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Comparative Evaluation of Orthogonal and Oblique Factor Rotations for Dimension Reduction: Evidence from a Female Undergraduate Obesity-Risk Survey

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ABSTRACT

Exploratory factor analysis is widely used to reduce questionnaire items to a smaller set of interpretable latent dimensions, but the substantive meaning of a solution can depend strongly on the rotation criterion. This study compares three orthogonal rotations (Varimax, Quartimax, and Equamax) and two oblique rotations (Promax and direct Oblimin) using responses from 416 female undergraduates at Michael Okpara University of Agriculture, Umudike, Nigeria. Ten four-point Likert items measured dietary practices, sedentary behaviour, exercise, perceived weight, and concern about weight gain. The data were suitable for exploratory reduction: the Kaiser–Meyer–Olkin measure was 0.65, Bartlett's test of sphericity was significant, and all variance inflation factors were below 2. A three-factor representation was retained from the scree pattern and interpretability, accounting for a reported 64.88% of cumulative variation. Across rotations, the first factor was defined primarily by items q1, q2, q3, q9, and q10, while q5 and q8 formed a second behavioural dimension. Varimax produced the clearest independent-factor solution; however, Promax gave the most coherent overall representation by allowing the dietary, activity, and weight-perception dimensions to correlate. The reported Tucker congruence coefficient of 0.72 indicates that the compared rotated structures were not equivalent. The findings show that rotation should be selected from substantive expectations and empirical clarity rather than habit. For this survey, Promax offered the best balance between simple structure and realistic dependence among obesity-related behaviours.

Keywords: exploratory factor analysis; dimension reduction; Varimax; Promax; Oblimin; Likert scale; obesity-risk behaviour

1 INTRODUCTION

Questionnaires used in health and behavioural research commonly contain several correlated items intended to represent a smaller number of unobserved constructs. Exploratory factor analysis (EFA) addresses this problem by representing observed variables through a reduced set of common factors and item-specific errors. Its usefulness, however, depends not only on extracting an appropriate number of factors but also on rotating the initial solution into a form that can be interpreted substantively [4, 6]. An unrotated loading matrix may reproduce the correlations adequately while distributing moderate loadings across several factors, thereby obscuring the simple structure sought by researchers. Rotation does not alter the fundamental fit or communalities of a fixed common-factor solution; it changes the coordinate system used to describe that solution. Orthogonal methods preserve zero correlations among factors, whereas oblique methods permit factor

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

correlations. Varimax simplifies factor columns and is the most familiar orthogonal criterion [11]. Quartimax emphasizes variable simplicity [16], and Equamax balances variable and factor simplicity within the Crawford–Ferguson family [3]. Promax and Oblimin relax the independence constraint and may better represent behavioural constructs that share causes or mutually reinforce one another [7, 9].

Diet, physical activity, sedentary behaviour, body-weight perception, and concern about weight gain are conceptually distinguishable but unlikely to be independent. A student who consumes energy-dense food may also exercise irregularly or spend long periods sitting, while perceived excess weight may influence concern and subsequent behaviour. An orthogonal rotation can yield convenient independent scores, but that convenience may be achieved by imposing an unrealistic constraint. Conversely, an oblique rotation can introduce additional matrices and may appear less parsimonious if correlations are negligible. Rotation choice should therefore be evaluated empirically and theoretically rather than treated as an automatic software setting.

This study compares five commonly available rotations on the same survey of female undergraduates. Its objectives are to (i) assess whether the item set is suitable for factor analysis, (ii) describe the reduced structure under Varimax, Quartimax, Equamax, Promax, and direct Oblimin, (iii) compare the clarity and similarity of the resulting structures, and (iv) identify the rotation that provides the most defensible interpretation for the study data. The analysis is a focused rotation case study rather than a validation of a clinical obesity scale.

2 Statistical Framework

For a p-dimensional response vector $\mathbf{x}$, the common-factor model is

$$\mathbf{x} - \boldsymbol{\mu} = \mathbf{L}\mathbf{f} + \boldsymbol{\varepsilon}, \qquad (1)$$

where $\mathbf{L}$ is the p × m loading matrix, $\mathbf{f}$ contains m common factors, and $\boldsymbol{\varepsilon}$ contains item-specific components. A rotated loading matrix may be written $\mathbf{L}^* = \mathbf{LT}$ for a suitable transformation $\mathbf{T}$. Under orthogonal rotation, $\mathbf{T}'\mathbf{T} = \mathbf{I}$ and the rotated factors remain uncorrelated. Under oblique rotation, this constraint is relaxed and the factor-correlation matrix $\boldsymbol{\Phi}$ need not be the identity.

Similarity between corresponding loading vectors $\mathbf{a}$ and $\mathbf{b}$ can be summarized by Tucker's congru-ence coefficient,

$$\phi = \frac{\sum_{i=1}^{p} a_i b_i}{\sqrt{\left(\sum_{i=1}^{p} a_i^2\right)\left(\sum_{i=1}^{p} b_i^2\right)}} \qquad (2)$$

Values above 0.95 generally indicate virtual identity, values from 0.85 to 0.94 indicate fair similarity, and values below 0.85 do not support factor equivalence [13]. Congruence is useful as a comparative index, but it does not replace substantive examination of salient and cross-loadings.

3 MATERIALS AND METHODS

3.1 Design, participants, and instrument

The study used primary cross-sectional questionnaire data from 416 female students at Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

Table 1: Questionnaire items included in the analysis.

Item	Statement
q1	I consume fast food (e.g., fried foods, snacks, or sugary drinks) more than three times a week.
q2	I engage in at least 30 minutes of physical exercise daily. (Reverse-coded)
q3	I often skip meals, especially breakfast.
q4	I feel that my current body weight is higher than what is considered healthy.
q5	I spend most of my day sitting (e.g., attending lectures, studying, or using devices).
q6	I regularly consume fruits and vegetables in my daily meals. (Reverse-coded)
q7	I eat late at night, within two hours before sleeping.
q8	I find it difficult to maintain a consistent exercise routine.
q9	I consume sugary beverages (e.g., soda or sweetened juices) frequently.
q10	I am concerned about gaining excess weight.

The analytical variables were ten statements rated on a four-point scale: 1 = strongly agree, 2 = agree, 3 = disagree, and 4 = strongly disagree. Items q2 and q6 were reverse-coded so that their direction was consistent with the obesity-risk orientation of the remaining behavioural items. Table 1 lists the instrument.

3.2 Analytical procedure

The analysis proceeded in four stages. First, the item-correlation matrix and variance inflation factors (VIFs) were examined to identify usable common variation and problematic redundancy.

Second, factorability was evaluated using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity [1, 12]. Third, communalities, eigenvalues, cumulative variation, and the scree pattern were assessed. Although the Kaiser greater-than-one rule pointed to two components, the scree elbow and substantive interpretability supported examination of three dimensions. Factor-retention decisions are best based on multiple forms of evidence rather than a single mechanical rule [6, 8].

Fourth, the retained solution was rotated separately using Varimax, Quartimax, Equamax, Promax, and direct Oblimin. Methods were compared by the concentration of salient item groupings, the extent of overlap, theoretical plausibility, and Tucker congruence. Because the indicators have four ordered categories, a polychoric correlation analysis would be a useful robustness check in a future reanalysis; ordinal estimators can outperform Pearson-correlation methods when category distributions are strongly non-normal [5]. The current report retains the correlation-based results supplied with the original study.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

3.3 Rotation methods

Let $\mathbf{A} = (a_{ij})$ denote the initial p×m loading matrix and let $\mathbf{L} = \mathbf{AT} = (\ell_{ij})$ denote a rotated loading matrix. Orthogonal rotations constrain $\mathbf{T}^{T}\mathbf{T} = \mathbf{I}$, so the factor axes remain perpendicular and factor correlations remain zero. Oblique rotations relax this condition and allow the factor-correlation matrix $\boldsymbol{\Phi}$ to contain nonzero off-diagonal elements. The criteria below are stated in unnormalized form; multiplying an objective by a positive constant does not change its optimum. Kaiser normalization may additionally be applied before rotation to prevent high-communality variables from dominating the criterion [2].

Varimax rotation. Varimax seeks factor simplicity by making the squared loadings within each factor as unequal as possible. The normalized criterion maximized over orthogonal transformations is

$$\mathrm{V}(\mathbf{L}) = \sum_{j=1}^{m}\left(\frac{1}{p}\sum_{i=1}^{p}L_{ij}^{4} - \left(\frac{1}{p}\sum_{i=1}^{p}L_{ij}^{2}\right)^{2}\right) \tag{3}$$

Thus, each factor tends to have a limited number of large loadings and many loadings close to zero, which simplifies interpretation of factor columns [11].

Quartimax rotation. Quartimax emphasizes variable simplicity rather than factor simplicity. It maximizes

$$\mathrm{Q}(\mathbf{L}) = \sum_{i=1}^{p}\sum_{j=1}^{m}1_{ij}^{4} \tag{4}$$

The criterion encourages each observed variable to load strongly on as few factors as possible. Because it simplifies rows of the loading matrix, Quartimax can sometimes produce a broad general factor on which many variables load [16].

Equamax rotation. The three orthogonal criteria can be expressed through the Orthomax family,

$$O_{\gamma}(\mathbf{L}) = \sum_{i=1}^{p}\sum_{j=1}^{m}1_{ij}^{4} - \frac{\gamma}{p}\sum_{j=1}^{m}\left(\sum_{i=1}^{p}1_{ij}^{2}\right)^{2} \tag{5}$$

Quartimax corresponds to $\gamma = 0$, Varimax to $\gamma = 1$, and Equamax to $\gamma = p/(2m)$. Consequently, the Equamax criterion may be written.

$$E(\mathbf{L}) = \sum_{i=1}^{p}\sum_{j=1}^{m}1_{ij}^{4} - \frac{1}{2m}\sum_{j=1}^{m}\left(\sum_{i=1}^{p}1_{ij}^{2}\right)^{2} \tag{6}$$

Equamax therefore balances the column simplification of Varimax with the row simplification of Quartimax [3].

Promax rotation. Promax is a computationally efficient oblique target rotation. It first obtains an orthogonally rotated loading matrix $\mathbf{V} = (v_{ij})$, usually by Varimax, and then constructs a sharpened target $\mathbf{P} = (p_{ij})$ using

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

$$p_{ij} = \frac{\left|v_{ij}\right|^{k+1}}{v_{ij}} = sign\left(v_{ij}\right)\left|v_{ij}\right|^{k+1}, \qquad k > 1 \tag{7}$$

with $p_{ij} = 0$ when $v_{ij} = 0$. A least-squares transformation is then fitted,

$$\hat{\mathbf{T}} = \left(\mathbf{V}'\mathbf{V}\right)^{-1}\mathbf{V}'\mathbf{P}, \qquad \mathbf{L}_p = \mathbf{V}\hat{\mathbf{T}}, \tag{8}$$

followed by conventional column rescaling. Larger values of the power k create a sharper target.

Because $\hat{\mathbf{T}}$ is not restricted to be orthogonal, the resulting factors may correlate [7].

Direct Oblimin rotation. Direct Oblimin searches directly for an oblique simple structure. A scalar form of the general oblimin criterion is

$$O_{\text{obl}}\left(\mathbf{L};\gamma\right) = \frac{1}{4}\sum_{j=1}^{m}\sum_{\substack{j=1\\ \mathrm{k}\neq\mathrm{j}}}^{m}\left[\sum_{i=1}^{p} l_{ij}^{2} l_{ik}^{2} - \frac{\gamma}{p}\left(\sum_{i=1}^{p} l_{ij}^{2}\right)\left(\sum_{i=1}^{p} l_{ik}^{2}\right)\right], \tag{9}$$

which is minimized over admissible oblique transformations. The parameter γ controls the form of the simplicity criterion; $\gamma = 0$ gives the direct Quartimin member commonly used as the default direct Oblimin solution. Unlike the orthogonal methods, the output includes a pattern matrix, a structure matrix, and factor correlations. The pattern matrix was treated as the primary basis for assigning items to factors [2, 9, 10].

4 RESULTS

4.1 Factorability and communalities

Moderate positive relationships were observed especially among q2, q3, q9, and q10. All VIFs were below 2, indicating that no item was an almost redundant linear combination of the others. The overall KMO value was 0.65, which is modest but adequate for an exploratory case study, and Bartlett's test was statistically significant. Together, these diagnostics reject an identity correlation structure and support a reduced representation, while the middling KMO cautions against overstating the stability of fine-grained loading differences. The highest reported communalities were for perceived unhealthy weight (q4 = 0.995) and regular fruit and vegetable consumption (q6 = 0.995). Difficulty maintaining exercise (q8 = 0.787) and concern about gaining weight (q10 = 0.659) were also well represented. Late-night eating (q7 = 0.086) and sedentary time (q5 = 0.167) had low communalities, suggesting that much of their variance was item-specific or not captured by the retained dimensions. These two items should therefore be interpreted cautiously and reconsidered in future instrument refinement.

4.2 Retained dimensions

Table 2 and Figure 1 reproduce the reported extraction profile. The first two dimensions accounted for 38.22% and 15.89%, respectively, for a cumulative 54.11%. The third contributed 10.77%, raising the reported cumulative variation to 64.88%. The clear decline after the first dimension, the smaller bend around the third, and the interpretability of a distinct weight-perception/healthy-diet grouping motivated retention of three factors for the rotation comparison.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

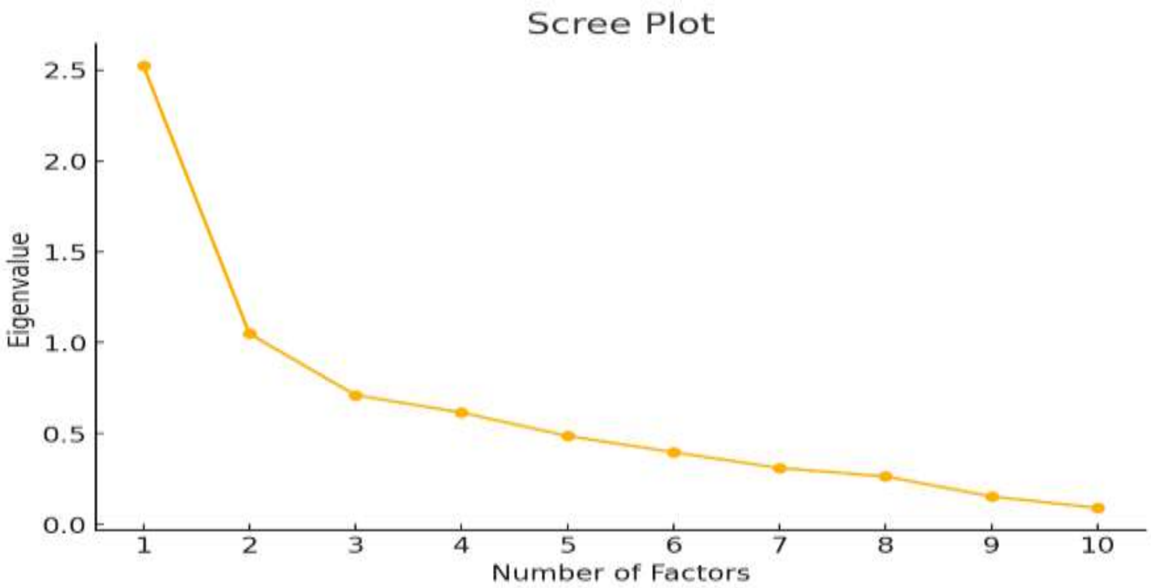

Figure 1: Scree profile for the ten questionnaire items.

Table 2: Reported eigenvalues and explained variation.

	Eigenvalue	Variation (%)	Cumulative (%)
1	2.523	38.22	38.22
2	1.049	15.89	54.11
3	0.711	10.77	64.88
4	0.616	9.33	74.21
5	0.487	7.38	81.59
6	0.397	6.01	87.60
7	0.310	4.70	92.30
8	0.264	4.00	96.30
9	0.154	2.33	98.63
10	0.090	1.36	99.99

4.3 Comparison of rotated structures

Table 3 summarizes the salient item groupings reported for each method. The first dimension was highly stable at the level of item membership: q1, q2, q3, q9, and q10 repeatedly clustered, linking fast-food and sugary-drink consumption, meal skipping, exercise orientation, and concern about weight gain. This dimension may be interpreted broadly as an unhealthy diet and weight-concern factor. The second grouping, q5 and q8, describes sedentary behaviour and exercise inconsistency.

Table 3: Comparative summary of the rotated factor structures.

Rotation	Factor 1	Factor 2	Factor 3	Interpretation of solution
Varimax	q1, q2, q3, q9, q10	q5, q8	q4, q6	Clearest orthogonal grouping
Quatimax	q1, q2, q3, q9, q10	q5, q8	Not clearly seperated	Greater overlap and stronger cross-loading tendency
Equamax	q1, q2, q3, q9, q10	q5, q8	Not clearly seperated	Balanced criterioum but residual ambiguity resembled Quartimax.
Promax	q1, q2, q3, q9, q10	q5, q8	q4, q6, q7	Clearest overall oblique interpretation; correlated factors permitted.
Oblimin	q1, q2, q3, q9, q10	q5, q8	Broadly similar to Promax	Plausible correlated solution with slightly overlap

Under the clearer three-factor solutions, q4 and q6 defined a third dimension combining weight perception and healthy dietary practice; q7 joined this grouping under Promax. Among orthogonal methods, Varimax provided the clearest separation. Quartimax concentrated variables but produced more overlap, and Equamax did not materially resolve that ambiguity. Both oblique methods accommodated the plausible dependence among dietary, activity, and perception-related constructs. Promax preserved the broad three-factor organization while sharpening its interpretation and avoiding the assumption that the dimensions were independent. Direct Oblimin produced a similar substantive pattern but with somewhat more overlap. The reported Tucker coefficient was $\phi = 0.72$. Since this value is below 0.85, the compared rotated structures cannot be regarded as equivalent under conventional guidance [13]. Thus, the choice of rotation had a meaningful effect on the representation of the item set. Considering simple structure, theoretical realism, and the placement of q7, Promax was selected as the preferred solution. Varimax remains a defensible alternative when independent factor scores are specifically required and independence can be justified.

5 DISCUSSION

The analysis demonstrates that rotation is a substantive modelling choice rather than a cosmetic final step. All five methods recovered a stable core involving q1, q2, q3, q9, and q10 and a smaller activity grouping involving q5 and q8. Their main difference concerned the separation and placement of q4, q6, and q7. Varimax organized q4 and q6 into a distinct independent dimension, whereas Promax included late-night eating and allowed the factors to correlate. For a behavioural survey, the latter structure is plausible because dietary routines, activity patterns, perceived body weight, and weight concern can coexist and interact within the same respondent.

The preference for Promax does not imply that oblique rotation is universally superior. If theory specifies independent constructs, or if estimated factor correlations are negligible, an orthogonal representation can be both useful and parsimonious. The present findings instead reinforce the recommendation that researchers

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inspect oblique solutions before imposing independence [4, 6]. When factor correlations are non-trivial, orthogonal rotation may redistribute shared variance into cross-loadings or alter the apparent meaning of the factors.The instrument also warrants refinement. The very low communality of q7 indicates that late-night eating was poorly represented despite its placement under Promax, and q5 was likewise weakly explained. These items may measure distinct behaviours, contain wording that does not align with the latent dimensions, or require additional companion items. By contrast, communalities near one for q4 and q6 deserve verification because unusually high values can indicate a near-Heywood condition, strong determinacy, or a reporting issue. Replication should report the complete pattern, structure, and factor-correlation matrices, confidence intervals or bootstrap stability measures, and the precise extraction method and convergence criteria. The three-factor decision also requires confirmation. Only two reported eigenvalues exceeded one, while the third factor was retained from the scree pattern and interpretability. Contemporary practice recommends parallel analysis or related simulation-based procedures rather than reliance on the eigenvalue-one rule alone [6, 8]. A polychoric correlation matrix is also advisable for four-category ordinal items [5]. These additions could determine whether the third dimension is reproducible or sample-specific. Spherical rotation component analysis and other nonlinear dimension-reduction methods have recently expanded the range of tools available for data with curved latent geometry [14, 15]. Such methods address a different problem from rotating a linear factor solution and should not be treated as interchangeable with Varimax or Promax. They may nevertheless be useful in future work if a larger and richer behavioural item set exhibits nonlinear structure.

5.1 Limitations

This case study is limited to one university, female students, ten self-reported items, and a moderate KMO value. Generalization to male students, other institutions, or clinical obesity outcomes may therefore not supported. The questionnaire captures obesity-related perceptions and behaviours; it does not establish obesity because no anthropometric measure such as body mass index was included in the analysed variables.

6 CONCLUSION

The female undergraduate obesity-risk questionnaire contained a factorable but only moderately compact correlation structure. A three-factor interpretation described unhealthy diet and weight concern, sedentary behaviour and exercise inconsistency, and weight perception/healthy dietary practice. Varimax yielded the clearest solution under an independence constraint, whereas Promax provided the strongest overall balance of clarity and behavioural realism by allowing the dimensions to correlate. The low reported congruence coefficient ($\phi = 0.72$) confirms that rotation choice materially affected the solution. Researchers should therefore compare theoretically plausible rotations, report complete matrices, and justify the final choice. Future work should refine weak items, use polychoric correlations and parallel analysis, collect anthropometric data, and replicate the structure in broader student samples.

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ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

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ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

Appendix A: Rotated Factor Loading Matrices

The following tables provide the complete loadings supplied for each rotation method. A dash indicates that no loading was displayed in the source matrix. The factor-column order (ML2, ML1, and ML3) is retained exactly as reported.

A1: Using the Varimax technique.

Item	ML2	ML1	ML3
q1	0.455	0.110	0.228
q2	0.574	–	0.137
q3	0.555	–	–
q4	–	–	0.586
q5	–	0.947	−0.305
q6	–	−0.112	0.354
q7	–	–	0.264
q8	–	0.303	0.121
q9	0.522	–	−0.190
q10	0.651	–	–

A2: Using the Quartimax technique.

Item	ML2	ML1	ML3
q1	0.445	–	0.262
q2	0.569	–	0.159
q3	0.558	–	–
q4	–	−0.119	0.576
q5	–	0.997	–
q6	–	−0.207	0.308
q7	–	–	0.268
q8	–	0.254	0.199
q9	0.526	–	−0.182
q10	0.653	–	–

A3: Using the Equamax technique.

Item	ML2	ML1	ML3
q1	0.441	–	0.268
q2	0.567	–	0.168
q3	0.558	–	–
q4	–	−0.115	0.576
q5	–	0.997	–
q6	–	−0.205	0.310
q7	–	–	0.269
q8	–	0.255	0.197
q9	0.528	–	−0.174
q10	0.654	–	–

A4: Using the Promax technique.

Item	ML2	ML1	ML3
q1	0.450	–	0.216
Q2	0.572	–	0.127
Q3	0.556	–	–
q4	–	–	0.585
q5	–	0.967	−0.378
q6	–	−0.129	0.364
q7	–	–	0.261
q8	–	0.299	–
q9	0.525	–	−0.194
q10	0.653	–	–

A5: Using the Oblimin technique.

Item	ML2	ML1	ML3
q1	0.439	–	0.264
q2	0.566	–	0.160
q3	0.559	–	–
q4	–	–	0.578
q5	–	0.996	–
q6	–	−0.174	0.308
q7	–	–	0.270
q8	–	0.279	0.205
q9	0.530	–	−0.183
q10	0.655	–	–