Cronbach's alpha (0.885 at baseline and 0.904 at follow-up), McDonald's omega (0.885 at baseline and 0.902 at follow-up), and an ICC value of 0.816 for 7 days demonstrated the robust reliability of the PSS-C-10.
Conclusion: The PSS-C-10 exhibited a stable two-factor structure with promising LMI and measurement properties.

1. Introduction

"Adopting the right attitude can convert a negative stress into a positive stress" [1,2]. Stress has been a significant research topic for many years, thanks to the work of the founder of the stress theory, Hans Selye [3–5]. Psychological stress is directly correlated with mental disorders, including symptoms of anxiety, depression, and even sleep disorders [6–11], and a higher risk of infectious and chronic non-infectious diseases [12–17]. Studies have also identified the indirect mediating role and moderating effect of stress on the relationships between

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multiple health outcomes [7,18–22]. As a result, researchers are increasingly focusing on the definition and measurement of stress.

The prevailing method of measuring stress is the psychological approach, which conceptualizes stress as a complex composition of aspects, such as coping abilities, and emotional responses [23,24]. Based on the transactional model, the core subjective stress evaluation of an individual has two main aspects: the individual's ability to cope with specific events or changes, and the individual's emotional appraisal of experiences [25–27]. The conception of stress that emerged from this model is called "perceived stress", which refers to an individual's feelings or thoughts about how much stress they are under at a given time or over a given period [28]. However, precisely measuring perceived stress presents a significant challenge to all researchers.

Despite the challenge, researchers have developed instruments to measure perceived stress, such as the 14-item Perceived Stress Scale (PSS) [29]. The PSS was developed by Cohen Sheldon in 1983 and has been translated into over 30 languages [30]. The PSS measures the extent to which individuals encounter situations that are "unpredictable, uncontrollable, and overloaded" within one month [15,29]. Two shorter forms were subsequently developed in 1988, including the 10-item scale (PSS-10) and the 4-item scale (PSS-4) [31]. Importantly, the overall psychometric properties of the PSS-10 form (Cronbach's alpha = 0.74–0.91; the two-factor structure accounted $\geq$ 50% of the total variance) are superior to the two other forms (Cronbach's alpha = 0.75–0.89 for the PSS-14 and 0.60–0.82 for the PSS-4; the two-factor structure of the PSS-14 accounted < 50% of the total variance and the scale structure of the PSS is not consistent) [32]. Moreover, the PSS-10 has at least been translated and evaluated in Spanish, Brazilian, Greek, Turkish, Arabic, French, Serbian, and Korean, with all showing a stable two-factor structure [30,33–40]. As a result, the PSS-10 form is recommended for use [32].

The PSS-10 has been translated into simplified Chinese (PSS-C-10) and then validated in various populations, included students, workers, psychiatric outpatients, community residents, smokers, athletes, and the general population [41–49]. It has demonstrated good psychometric properties, with Cronbach's alpha values ranging from 0.70 to 0.85 and a structure consistent with the original design [41–46,48,49]. However, no assessment of the longitudinal measurement invariance (LMI) has yet been conducted on the PSS-C-10. LMI is crucial for the longitudinal applicability of the instrument, as it demonstrates that the construct has the same meaning across the repeated assessment. Unfortunately, the LMI of the PSS-C-10 has yet to be evaluated being a limitation in previous studies despite populations, resources, and survey designs [41–46,48,49].

Although a 7-day interval may be considered short for assessing measurement invariance over time, given dynamic nature of stress, which can quickly fluctuate over a short period, it is worth starting by testing the LMI over a relatively brief lag [29,31,47,50–53]. Consequently, the current study aims to evaluate the 7-day short-term interval LMI of the PSS-C-10, along with other measurement properties of the questionnaire. We hypothesize that the LMI of the PSS-C-10 could be supported in a short-interval longitudinal design and that the related measurement properties are appropriate.

2. Material and methods

2.1. Procedures

The Institutional Review Board of the School of Public Health, Hangzhou Normal University, approved the research protocol that followed the relevant ethical tenets of the Declaration of Helsinki (Reference No. 20210014) [54]. A two-wave longitudinal survey with a 7-day interval setting was conducted between September 2021 and March 2022 at a university in Hangzhou, China [50–53]. Participants were recruited through convenient sampling, and included healthcare students of all grades, i.e., freshman, sophomore, junior, and senior. However, international exchange students who were not proficient in Chinese, and students who were on long-term medical internship leave or suspension were excluded. Data were collected using a paper and pencil method, and responses from the same participant at the two time points were matched with the unique student ID. The final sample size included in the analysis was 492 valid questionnaires, which exceeded the recommended minimum sample size of 10 times the number of items in the scale [55], and minimum sample size of 200 for factor analysis based on the ratio of items to factors in our study, i.e., 5 [56].

2.2. Measures

2.2.1. Sociodemographic variables questionnaire

A self-designed questionnaire was utilized to gather sociodemographic information about the participants for assessing the cross-sectional measurement invariance (CMI). The questionnaire included items related to participants' gender, age, home location, single-child status, monthly household income (measured in CNY, with 1 CNY $\approx$ 0.160 US dollars), and part-time status. The Self-Rated Health Questionnaire (SRHQ) consisting of two items measuring physical health and mental health was also used. The total score of the SRHQ ranged from 2 to 10, with higher scores representing better self-rated health. In the current study, the Cronbach's alpha of the SRHQ was 0.706 at baseline and 0.761 at follow-up.

2.2.2. Perceived Stress Scale (Chinese Version)

This study utilized the PSS-C-10 [29,31,47]. The PSS-C-10 had two dimensions (*positive* and *negative*), and a five-point item response scale ranging from 0 (never) to 4 (very often). The PSS-C-10 has been validated and found to have adequate measurement properties, consistent with the original English version of the PSS in a sample of policewomen (Cronbach's alpha = 0.770–0.860; comparative fit index [CFI] = 0.980, root mean square error of approximation [RMSEA] = 0.048) [47].

2.2.3. Perceived Stress Questionnaire (Chinese Version)

The Chinese version of the Perceived Stress Questionnaire (PSQ-C-30) is a 30-item self-report scale scored on a four-point Likert-type scale (1 = almost never, 2 = sometimes, 3 = often, 4 = usually), comprising five factors: *conflict*, *overload*, *joy*, *worries/tension*, and *self − realization* [57,58]. The Cronbach's alpha of the PSQ-C-30 was 0.922, indicating strong reliability, and the goodness-of-fit (GOF) indices demonstrated good structural validity (CFI = 0.916; RMSEA = 0.048) [57]. The PSQ-C-30 was used as the criterion instrument in this study.

2.3. Data analysis

The database was constructed using EpiData (version 3.1) software. All statistical analyses were conducted using R (version 4.2.1). Descriptive statistics were used to summarize the characteristics of the sample variables. Multivariate normality of the scores was tested using the "*MVN*" package [59]. The measurement properties of the PSS-C-10 were evaluated according to the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) methodology manual and the taxonomy of measurement properties, including structural validity, measurement invariance, construct validity, internal consistency, and test–retest reliability [60–62].

2.3.1. Structural validity

Exploratory graph analysis (EGA), with least absolute shrinkage and selection operator (LASSO) regularization, was used to identify the possible factor structure of the PSS-C-10 using the "*EGAnet*" R package [63,64]. The walktrap algorithm was used to recognize the number of dense clusters to identify the factor structure, and the estimated accuracy of EGA can reach approximately 100% with a sample size of 500 for a two-factor structure [63]. Comparison between the two network structures, i.e., baseline and follow-up, was performed using the

"*NetworkComparisonTest*" package [65] based on 1000 iterations, which investigated the network invariance (possible edge weight differences) and global strength invariance (possible difference in the absolute sum of network edge weights). The primary goal of the EGA was to determine whether the factor structure of the PSS-C-10 was consistent with the original form of the PSS-10 (*positive* and *negative*) [29,31].

Confirmatory factor analysis (CFA) was then employed to further evaluate the identified structure of the PSS-C-10. The weighted least squares mean- and variance-adjusted (WLSMV) estimator was used to accommodate the ordinal nature of the item ratings [66–68]. The factor structure of the PSS-C-10 was estimated by the scaled GOF indices, including the CFI [69], Tucker-Lewis index (TLI) [69], and RMSEA, using the R package "*lavaan*" [70–72]. Cut-off values for appropriate GOF indices were set at CFI $\geq$ 0.900, TLI $\geq$ 0.900, and RMSEA $\leq$ 0.080 [73]. The main objective of the CFA was to evaluate whether the factor structure of the PSS-C-10 was consistent with the original form of the PSS-10 [29,31].

2.3.2. Measurement invariance

Configural, threshold, metric, scalar, and strict models were used to assess both CMI and LMI using the R package "*semTools*". Parameters were coordinately constrained (Supplementary Material in Table S1) for each model mentioned above. The scaled CFI, TLI, and RMSEA as well as their changes (Δ), were used to evaluate measurement invariance: 1) CFI $\geq$ 0.900, TLI $\geq$ 0.900, and RMSEA $\leq$ 0.080 were required; and 2) ΔCFI $\leq$ 0.010, ΔTLI $\leq$ 0.010, and ΔRMSEA $\leq$ 0.015 were required. If two, one, or no GOF indices had changes found to be unacceptable, the model was judged as unsupported, nearly supported, or unsupported, respectively. The chi-square statistic (χ^2) and the chi-square change ($\Delta\chi^2$) were also compared between the models, rather than relying on statistical significance, which is sensitive to the sample size. The LMI was built under a setting of 7-day interval to align with the study hypothesis and the original design of the PSS-10 [29,31,47]. Serval studies supported the rationality of such a short lag between measurements [74–78].

2.3.3. Construct validity

To examine the construct validity of the PSS-C-10, at least 75% of the hypotheses needed to be met accordance with the COSMIN guidelines [62]. Specifically, we tested the following hypotheses:

1) A positive correlation (i.e., $\geq$ 0.500) between the overall PSS-C-10 score and the overall PSQ-C-30 score, since both instruments measure the same construct of perceived stress [79].

2) A moderate positive correlation (i.e., 0.300–0.500) between the subscales of the PSS-C-10 and those of the PSQ-C-30, since both instruments were intended to measure related constructs, but the PSQ gives more consideration to negative affect and psychosomatic conditions [16,58].

3) A moderate negative correlation (i.e., 0.300–0.500) between the PSS-C-10 and the SRHQ, since the two instruments measure related yet dissimilar constructs.

2.3.4. Internal consistency

Using the "*ufs*" R package, ordinal forms of Cronbach's alpha, McDonald's omega, and their confidence interval were computed to evaluate the internal consistency of the PSS-C-10 [80–82]. The internal consistency was considered good when Cronbach's alpha or McDonald's omega was at least 0.700 [79,83].

2.3.5. Test–retest reliability

The intraclass correlation coefficient (ICC) was used as the primary test–retest reliability indicator [84,85]. The ICC was obtained using the R package "*irr*" [86], and the measure was considered poor, moderate, good, or excellent when it was < 0.500, between 0.500 and 0.750, between 0.750 and 0.900, and > 0.900, respectively [84,85,87]. In addition, we calculated the standard error of measurement (SEM) using the formula "standard deviation × sqrt (1 – ICC)" [84], as a complementary indicator to further evaluate the test–retest reliability.

3. Results

3.1. Participants

We approached 525, of whom 492 consented to participate in the study, resulting in a response rate of 93.71%. Their average age was 19.421 (SD = 1.197) years, and other characteristics are summarized in Supplementary Material in Table S2. The average time interval from baseline to follow-up measurement was 7 days + 7.008 hours. Examination of the skewness, kurtosis, and *P* values ($P < 0.001$) revealed that a multivariate normal distribution was not supported on the item scores of the PSS-C-10 (Supplementary Material in Table S3).

3.2. Psychometric properties

3.2.1. Structural validity

The EGA was applied to both baseline and follow-up tests to identify the best structure for the PSS-C-10. The EGA recognized two clusters with an accuracy of 98.6% (baseline) and 100% (follow-up), indicating that the PSS-C-10 had the same two-factor structure as the original design (Fig. 1A and B). The average item stability of the two clusters at both test times was excellent (0.994–1.000; Supplementary Material in Figs. S1 and S2). The network comparison test showed that the networks for baseline and follow-up were not significantly different, since the network invariance and test global strength invariance test was not significant (P = 0.839 and 0.727 at baseline and follow-up, respectively).

CFAs were then conducted to examine three factorial models (Supplementary Material in Table S4). The two-factor model presented a relatively better fit as indicated by the GOF indices (CFI = 0.963 [baseline] and 0.987 [follow-up]; TLI = 0.951 [baseline] and 0.983 [follow-up]; RMSEA = 0.103 [baseline] and 0.074 [follow-up]) compared to the one-factor and second-order factor models. Consequently, the two-factor model was confirmed to be consistent with the original design and chosen for further analysis.

3.2.2. Measurement invariance

Cross-sectional CFAs and longitudinal CFA were conducted with the selected two-factor model to test measurement invariance. Most of the GOF values of CMIs remained in an acceptable range, although some RMSEA values slightly fell outside the cut-off criteria. Based on the evaluation of the ΔCFI, ΔTLI, and ΔRMSEA, the measurement invariance models of most subgroups were found to be fully supported or nearly supported (Table 1). However, the gender invariance on the strict model was not supported based on ΔGOF values and $\Delta\chi^2$ comparison (ΔCFI = -0.017 [baseline] and -0.010 [follow-up]; ΔTLI = -0.011 [baseline] and -0.007 [follow-up]; ΔRMSEA = 0.014 [baseline] and 0.017 [follow-up]; $\Delta\chi^2$ = 57.204 [baseline] and 44.712 [follow-up], $P <$ 0.001).

The longitudinal CFA showed that the GOF indices fully supported the LMI for all five models. The GOF indices and their changes did not fall outside the cut-off values and remained in an excellent range (CFI $\geq$ 0.950, TLI $\geq$ 0.950, and RMSEA $\leq$ 0.060). The strict invariance for changes with chi-square was the only one that showed a significant difference (Table 2).

3.2.3. Construct validity

The correlation matrix of the PSS-C-10 and other measures is presented in Fig. S3 of the Supplementary Material. As divided by the vertical line, the left area of the figure displays the inter-factor correlations, and the right area displays the concurrent validity correlations. Moderate to high correlations were found, with inter-factor correlations ranging from 0.461 to 0.926. Except for the PSS *positive*-subscale

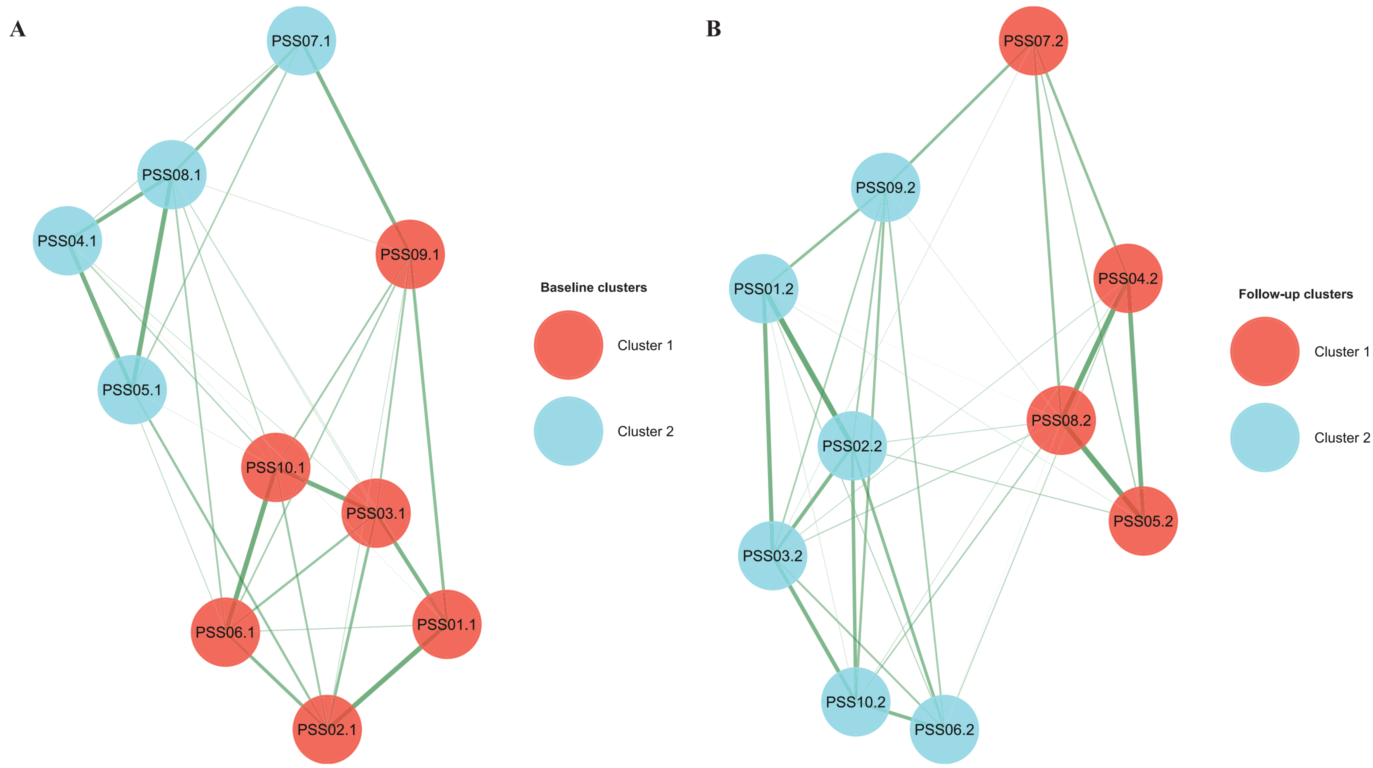

Fig. 1. Visualization of the EGA network on the PSS-C-10 (T1 and T2, $N = 492$). The different color represent different clusters that item belongs to. The thickness of the line indicates the strength of the edge, with thicker lines indicating a stronger link. A was produced under the baseline database while B was produced under the follow-up database.(For interpretation of the references to colour in this figure legend, the reader is referred to the online version of this chapter.)

(baseline) which weakly correlated with the PSQ *overload*-subscale (baseline and follow-up), other subscales and the total scale of the PSS-C-10 were moderately correlated with the PSQ-C-30 and its subscales. Furthermore, the correlations between the PSS-C-10 and the SRHQ fell within the expected range. In summary, the PSS-C-10 and its subscales showed relatively satisfactory construct validity.

3.2.4. *Internal consistency*

The internal consistency of the PSS-C-10 was found to be satisfactory based on the values of Cronbach's alpha (0.788–0.886 at baseline, 0.838–0.911 at follow-up) and McDonald's omega (0.793–0.887 at baseline, 0.842–0.912 at follow-up). Similarly, the PSQ-C-30 showed adequate internal consistency based on Cronbach's alpha values (0.945 at baseline and 0.958 at follow-up) and the McDonald's omega values (0.947 at baseline and 0.958 at follow-up]). Detailed information on the internal consistency is presented in Table 3.

3.2.5. *Test–retest reliability*

The ICCs of the PSS-C-10 and *positive* subscale at baseline and follow-up were 0.816 and 0.790, respectively, suggesting good test–retest reliability. The value of 0.664 for the PSS *negative* subscale indicated moderate test–retest reliability. The SEMs for the PSS-C-10 were 1.751 at baseline and 1.438 at follow-up, and those for the PSQ-C-30 was 1.766 at baseline and 0.758 at follow-up. Generally, the reproducibility across time points of the PSS-C-10 was acceptable (Table 3).

4. Discussion

The present study provided robust psychometric evidence regarding the validity, reliability, and measurement invariance of the PSS-C-10.

4.1. *Structural validity*

Both EGA and CFA were used as complementary analytical approaches to determine the structure of the PSS-C-10, rather than using the traditional exploratory factor analysis. The results of the two approaches indicated that the PSS-C-10 in the present study is consistent with the original design of the English version, and the results are also consistent with previous research on the Chinese version of the PSS-10 [31,47]. The high accuracy of the EGA analysis provided initial evidence of the structure of the PSS-C-10, and the subsequent CFA analysis confirmed the structure. Our proposed procedures may provide guidance to researchers for replicating the psychometric structure of the PSS-C-10 in diverse/heterogeneous samples.

4.2. *Measurement invariance*

The CMI was found to be supported across most subgroups, such as age. However, the gender invariance was not passed in the strict model, since the ΔGOF repeatedly fell outside the range of acceptance, and the chi-square difference test was significant. We suggest that this suboptimal measurement invariance may have occurred due to the unbalanced gender distribution in the sample [88]. Thus, a more balanced participant characteristics should be a goal in future studies when investigating the CMI, especially in relation to gender.

The LMI was supported by the evaluation of the longitudinal CFA based on the comprehensive assessment of the GOF and its changes. Despite the $\Delta\chi^2$ test being significant in the strict model, we speculate that the LMI could still be concluded due to the high dependency on the sample size of the chi-square test [89]. To our knowledge, this is the first assessment of the LMI of the PSS-C-10 [41–46]. However, more balanced and diverse samples with a larger sample size may be required to confirm the comparability of the PSS-C-10 across populations, such as clinical and community settings. Moreover, as a preliminary result to

Table 1
Tests of multi-group measurement invariances of the PSS-C-10 ($N = 492$).

Model	Baseline						Follow-up					
	χ^2 (*df*)	$\Delta\chi^2$ (Δ*df*)	CFI	ΔCFI	RMSEA (90% CI)	ΔRMSEA	χ^2 (*df*)	$\Delta\chi^2$ (Δ*df*)	CFI	ΔCFI	RMSEA (90% CI)	ΔRMSEA
Gender (male vs. female)												
Configural	262.523 (68)***	/	0.959	/	0.108 (0.094, 0.122)	/	169.313 (68)***	/	0.985	/	0.078 (0.063, 0.093)	/
Thresholds	273.233 (87)***	17.67 (19)	0.960	0.002	0.093 (0.081, 0.106)	-0.015	178.037 (85)***	13.106 (17)	0.987	0.001	0.067 (0.053, 0.081)	-0.011
Metric	251.975 (95)***	8.75 (8)	0.967	0.006	0.082 (0.070, 0.095)	-0.011	169.562 (93)***	7.640 (8)	0.989	0.002	0.058 (0.044, 0.072)	-0.009
Scalar	262.680 (103)***	13.819 (8)	0.966	-0.001	0.080 (0.068, 0.092)	-0.003	178.168 (101)***	10.638 (8)	0.989	0.000	0.056 (0.042, 0.069)	-0.002
Strict	353.849 (113)***	57.204 (10)***	0.949	*-0.017*	0.093 (0.082, 0.104)	0.014	256.108 (111)***	44.712 (10)***	0.979	*-0.010*	0.073 (0.061, 0.085)	*0.017*
Age (< 20 years vs. ≥ 20 Years)												
Configural	253.548 (68)***	/	0.960	/	0.106 (0.092, 0.120)	/	207.888 (68)***	/	0.981	/	0.092 (0.078, 0.106)	/
Thresholds	269.940 (85)***	19.921 (17)	0.960	0.000	0.094 (0.082, 0.107)	-0.011	232.505 (88)***	26.985 (20)	0.980	-0.001	0.082 (0.069, 0.095)	-0.010
Metric	273.403 (93)***	15.937 (8)**	0.961	0.001	0.089 (0.077, 0.101)	-0.005	224.078 (96)***	8.777 (8)	0.982	0.002	0.074 (0.061, 0.086)	-0.008
Scalar	282.744 (101)***	11.241 (8)	0.961	0.000	0.086 (0.074, 0.098)	-0.003	241.169 (104)***	17.476 (8)**	0.981	-0.001	0.073 (0.061, 0.086)	0.000
Strict	301.695 (111)***	27.546 (10)***	0.959	-0.002	0.084 (0.072, 0.095)	-0.002	248.584 (114)***	15.809 (10)	0.982	0.000	0.069 (0.058, 0.081)	-0.004
Home location (city vs. non-city)												
Configural	294.233 (68)***	/	0.953	/	0.117 (0.103, 0.130)	/	196.124 (68)***	/	0.982	/	0.088 (0.074, 0.102)	/
Thresholds	313.567 (87)***	21.460 (19)	0.953	0.000	0.103 (0.091, 0.116)	-0.013	211.069 (88)***	19.245 (20)	0.983	0.001	0.076 (0.063, 0.089)	-0.012
Metric	292.688 (95)***	21.460 (19)	0.959	0.006	0.092 (0.080, 0.104)	-0.011	212.842 (96)***	12.244 (8)	0.984	0.001	0.070 (0.058, 0.083)	-0.005
Scalar	294.694 (103)***	6.761 (8)	0.960	0.001	0.087 (0.076, 0.099)	-0.005	218.430 (104)***	8.096 (8)	0.984	0.000	0.067 (0.055, 0.079)	-0.003
Strict	301.376 (113)***	17.554 (10)	0.961	0.001	0.082 (0.071, 0.094)	-0.005	233.618 (114)***	19.733 (10)**	0.984	-0.001	0.065 (0.053, 0.077)	-0.002
Cut-off value	N/A	N/A	≥ 0.900	≤ 0.010	≤ 0.080	≤ 0.015	N/A	N/A	≥ 0.900	≤ 0.010	≤ 0.080	≤ 0.015
Single-child (single-child vs. non-single-child)												
Configural	236.380 (68)***	/	0.966	/	0.101 (0.087, 0.115)	/	190.141 (68)***	/	0.982	/	0.086 (0.071, 0.100)	/
Thresholds	249.654 (86)***	16.469 (18)	0.967	0.001	0.088 (0.076, 0.101)	-0.012	204.829 (87)***	17.973 (19)	0.983	0.001	0.074 (0.061, 0.088)	-0.011
Metric	238.649 (94)***	8.747 (8)	0.971	0.004	0.079 (0.067, 0.092)	-0.009	205.155 (95)***	11.325 (8)	0.984	0.001	0.069 (0.056, 0.082)	-0.006
Scalar	248.401 (102)***	11.528 (8)	0.970	0.000	0.077 (0.065, 0.089)	-0.003	204.621 (103)***	2.822 (8)	0.985	0.001	0.063 (0.051, 0.076)	-0.005
Strict	269.326 (112)***	26.231 (10)**	0.968	-0.002	0.076 (0.064, 0.087)	-0.001	227.848 (113)***	25.348 (10)**	0.983	-0.002	0.064 (0.052, 0.076)	0.001
Monthly households' income (< 10000 vs. ≥ 10000)												
Configural	240.815 (68)***	/	0.964	/	0.102 (0.088, 0.116)	/	160.592 (68)***	/	0.988	/	0.075 (0.060, 0.090)	/
Thresholds	259.985 (85)***	21.106 (17)	0.964	0.000	0.092 (0.079, 0.104)	-0.010	174.268 (87)***	16.932 (19)	0.989	0.001	0.064 (0.050, 0.078)	-0.011
Metric	242.728 (93)***	21.46 (19)	0.969	0.005	0.081 (0.069, 0.094)	-0.011	192.332 (95)***	16.778 (8)	0.988	-0.001	0.065 (0.051, 0.078)	0.001
Scalar	242.421 (101)***	4.139 (8)	0.971	0.002	0.076 (0.063, 0.088)	-0.005	197.607 (103)***	7.719 (8)	0.988	0.000	0.061 (0.048, 0.074)	-0.003
Strict	241.393 (111)***	7.941 (10)	0.973	0.002	0.069 (0.057, 0.081)	-0.006	231.051 (113)***	28.546 (10)**	0.985	-0.003	0.065 (0.053, 0.077)	0.004
Part-time (do part-time job vs. no part-time job)												
Configural	199.451 (68)***	/	0.972	/	0.089 (0.075, 0.103)	/	140.458 (68)***	/	0.990	/	0.066 (0.050, 0.081)	/
Thresholds	207.551 (83)***	13.863 (15)	0.973	0.001	0.078 (0.065, 0.092)	*-0.011*	149.672 (83)***	14.129 (15)	0.991	0.001	0.057 (0.042, 0.072)	-0.009
Metric	194.051 (91)***	7.751 (8)	0.978	0.005	0.068 (0.055, 0.081)	-0.010	148.900 (91)***	8.489 (8)	0.992	0.001	0.051 (0.036, 0.065)	-0.006
Scalar	196.169 (99)***	7.531 (8)	0.979	0.001	0.063 (0.050, 0.076)	-0.005	155.814 (99)***	8.673 (8)	0.992	0.000	0.048 (0.033, 0.063)	-0.003
Strict	197.276 (109)***	8.986 (10)	0.981	0.002	0.057 (0.044, 0.070)	-0.006	159.467 (109)**	9.262 (10)	0.993	0.001	0.043 (0.028, 0.057)	-0.005
Cut-off value	N/A	N/A	≥ 0.900	≤ 0.010	≤ 0.080	≤ 0.015	N/A	N/A	≥ 0.900	≤ 0.010	≤ 0.080	≤ 0.015

χ^2 Chi-square, *df* degrees of freedom, *CFI* comparative fit index, *RMSEA* root mean square error of approximation, *CI* confidence interval, *Δ* a change in χ^2, *df, CFI*, and *RMSEA*, *N/A* not applicable.
***$P < 0.001$, ** $P < 0.01$.
Bold fonts stand for different models. Italic fonts stand for indices that fell outside the cut-off value.
Table shadings of the first column represent various meaning: 1) Blue represent that this is the configural model; 2) Green represent that this model is fully supported; 3) Yellow represent that this model is nearly supported; 4) Red represent that this model is unsupported.

provide initial support for the subsequent LMI studies, this short-term interval may provide limited evidence, and a longer interval may still be indispensable for testing LMI.

4.3. Construct validity

This is the first study to assess the construct (convergent) validity of the PSS-C-10 using the PSQ-C-30, which measures similar constructs [41–46]. The moderate to high Spearman's correlations between the PSS-C-10 and the PSQ-C-30 identified in this study indicate that two key sub-constructs, namely *coping strategies* and *perceived demands*, may share appreciable amount of variance [15,29,58,90,91].

When measuring perceived stress, one key subconstruct, i.e., *coping strategies* and *perceived demands*, is often chosen by practitioners, and the

Table 2
Test of longitudinal measurement invariance of the PSS-C-10 (N = 492).

Model	χ^2 (*df*)	$\Delta\chi^2$ (Δdf)	CFI	ΔCFI	TLI	ΔTLI	RMSEA (90% CI)	ΔRMSEA
Configural	479.057 (154) ***	/	0.976	/	0.971	/	0.066 (0.059, 0.072)	/
Thresholds	488.871 (174) ***	14.721 (20)	0.977	0.001	0.975	0.004	0.061 (0.054, 0.067)	-0.005
Metric	458.235 (182) ***	4.842 (8)	0.980	0.003	0.979	0.004	0.056 (0.049, 0.062)	-0.005
Scalar	465.127 (190) ***	10.993 (8)	0.980	0.000	0.980	0.001	0.054 (0.048, 0.061)	-0.001
Strict	470.883 (200) ***	35.946 (10) ***	0.980	0.000	0.981	0.001	0.053 (0.046, 0.059)	-0.002
Cut-off value	N/A	N/A	> 0.900	< 0.010	> 0.900	< 0.010	< 0.080	< 0.015

χ^2 Chi-square, *df* degrees of freedom, *CFI* comparative fit index, *TLI* Tucker-Lewis index, *RMSEA* root mean square error of approximation, *CI* confidence interval, *Δ* a change in χ^2, *df*, CFI, TLI, and RMSEA, *N/A* not applicable.
***$P < 0.001$.
Table shadings of the first column represent various meaning: 1) Blue represent that this is the configural model; 2) Green represent that this model is fully supported.

Table 3
Internal consistency and test–retest reliability of the measures (N = 492).

Variable	Cronbach's alpha		McDonald's omega		ICC (95% CI)	SEM	
	Baseline	Follow-up	Baseline	Follow-up		Baseline	Follow-up
PSS-C-10	0.885 (0.870, 0.901)	0.904 (0.891, 0.917)	0.885 (0.870, 0.900)	0.902 (0.889, 0.915)	0.816 (0.783, 0.843)	1.751	1.438
Positive	0.788 (0.757, 0.819)	0.838 (0.815, 0.862)	0.793 (0.764, 0.823)	0.842 (0.820, 0.865)	0.790 (0.755, 0.821)	1.025	1.038
Negative	0.886 (0.871, 0.902)	0.911 (0.899, 0.923)	0.887 (0.871, 0.902)	0.912 (0.900, 0.924)	0.664 (0.608, 0.713)	3.225	6.385
PSQ	0.945 (0.939, 0.952)	0.958 (0.952, 0.963)	0.947 (0.940, 0.953)	0.958 (0.953, 0.964)	0.879 (0.857, 0.898)	1.813	0.867
Conflict	0.793 (0.764, 0.822)	0.826 (0.801, 0.850)	0.795 (0.766, 0.823)	0.827 (0.802, 0.851)	0.742 (0.699, 0.779)	1.120	1.164
Overload	0.739 (0.701, 0.777)	0.817 (0.790, 0.844)	0.748 (0.711, 0.784)	0.827 (0.803, 0.852)	0.684 (0.622, 0.736)	3.427	1.970
Joy	0.853 (0.833, 0.872)	0.895 (0.880, 0.909)	0.854 (0.835, 0.874)	0.897 (0.883, 0.911)	0.783 (0.746, 0.815)	0.848	3.054
Worries/tension	0.928 (0.918, 0.937)	0.940 (0.932, 0.947)	0.928 (0.919, 0.938)	0.940 (0.933, 0.948)	0.842 (0.814, 0.866)	1.157	0.510
Self-realization	0.630 (N/A, N/A)	0.665 (N/A, N/A)	N/A	N/A	0.638 (0.582, 0.687)	1.919	8.378

This table shows ordinal forms of Cronbach's alpha and McDonald's omega. Standard error of measurement was calculated as "SD × sqrt (1-ICC)". The McDonald's ω and the 95% confidential interval of Cronbach's alpha cannot be calculated due to the self-realization subscale containing only 2 items.
PSS-C-10 the 10-item Chinese version of the Perceived Stress Scale-10, *PSQ-C-30* the 30-item Chinese version of the Perceived Stress Questionnaire, *ICC* intraclass correlation coefficient, *SEM* standard error of measurement, *CI* confidence interval, *N/A* not applicable.
Bold fonts stand for the overall scores.

other may be easily ignored [15,29,58,90,91]. The good convergent validity shown by the PSS-C-10 provides a new opportunity to explore its association with the PSQ-30-C. For example, it would be useful to examine whether the PSS and the PSQ could be combined to form a new instrument for measuring both *coping strategies* and *perceived demands* under perceived stress. Although a previous study examined this question, the outcome was unsatisfactory [90]. The next step in future studies would be to examine the possible combination of the Chinese versions of the PSS and the PSQ.

4.4. Internal consistency

Both the subscales and total scale of the PSS-C-10 were reliable, as indicated by the Cronbach's alpha and McDonald's omega values, which were all above 0.700. These findings are consistent with those of previous studies that evaluated the PSS-C-10 [41–46,92]. However, the relatively lower indices of the subscales are a phenomenon worth noting, and future researchers may need to exercise extra caution if they intend to solely utilize the *positive* or *negative* subscale. Overall, this 10-item instrument has strong reliability when measuring stress perception levels in contexts with a shortage of resources and time.

4.5. Test–retest reliability

The test–retest reliability of the PSS-C-10, as evaluated by the bias-sensitive ICC, was good overall, although the reliability for the *negative* subscale was moderate. The reason for the comparably lower ICC of the *negative* subscale may be attributed to the fact that answers to the measuring item, e.g., "… how often have you felt that you were unable to control the important things in your life?", may vary significantly even in a short time. The way individuals cope when negative incidents occur may vary, and therefore, caution is needed when discussing the longitudinal results of the negative subscale.

4.6. Strengths and limitations

Several strengths of this study can be highlighted. Firstly, this is the first longitudinal survey undertaken to evaluate the performance of the PSS-C-10. Secondly, our analytical approaches, which integrate the EGA and CFA for assessing the psychometric structure of instruments, may be applied in other psychometric evaluation studies. Thirdly, we evaluated the LMI of the PSS-C-10 for the first time, and the relatively sufficient result provides a direction for future research to study trends in stress. Lastly, we assessed the convergent validity of the PSS-C-10 for the first time using the PSQ-C-30. Given that the PSS-C-10 and PSQ-C-30 are highly analogous in terms of measuring the same construct yet with emphasis on different key constructs, the correlations between the PSS-C-10 and the PSQ-C-30 are meaningful and insightful.

Alternatively, some limitations should be mentioned as well. Firstly, the imbalanced gender composition (primarily females) in the sample made it challenging to conclude whether the surveyed sample was adequately representative, even though the response rate met the expectations. Secondly, the deductions of the CMIs, especially in terms of gender invariance, may have been biased due to the imbalanced composition of participants. Thirdly, the interval of short-term periods might limit evidence strength of the LMI. Lastly, recruiting participants from one university and one major discipline may have resulted in selection bias and information bias, respectively.

4.7. Future directions

Concerning the disadvantages presented above, we propose several recommendations regarding future directions. Firstly, future research could apply quota sampling or probability sampling to balance the proportion of participants. Secondly, more than two repeated measures and a longer follow-up gap than the current short-term period could be set to provide stronger evidence of the LMI. Thirdly, instruments measuring other constructs, e.g., sleep disorders and quality of life, can be utilized to assess the discriminant validity of the PSS-C-10. Lastly, applications of the PSS-C-10 could be delivered to different populations from various settings, such as community residents, general patients, and even the general population.

5. Conclusion

At the 10th development anniversary of the simplified Chinese version of the PSS-10, the scale generally has desirable and stable measurement properties for assessing perceived stress with the *positive* and *negative* subscales. Notably, validation with modern test theory should be conducted in multicenter and longitudinal studies, and more diverse populations.

Ethical approval

The research proposal has been reviewed and approved by the Institutional Review Board of School of Public Health, Hangzhou Normal University, China (Reference No. 20210014), thus ensuring that all procedures were carried out in accordance with the Declaration of Helsinki. All healthcare students freely consented to answer the questionnaires and provided their informed consent before data collection. The authors confirmed full respect and protection of individual privacy rights before, during and after the data collection and processing. Data in this study were all anonymous and used exclusively for academic purposes.

Material availability

Not available.

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CRediT authorship contribution statement

Chen Jiang: Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Haiyan Ma:** Project administration, Resources, Supervision, Validation. **Yi Luo:** Methodology, Validation, Writing – review & editing. **Daniel Yee Tak Fong:** Methodology, Validation, Writing – review & editing. **Emre Umucu:** Writing – review & editing. **Huiqiu Zheng:** Writing – review & editing. **Xiao Liu:** Writing – review & editing. **Xiaoxue Liu:** Writing – review & editing. **Karen Spruyt:** Methodology, Validation, Writing – review & editing. **Runtang Meng:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

The study was conducted in the absence of any potential conflict of interest.

Data availability

Not available.

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Appendix A. Supplementary data

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