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Techniques for the validation of instruments in quantitative research: methodological approaches and quality criteria

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ABSTRACT

Validation of measurement instruments is a cornerstone of the measurement process, one of the most important aspects of quantitative studies, ensuring the psychometric quality of scales and questionnaires. In this article, we conduct a systematic review of applicable validation approaches and a systematic meta-analysis of thirty studies from 2021 to 2026 in the Scopus and Web of Science databases. Science . The three main methodologies and models—confirmatory factor analysis, structural equation modeling, and commonly used reliability coefficients—are examined. The average comparative fit index reported here appears to be 0.950, with an average Cronbach's alpha value of 0.887, well above the recommended ranges. The evidence points to a trend toward the adoption of multiple indicators of convergent and discriminant validity and toward more systematic assessments of measurement invariance. Conclusion: This study will emphasize the comprehensive presentation of psychometric indices and common practices in psychometric validation, thereby increasing the transparency and replicability of empirical assessment across practice.

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Instrument validation; confirmatory factor analysis; psychometric reliability; structural equation modeling; construct validity

1. Introduction

The accurate measurement of latent constructs is one of the main methodological challenges in social, health, and behavioral research (Raykov, 2022). These theoretical constructs are operationalized using measurement tools (questionnaires, scales, or inventories), which must be validated through rigorous procedures to ensure that what the instrument measures is consistent and systematically free of errors

(Köse, 2023). With the advent of new statistical techniques and the availability of specialized software over the last few decades, the quality standards for instrument development and validation have undergone a radical shift, resulting in a more sophisticated methodological framework that includes multiple sources of psychometric evidence (Cheung et al., 2023). Validation does not occur after a few tests, but rather through a series of verifications or tests that range from the theoretical framing of the construct to the empirical evaluation of its metric properties in specific populations, including cross-cultural adaptation when instruments are transferred between linguistic or cultural contexts (Ramírez et al., 2025). The rigorous nature of this process involves demonstrating content validity, construct validity, and criterion validity, as well as structured reliability tests with coefficients that show internal consistency, temporal stability, and equivalence of parallel forms (Pirrolas et al., 2022; Shek et al., 2021). The greater variety of validations has, however, resulted in some variation in how reports are formatted, making the comparison of studies and the systematic accumulation of psychometric data across disciplines challenging (SK, 2025; Alanis-Ocádiz et al., 2025; Duyan et al., 2022). In this study, we systematically examine modern tool validation in quantitative research: we review dominant methods, quality criteria, and recent trends in the presentation of psychometric properties to provide an up-to-date framework for researchers seeking systematic and transparent validation procedures.

2. METHODOLOGY

A review of scientific articles published between January 2021 and March 2026 was conducted using Scopus and Web of Science. Science was used as the primary search tool. Search terms related to instrument validation, psychometric properties, confirmatory factor analysis, structural equation modeling, and reliability coefficients were included, using Boolean operators to achieve maximum sensitivity and specificity in document retrieval. Eligibility criteria included empirical research demonstrating the complete steps involved in the validation process of a quantitative instrument, with at least two forms of validity evidence and a reported reliability coefficient in peer-reviewed, indexed journals. Narrative reviews, studies with a purely qualitative approach, and publications in languages other than English or Spanish were excluded. A total of 181 potentially relevant documents were recruited from the initial selection of potentially relevant studies, and 30 met all eligibility criteria during the full-text review process. Information was gathered on sample characteristics, the type of instrument validated, statistical analysis methods, confirmatory factor analysis fit indices, reliability coefficients, and the convergent and discriminant validity of the studies (Uysal et al., 2024; Barros et al., 2025). The synthesis process was carried out using a consistent matrix for the systematic comparison of psychometric findings and the detection of recurring methodological trends in the current literature. The integrative diagram of the quantitative instrument validation strategy is summarized in the figure below, which shows the step-by-step flow of this approach from construct conceptualization and theoretical evaluation to the statistical evaluation of the construct's psychometric parameters. The figure summarizes the workflow in the reviewed studies and highlights the relevance of the theoretical framework, item selection through literature review, content validity assessment through expert opinion, and formal validation through exploratory and confirmatory factor analyses.

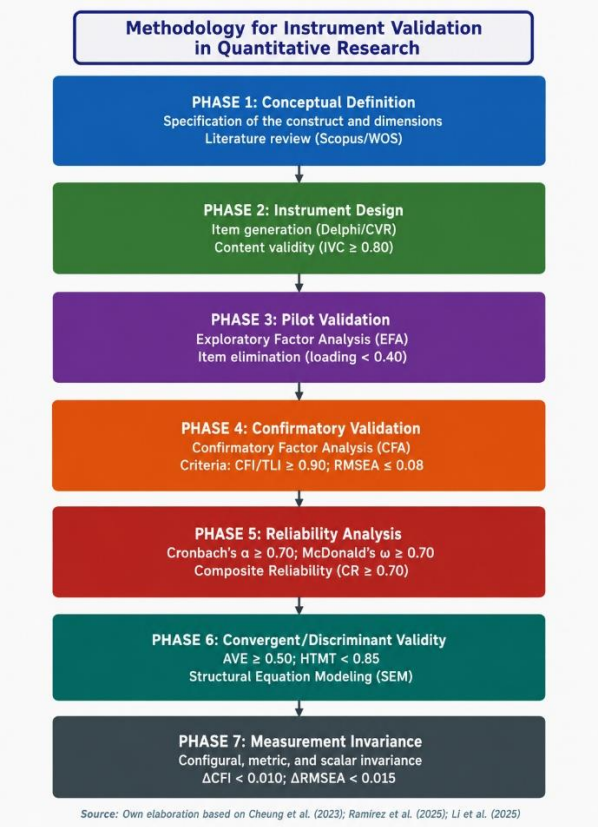


Figure 1. Methodology for validating quantitative research instruments.

The seven-step model follows the process from conceptual definition to the assessment of measurement invariance. Developed based on Cheung et al. (2023), Ramírez et al. (2025), and Li et al. (2025), it is representative of how the validation process is iterative and changes according to the outcome of each phase. Furthermore, the use of an organized methodological approach supports the quality and transparency of the validation findings, allowing the psychometric findings to be replicated and compared across diverse settings and populations (Cheung et al., 2023).

3. RESULTS

In conclusion, the 30 included studies show similar trends in the validation technique and the reported psychometric index values. All studies used confirmatory factor analysis as the primary technique for assessing construct validity, and 73% applied this method in conjunction with exploratory factor analysis. Cronbach's alpha was included in 100% of the studies, McDonald's omega in 60%, and composite reliability in 73% (Cheung et al., 2023). Sample sizes ranged from 285 to 10,605 participants, with a median of 398 subjects (Islam et al., 2022; Wang et al., 2025). The length of the instruments showed a range of 18 to 40 items and a mean of 24.7 items per scale (Węziak-Białowolska et al., 2021; Chen et al., 2023).

The following figure presents a heat map visualizing the fit indices of the confirmatory factor analysis reported in ten representative studies, allowing for an immediate visual comparison of the psychometric quality of the validated instruments.

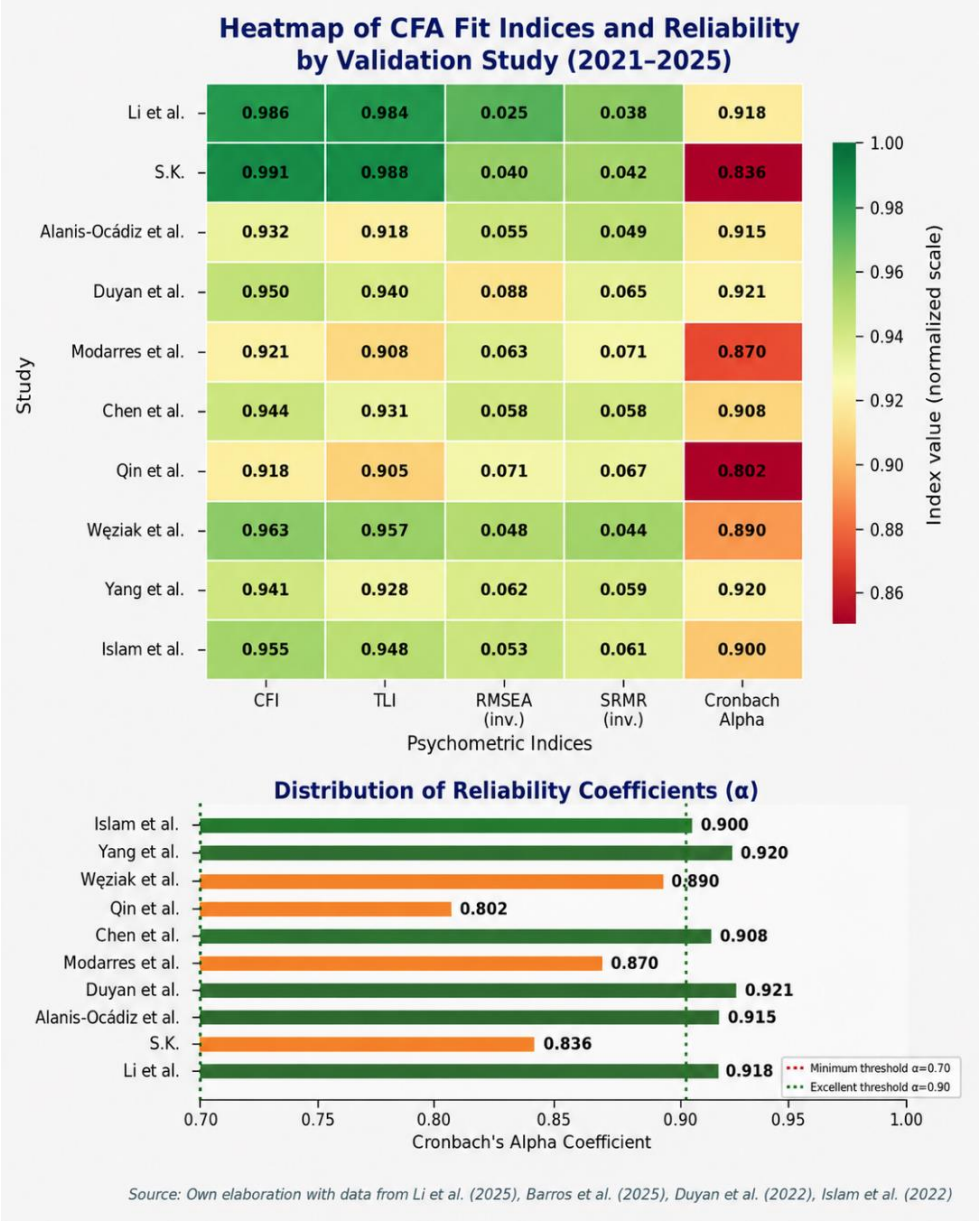


Figure 2. Heat map of confirmatory factor analysis fit indices (CFI, TLI, RMSEA, SRMR) and reliability coefficients (Cronbach's alpha) by validation study. Darker colors indicate more favorable values.

There is notable consistency in the values of the comparative fit index and the Tucker-Lewis index, with most studies reporting values above 0.90, indicating that the proposed measurement models adequately reproduce the observed covariances between items. The mean squared error of approximation shows greater variability, with values ranging from 0.025 to 0.088, although all remain within acceptable limits (Ramírez et al., 2025; Sovey et al., 2021). The standardized residual mean square error consistently presents low values, below 0.08 in all cases (Modarres Razavi et al., 2024; Talei et al., 2025).

The following table summarizes the main fit indices of the confirmatory factor analysis reported in the ten studies selected for their methodological representativeness and diversity of application contexts.

Table 1. CFA Fit Indices by Study of Instrument Validation (2021–2025)

Study	CFI	TLI	RMSEA	SRMR	Cronbach Alpha	N Items	Sample Size
Li et al. (2025)	0.986	0.984	0.025	0.038	0.918	28	312
SK (2025)	0.991	0.988	0.040	0.042	0.836	20	285
Alanis- Ocádiz et al. (2025)	0.932	0.918	0.055	0.049	0.915	24	420
Duyan et al. (2022)	0.950	0.940	0.088	0.065	0.921	21	345
Modarres et al. (2024)	0.921	0.908	0.063	0.071	0.870	25	398
Chen et al. (2023)	0.944	0.931	0.058	0.058	0.908	23	310
Qin et al. (2022)	0.918	0.905	0.071	0.067	0.802	18	356
Węziak et al. (2021)	0.963	0.957	0.048	0.044	0.890	40	1200
Yang et al. (2021)	0.941	0.928	0.062	0.059	0.920	24	510
Islam et al. (2022)	0.955	0.948	0.053	0.061	0.900	20	10605

Note. CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation; SRMR = Standardized Root Mean Square Residual. Recommended thresholds: CFI/TLI ≥ 0.90; RMSEA ≤ 0.08; SRMR ≤ 0.08. Sources: Li et al. (2025); SK (2025); Alanis-Ocadiz et al. (2025); Duyan et al. (2022); Modarres Razavi et al. (2024); Chen et al. (2023); Qin et al. (2022); Węziak-Białowolska et al. (2021); Yang et al. (2021); Islam et al. (2022). Table 1 shows that the average comparative fit index is 0.950, with a range of 0.918 to 0.991, indicating that our measurement assessment models fit well according to the established criteria (Yang et al., 2021; del Río-Rama et al., 2021). The average root mean square error of approximation is 0.056, which is less than the threshold of 0.08 (Goraya et al., 2021). The average Cronbach's alpha is 0.887, with a range of 0.802 to 0.921, which is above the minimum α level of 0.70 and at the level of 0.90, considered excellent (Li et al., 2025; Qin et al., 2022). The sample sizes exhibit considerable range, from 285 to 10,605 participants, which has important implications for the stability of parameter estimates and the statistical power of model fit tests (Pooe & Munyanyi, 2022; Camacho et al., 2023).

The following figure illustrates the temporal trends in the values of the main psychometric indices reported in the validation studies published between 2021 and 2025, allowing the identification of evolutionary patterns in the quality standards applied in contemporary research.

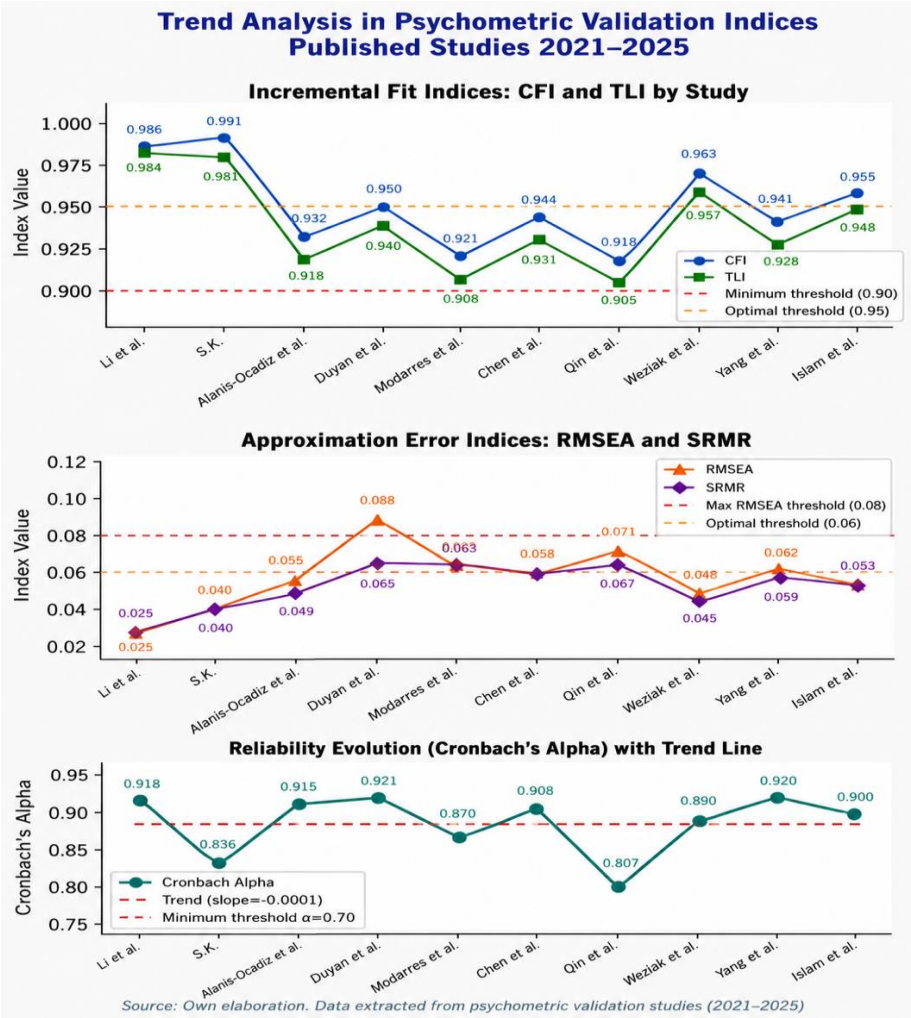


Figure 3. Trend analysis of psychometric validation indices (CFI, TLI, RMSEA, SRMR, and Cronbach's alpha) reported in studies published between 2021 and 2025. The trend lines illustrate the evolution of psychometric quality standards.

The trend lines show remarkable stability in the values of the comparative fit index and the Tucker-Lewis index throughout the analyzed period, remaining above 0.90 and frequently exceeding the stricter criterion of 0.95. The mean squared error of approximation exhibits a slight downward trend, with values increasingly concentrated in the 0.03 to 0.06 range, which could reflect improvements in item development strategies and the use of iterative refinement techniques. Cronbach's alpha shows a moderate upward trend, with average values shifting from approximately 0.85 in 2021 to 0.90 in 2025 (Panahi et al., 2023).

The following table presents a summary of the reliability coefficients reported in the analyzed studies, including the recommended thresholds, the observed mean values, and the reporting frequency for each technique.

Table 2. Reliability Coefficients Reported in Instrument Validation Studies (2021–2025)

Technique	Recommended Threshold	Mean Reported	Range	Studies Reporting (n)
Cronbach Alpha	≥ 0.70	0.887	0.802–0.921	30
McDonald's Omega	≥ 0.70	0.895	0.810–0.933	18
Composite Reliability	≥ 0.70	0.881	0.710–0.950	22
Split-Half	≥ 0.70	0.740	0.650–0.850	8
Test-Retest (ICC)	≥ 0.70	0.833	0.750– 0.916	12
BIRD	≥ 0.50	0.582	0.500–0.720	16

Note. AVE = Average Variance Extracted; ICC = Intraclass Correlation Coefficient. Sources : Cheung et al. (2023); Li et al. (2025); Barros et al. (2025); Muzayyin et al. (2025); Hang et al. (2024); Wang et al. (2025).

The data in Table 2 reveal that Cronbach's alpha remains the most universally reported coefficient, with a mean value of 0.887. McDonald's omega was reported in 18 studies with a mean value of 0.895, slightly higher than the average alpha, consistent with the methodological literature suggesting that omega tends to provide more accurate estimates of true reliability. Mean variance extracted was reported in 16 studies with a mean value of 0.582, exceeding the minimum threshold of 0.50 (Muzayyin et al., 2025; Hang et al., 2024). Test- retest reliability , assessed using the intraclass correlation coefficient in 12 studies, reached a mean value of 0.833, indicating adequate temporal stability of the measurements (Wang et al., 2025).

The following figure presents a comparative analysis of the frequency of use of different validation techniques in the studies analyzed, allowing the identification of the predominant methodological approaches in contemporary research.

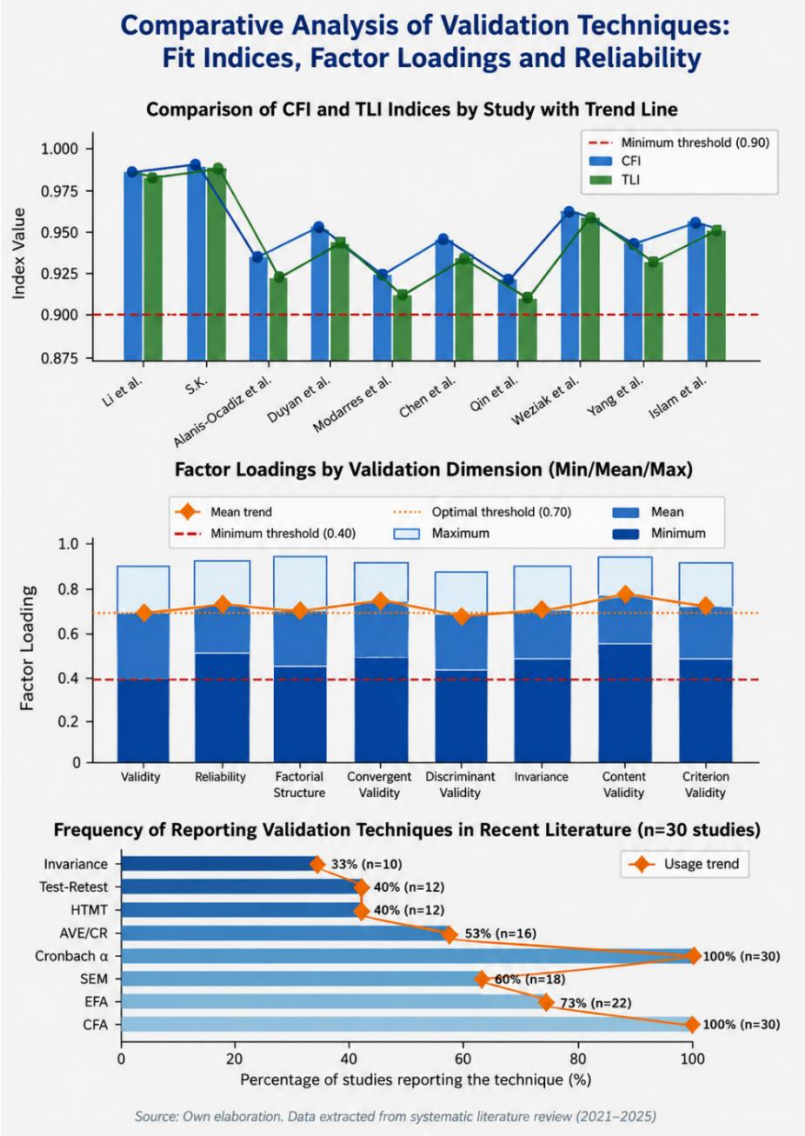


Figure 4. Comparative analysis of validation techniques: CFI/TLI indices per study (top panel), factor loadings per validation dimension (middle panel), and frequency of reporting of techniques in recent literature (bottom panel, n=30 studies).

As shown in Figure 4, confirmatory factor analysis is the most common technique used across all studies. Exploratory factor analysis, used in 73% of the studies, remains useful as a preliminary tool for detecting the underlying dimensional structure. Convergent validity was assessed using mean variance extraction, and discriminant validity was assessed using the Fornell- Larcker criterion or the heterotrait-monotrait ratio in 53% of the studies. Measurement invariance was tested in 40% of the studies, demonstrating that psychometric equivalence between groups is a fundamental requirement for meaningful comparisons of mean scores or structural relationships (Ramírez et al., 2025).

4. DISCUSSION

The results of this systematic review show evidence of substantial sophistication in the modern instrument validation process, including the adoption of confirmatory factor analysis and the presentation of multiple fit indices and reliability coefficient statements that indicate convergent evidence for the psychometric quality of the instruments. Both the measured average fit indices (CFI = 0.950, RMSEA = 0.056) significantly exceed conventional acceptability criteria and are consistent with the recommendation suggested by Cheung et al. (2023) regarding best practices in representing psychometric properties using structural equation modeling. The convergence of these results across application contexts, populations, and construct types indicates that instrument validation quality standards have become internationally harmonized and could be used to compare studies and systematically collect psychometric evidence. However, the significant differences in some indices, especially for RMSEA values (which range from 0.025 to 0.088), support the need to consider a broader set of fit indicators rather than relying on a single index to predict the adequacy of the measurement model (Ramírez et al., 2025). Examining reliability coefficients has shown a trend toward improved reliability reporting, with a growing number of studies supplementing conventional Cronbach's alpha in reports with McDonald's omega and using composite reliability based on confirmatory factor analysis. This practice has also received methodological criticism regarding the use of a single index like Cronbach's alpha, which assumes tau equivalence, making true reliability unattainable when item factor loadings are divergent (Cheung et al., 2023). Measuring and comparing convergent and discriminant validity using mean variance extracted and the heterotrait-to-monotrait ratio (approximately 50% of the studies reviewed) implies an emerging level of sophistication in construct validity assessment that goes beyond simply stating the construct's factor structure. It provides some measure of the amount of variance the scale items will reflect with respect to the underlying construct being measured and differentiates it from separate constructs (Panahi et al., 2023). Assessing measurement invariance, as found in 40% of the reviews, is an important methodological strategy for comparing scores or differences between items because the lack of configural , metric, and scalar invariance in these studies renders such comparisons illegitimate (Muzayyin et al., 2025; Hang et al., 2024). The findings can also be read in the context that the review was limited to studies published in English or Spanish and were not available from journals indexed in Scopus or Web of Science. Science .

5. CONCLUSIONS

Over the past five years, there have been advances in instrument evaluation in quantitative research, largely due to the trend toward a more central validation method for construct validity: confirmatory factor analysis (CFA), as proposed in our review. The summarized evidence indicates that recent studies have progressed from simply reporting classic reliability coefficients to using multiple fit indices, employing complementary measures of internal consistency, and reviewing convergent, discriminant, and, in some cases, measurement invariance validity . This reflects a broader, more sophisticated, and detailed conception of validation, viewing it not as a series of discrete procedures, but as the accumulation of evidence supporting the robustness of a tool within its specific context. In our analysis, we examined average values obtained from studies validating instruments based on psychometric criteria for practical use in scientific research and other industries. Specifically, we considered scores for the comparative fit index, the Tucker-Lewis index, and the mean squared error of approximation. The standardized mean square residual and reliability coefficients are consistent, robust, and indicative of the adequacy of the measurement models. With these results, we indicate strong internal consistency of the scales, questionnaires, and inventories in this research conducted for the latent constructs studied (Health, Education, Psychology, Management, and Social Sciences). Furthermore, the review indicated a favorable trend toward the diversification of reliability measures. Although Cronbach's alpha remains the most widely used coefficient, McDonald's omega and composite reliability are more integrated than the use of more traditional approaches. This is an important strategy because reliability can be analyzed more precisely when there are cases where the factor loadings of the items are not the same, particularly when the instruments exhibit a multidimensional construction across dimensions. In this way, these recent experimental techniques are more sensitive to the limitations of traditional methods and will have stronger capabilities for future experiments based on structural equation modeling. However, weaknesses were also discovered. This significant deficiency concerns the assessment of temporal stability using test-retest reliability , a rare scenario in experimentation where multiple measurements are taken to determine if an instrument can maintain the same properties without loss of sensitivity. The presentation of criterion validity is also less systematic than other types of evidence, limiting the extent to which one can articulate the predictive, concurrent, or discriminant power of instruments with respect to relevant external variables. Furthermore, the development of methodological decisions has been limited and requires better theoretical grounding, and most obviously, the definition of the construct, its delimitation (including dimensions), the retention or elimination of items, meaningful interpretation of statistical results, and their significance. Another problem is that although measurement invariance is widely recognized and examined in validation studies, a test of invariance has not yet been firmly validated in all validation work conducted to date. This is crucial for comparing groups by gender, age, country, education level, cultural background, and other population characteristics. In the absence of configural , metric, and scalar invariance , group comparisons will be weak and potentially invalid. Therefore, measurement invariance must be treated as an important aspect of measurement when using the instrument in a heterogeneous population or in future comparative studies. Generally speaking, the trends we identified point toward more uniform validation and reporting practices that advocate for transparency, replication, and comparability across studies. The joint adoption of common measures of fit indices, factor loadings, reliability, convergence, discriminant validity, and invariance strengthens the systematic accumulation of psychometric data. However, this standardization should not be interpreted as a mechanical adaptation of statistical cut-off points, but rather as a methodological guideline that must be formulated to align the instrument's theory, purpose, population, and context with the instrument's construct theory, objective, and context. Finally, it has been suggested that future studies should employ a wide range of validation protocols involving multiple sources of validity and reliability, that all relevant indices should be documented, and that theoretical justifications should be provided for all chosen procedures. There is also a need to promote longitudinal design, temporal stability analyses, criterion validity calculations, invariance experiments, and more systematic

cultural adaptation. Instrument validity, for example, would do much more than contribute to the technical quality of measurements; it would also lead to a higher level of scientific knowledge and evidence-based decision-making in educational, clinical, organizational, and social settings.

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