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USING A DETERMINATION COEFFICIENT AND RASCH MODEL TO INVESTIGATE NURSE- PATIENT RATIOS AMONG TAIWANESE HOSPITALS

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Abstract

Nurse- to- patient ratio is an important indicator of nursing quality. This paper investigates nurse- to- patient ratio in Taiwanese hospitals using a novel Rasch continuous model on Microsoft Excel developed by the authors. Data on nurse- to- patient ratios were obtained from 444 hospitals in 2015 from the Taiwanese Central Health Insurance Agency and the Ministry of Health and Welfare (CHIAMHW) and analyzed. Findings indicated that (1) the minimal determination coefficient (=0.71) among hospital levels is attributable to the respective medical centers, (2) while 21 hospitals met the criterion of 9 patients per nurse set by the Taiwan Joint Commission on Hospital Accreditation (TJCHA), one hospital did not meet the criterion, (3) two hospitals in medical centers were shown to be significantly unstable (i.e., outfit mean square error greater than 2.0), and (4) improvements were made from 2007 to 2015. Results further indicated that the model used in this study is practical and useful for detecting organizational performances within hospitals. This online model and the visual Google Maps presentation have rarely been used in prior literature.

Keywords: Nurse- to- patient ratio, Medical center, Hospital level, Coefficient of

determination, Item response theory

Introduction

A popular Chinese proverb states "there is no radius without a standard," meaning that a criterion is required in order to achieve a goal. The shortage of nurses in the workforce has become a global issue (International Council of Nursing, 2007). Prior research has shown that nursing workforce allocation can directly affect patient safety and care quality (Dembe, Delbos, & Erickson, 2009; Su, Liu, & Su, 2010) and is significantly related to patient-care outcomes (Carayon & Gu¨ rses, 2005; Hugonnet, Chevrolet, & Pittet, 2007; Stone et al., 2007). It may be the case that no criterion has been set by the government for making improvements on nursing workforce allocation in healthcare facilities.

Lack of nurses may increase medical incidents due to negligence. These incidents include infection, death, fall, medication errors, tube dislodgement, physical restraints, and pressure sores (Dunton, Gajewski, Taunton, & Moore, 2004; Rafferty et al., 2007). Nurses responsible for an excessive number of patients may experience increased work- related stress, which has been identified as a key factor that leads to increased nurse turnover. Furthermore, nursing work overload may prolong patient hospitalization, increase patient morbidity and mortality, and increase the incidence of adverse events (Aiken, Clarke, Sloane, Sochalski, & Silber, 2002; Lu, 2008). Based on the above, it is important to determine the optimal criterion of a nursing workforce allocation ratio for Taiwan's acute care general nursing wards (Lin, Huang, Lu, 2013).

The term "nurse- to- patient ratio" is defined as the average number of patients cared for by one nurse per day. For instance, 1:9 stands for nine daily patients per nurse. The formula for nurse- to- patient ratio is calculated as the number of a hospital beds × average bed occupancy rate in a month × 3 ÷ the number of nurses serviced in a day, in which the head nurse and nurses working eight hours a day are both included but specialist nurses and practice intern nurses are not included. The higher the ratio, the higher the possibility of increased patient morbidity and mortality care due to insufficient nursing workforce allocation.

Taiwanese nurses were reportedly serving considerably more patients than nurses in other developed countries (i.e. in 2007, 1:13 vs. 1:6) (California Nurses Association, 2007; Goo, Lin- Wang, & Lu, 2007; Hou, 2010; Victorian Public Health Sector, 2007), with the nurse- to - patient ratio in Taiwan being about 2.0 to 2.5 times higher than the international average. As a result of the above statistics, the Taiwan Joint Commission on Hospital Accreditation (TJCHA) specified a guide for nurse- to- patient ratios in 2014 for each type of hospital classification in order to improve the quality of care in Taiwanese hospitals. These ratios were set as 1:12 for academic medical centers, 1:12 for metropolitan hospitals, and 1:15 for local community hospitals.

On July 20, 2016 the Taiwan Ministry of Health and Welfare (TMOHW) released all hospitals' average daily nurse- to- patient ratios since 2015 (TMOHW, 2016). We were interested in collecting and analyzing those released data and determining whether any improvements in hospital nurse- to- patient ratios were made from 2007 to 2015, as well as whether any aberrant patterns in data consistency of nurse- to- patient ratios can be found using modern statistical techniques.

Using these data, this study has several aims: (1) To screen out the most aberrant pattern in hospital classification on data consistency of nurse- to- patient ratios with the minimal determination coefficient (i.e., R square stands for the ratio explained by the variance), (2) to count the number of hospitals by type that are meeting the required nurse- to - patient ratio due to insufficient nursing workforce allocation, (3) to explore the least reliable hospitals with aberrantly unstable response patterns by type, and (4) to evaluate the improvement in nurse- to- patient ratios made from 2007 to 2015.

Data Sources

We downloaded nurse- to- patient ratio data from 2015 for 479 hospitals, including 22 academic medical centers, 4 children's hospitals affiliated with academic medical centers, 91 metropolitan hospitals, and 362 local community hospitals from the Central Health Insurance Agency, Ministry of Health and Welfare (CHIAMHW, 2016) in Taiwan. After removing those hospitals with missing values (including one metropolitan hospital and 34 local community hospitals), a total of 444 hospitals were recruited for analysis in this study.

Methods

Measurement indicators

We applied a Rasch (1960) continuous model (Chien, Shao, 2016) to the downloaded data of 12- month nurse- to- patient ratios for computing (1) hospital estimated measures (i.e., ability in latent trait scores) in a log-odds logit unit. Because of the specific objectivity feature of the Rasch model, we adopted the original raw scores of nurse- to- patient ratios as the vertical axis to draw the scatter plot, and used the interval logit measures to compare differences among hospital classifications; (2) determination coefficients through the formula of $R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$, where $SSE = \sum_{n=1}^{N}\sum_{i=1}^{L}(Y_{ni} - E_{ni})^2$, $SST = \sum_{n=1}^{N}\sum_{i=1}^{L}(Y_{ni} - \bar{Y})^2$, Y is the observed nurse- to- patient ratio, E is the model expected values, $\bar{Y}$ is the mean of all Y_{ni}, SSR is the sum squared regression, N is the number of hospitals, and L is the length of items (i.e., months in this study); and (3) far-away- from- stability indicators using the Rasch person outfit mean square errors (MNSQ)(= $[\sum_{i-1}^{L}(Y_{ni} - E_{ni})^2 * SE_{ni}^2]/L$), where SE is the person estimated standard error

(= $\sqrt{1/\sum_{i=1}^{L} Variance_{ni}}$). We adopted the far- away- from- stability indicators as the vertical horizontal axis to draw the scatter plot. In addition, a circle with a 95% confidence interval referring to the two axes is drawn on the scatter plot to identify the outliers in the above selected hospital classification with a minimal determination coefficient.

Statistical analysis

We use the author- designed computer Rasch continuous model in Microsoft Excel (Chien, Shao, 2016) using VBA (Visual Basic For Application) to do the following: (1) estimate hospital logit measures of nurse- to- patient ratio, (2) compute determination coefficients for each hospital classification, (3) calculate far- away- from- stability indicators for each hospital in the selected hospital classification, and (4) draw the control- type scatter plot and the item- person map for determining data fitting to the Rasch unidimensionality requirement when all items' Infit MNSQ (= $\sum_{i-1}^{L}(Y_{ni}-E_{ni})^2/\sum_{i-1}^{L} Variacne_{ni}$) are less than 1.5 (Bond, Fox, 2001).

The other two coefficients are incorporated with determination coefficients to identify the quality and consistency of data. The dimension coefficient (DC, Chien, 2012) ranging from 0 to 1.0 indicates the strength toward unidimensionality with a formula: DC=Z / (1+Z) , where Z= (a1/a2) / (a2/a3) , a1 is the first eigenvalue of raw scores, a2 is the second, and a3 is the third. Cronbach's alpha represents the scale's internal consistency reliability: the higher, the better.

Results

The minimal logit measure (i.e., better nurse- to- patient ratios) refers to children's hospitals affiliated with academic medical centers (=0.08). The maximum measure comes from the local community hospitals (=1.28). The odds ratio between local community hospitals and academic medical centers is 3.29 (=exp (1.28- 0.09)), indicating the nurse- to- patient ratios in academic medical centers are 3.29 times higher than those in local community hospitals.

The number of iterations for estimating model parameters increases with the data size (see Table 1). The minimal determination coefficient as well as DC and Cronbach's alpha are all attributable to academic medical centers (=0.71), indicating the most misfit to the Rasch model's expectation and that some hospitals exhibit aberrant behavior and substantially differ from other hospitals in the response pattern of nurse- to- patient ratios across months.

The Rasch item- person map (hospitals on left and months on right) for academic medical centers is shown in Figure 1, indicating the most difficult month (i.e., with a few values in nurse- to- patient ratio possibly due to lower bed occupancy rates during the Chinese New Year) is February (=0.37 logits) and that the he easiest month is April (=- 0.22 logits with a high ratio of nurse to patient). All the months' Infit MNSQs are less than 1.5, indicating that the data of academic medical centers still form a single dimension even with a low determination coefficient (=0.71).

The mean of measures in academic medical centers is 1.71 logits when the mean of difficulties in months is set at zero. The log odds is 8.41 (=exp (3.38- 1.25)) between the highest and the lowest (see the left-hand side in Figure 1).

We use both indicators of far- away- from- stability and average nurse- to- patient ratios in the last two columns of Table 2 to draw a control-type scatter plot (see Figure 2), indicating that three hospitals are outliers outside the controlling circle. These outliers are in need of further inspection and improving either the high value of nurse- to- patient ratio or the far- away- from- stability indicator beyond the criterion of 2.0 (Linacre, 2002).

The Z- scores (model residual*SE=model residual/SD in each cell) in Table 2 imply the goodness- of- fit of model data. A value greater than 2.0 indicates a significantly high nurse- to- patient ratio ($p< .05$), while a lower nurse- to - patient ratio is found when the value is less than - 2.0 ($p< .05$). For instance, the Z- score of - 5.34 exhibits an aberrant interaction on hospital 10 in January when the observed nurse- to- patient ratio was 1:6, obviously lower than the average in academic medical centers. We also see the cells interacted in September and October with significantly high values to produce a high far- away- from- stability indicator of 3.92, indicating that

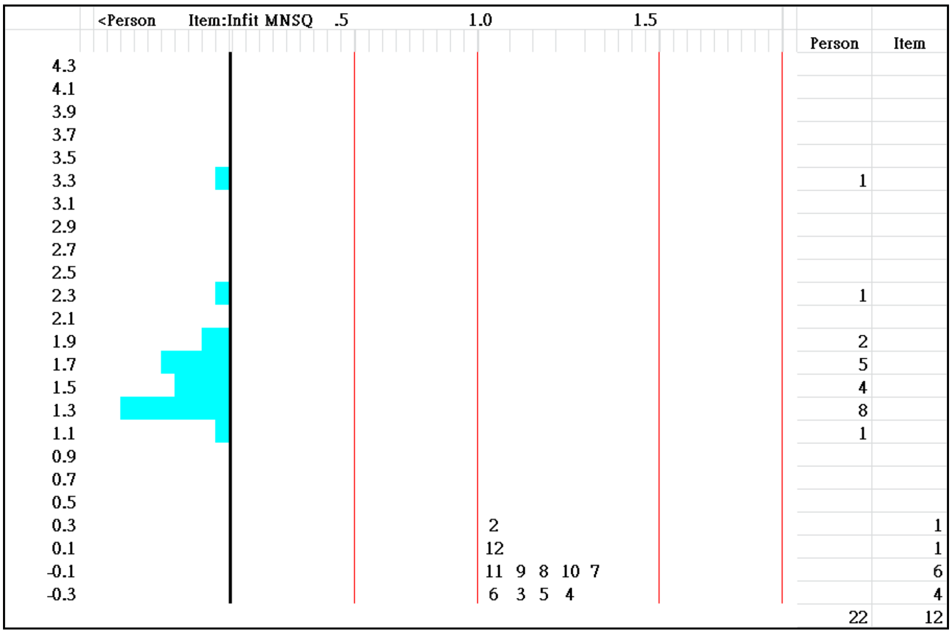


Figure 1. Rasch item- person map

Table 1. Coefficients across hospital classifications

Classification	n	Logit	Iteration	R- square	DF	Alpha	Selected
Overall	444	1.00	6	0.91	0.95	0.99	
Medical Centers	22	0.09	5	0.71	0.67	0.96	√
Children (MC)	4	0.08	5	0.96	0.86	0.99	
Region H.	90	0.26	5	0.94	0.95	0.99	
Local H.	328	1.28	6	0.91	0.95	0.99	

hospital 10 showed a low prediction in ratios of nurse to patient. Due to a typographical error, unstable bed occupancy rate, and fluctuations in nurse manpower supply, further investigation is required.

Traditionally, we use standard deviation (SD) to describe deviation from the mean. Three indicators (mean, SD, and far- away- from- stability) are simultaneously shown in Figure 3. We see that two hospitals are outliers beyond the 1:9 ratio of nurse-to- patient. The SD = ($\sum_{i-1}^{L}(Y_i - \bar{Y})^2$ /(L-1) is calculated from specified individual data for 12 months, and the stability (i.e., standardized residual score) indicator is calculated from data of all other hospitals. That is why the similarity exists in SD and stability, but they are still somewhat different (see Figure 3). We found the lowest three far- away- from stability indicators are derived from hospitals 20, 17, and 5, respectively.

Performances based on either the mean or fit statistics can be shown on website using the clock- type plot on Google Maps; the wider the line, the worse the performance. Interested readers are invited to see the details in the appendix files 1 and 2.

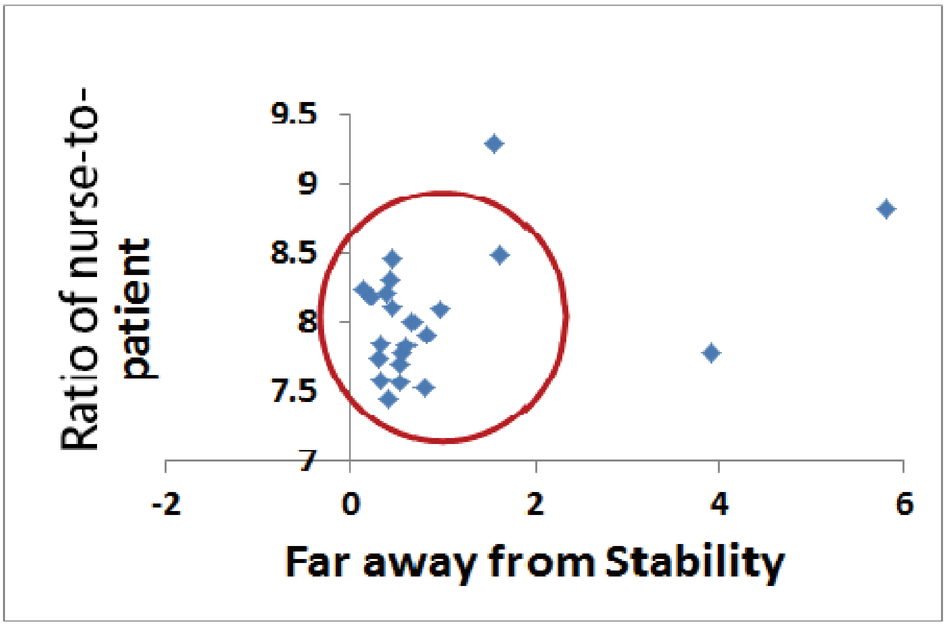
Discussion and Conclusion

The results provide a number of novel findings: (1) the minimal determination coefficient (=0.71) among hospital levels is attributable to medical centers, (2) one hospital within a medical center did not meet the criterion (i.e., 9 patients per nurse) set by the Taiwan Joint Commission on Hospital Accreditation (TJHCA) while the other 21 hospital met the criterion, (3) two hospitals in medical centers are shown to be the most significantly unstable (i.e., outfit mean square error greater than 2.0), and (4) improvement was made from 2007 to 2015.

The determination coefficient (i.e., R- square) is associated with the ratio of variance explained by the model predication using the formula $R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$. In the Rasch model, we manually calculate SST with the formula(= $\sum_{n=1}^{N}\sum_{i=1}^{L}(Y_{ni} - \bar{Y})^2$) and SSE(= $\sum_{n=1}^{N}\sum_{i=1}^{L}(Y_{ni} - E_{ni})^2$) to screen out the minimal R- square for investigation. Furthermore, the far- away- from- stability indicator yielded by both item (month) difficulties and person (hospital) abilities is more sophisticated than the traditional SD used for detecting data instability (Wang, 2010). Many researchers (Linacre, 2001; Mellenbergh, 1994; Müller, 1987; Ferrando, 2001; Samejima, 1973/1974; Wang, Zeng, 1998) have devoted their efforts to developing continuous item response models similar to the model used in this study for detecting misfit items (on the left panel in Figure 1) and persons (on the horizontal axis in Figure 2) using the model's fit statistics.

Hospital data for nurse- to- patient ratios released by the Taiwanese government was used in the analysis and surprisingly found that the category of academic medical centers suffers the

Figure 2. Scatter plot for detecting outlier subjects



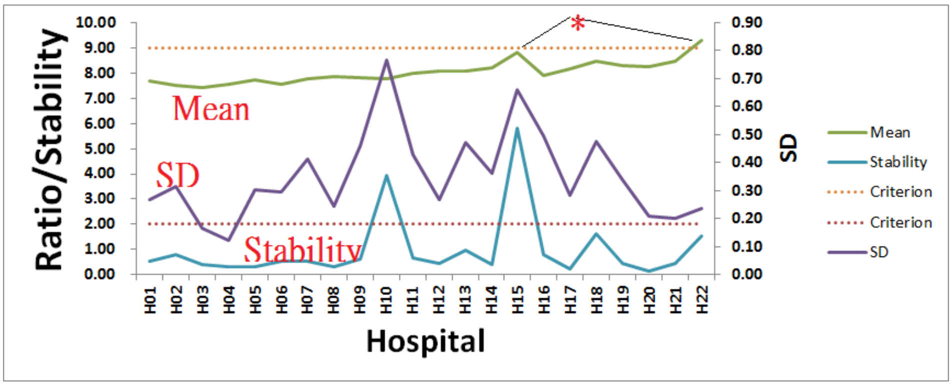


Figure 3. Comparison of indicators of SD and far- away- from stability

lowest determination coefficient (=0.71). The results showed that hospitals with a higher level of classification should gain a higher bed occupancy rate, lower nurse turnover rate, and have a better fitting data model than hospitals with lower classification levels, such as metropolitan local community hospitals.

The overall acute hospital nurse to patient ratio has decreased in Taiwan from 1:1.13 (SD=3.09, this study) in 2007 to 1:8.39 in 2015 (California Nurses Association, 2007; Goo, Lin-Wang, & Lu, 2007; Hou, 2010; Victorian Public Health Sector, 2007). The individual hospital classifications also show them reaching the minimum criteria for hospital accreditation in nurse-to- patient ratios: 8.04<9.0 for academic medical centers, 1:9.45<1:12 for metropolitan hospitals and 8.13<15 for local community hospitals.

There are several components of this study that should be highlighted that separate this study from previous literature. First, graphical presentations such as those seen in Figures 1, 2, and 3 show more informative messages (especially with the far- away- from-stability indicators) to readers than the traditional methods using monochromatic- type tables.

Second, both coefficients of determination and dimension in Table 1, which are more sensitive than Cronbach's alpha, clearly reveal the quality and consistency of the data. Researchers seldom use these two coefficients in social science literature. These two coefficients were calculated manually and applied to evaluate the structure and consistency of the data quality.

Before conducting any statistical analyses, data had to be confirmed as useful, correct, linear, interval, and can be summed in accordance with the measurement principle. Rasch analysis is a novel way to help meet this measurement premise and reach accurate, precise, and reliable analytic results (Bond, Fox, 2001; Wang, 2010) (see Figure 1). In addition, there were many continuous variables across months of analysis in this study, such as quality clinical treatment and service indicators, accounting costs in divisions and departments, reasonable outpatient visitors consulted by a physician, hospital indicators of a balanced score card, and other operational items in hospital internal flows. Modern statistical techniques based on the item response theory should be used on all of these variables to detect data- model fits across items and persons and to ensure high enough data quality to merit further inspection.

Third, we demonstrate the scatter plot with a circle of 95% confidence interval using trigonometric functions to show the least stable hospital with respect to nurse to patient ratios (see Figure 2) (Chien, 2015). The model developed in this study, like Youden plot (Youden, 1959), can be more informative than the traditional scatter plot without the control circle.

In summary, this study is practical and useful in detecting organizational performances. The online model at http://www.healthup.org.tw/kpiall/raschcontinous_st.asp and the visual presentation on Google Maps at http://www.healthup.org.tw/gps/reliabilitymurse.htm are provided for readers; these have rarely been seen in past publications. Finally, the variable map used for showing the hospital performances is suitable and for innovative administrators in the future.

Table 2. Z- score, and indicators of stability and logit measure across months

Hospital	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Stability	Logit
H01	0.44	2.09	-0.31	-0.38	-0.36	0.09	0.54	-0.27	-0.24	-0.59	-0.52	-0.77	0.55	1.40
H02	0.33	1.79	-0.16	0.06	-0.21	- 0.9	-1.77	- 0.6	- 0.3	0.98	0.78	-0.27	0.79	1.30
H03	-0.28	1.77	-0.24	- 0.6	-0.29	-0.67	-0.16	- 0.1	-0.33	-0.41	0.47	0.49	0.41	1.25
H04	0.19	1.14	-0.29	-0.66	-0.94	-0.76	-0.26	0.07	-0.17	0.3	0.37	0.65	0.34	1.33
H05	-0.54	-0.63	-0.42	-0.49	-0.47	-0.03	0.43	-0.11	-0.36	0.69	0.76	1.02	0.31	1.43
H06	-1.16	0.43	-1.73	-0.02	0.01	0.73	0.34	0.66	0.42	- 0.2	- 0.4	0.7	0.54	1.32
H07	0.23	-1.78	-0.52	-0.59	-0.26	-0.12	0.05	-0.21	0.38	0.88	0.95	0.93	0.55	1.45
H08	0.91	1.13	- 0.1	0.15	-	-	-	-	0.17	-	- 0.7	0.43	0.33	1.50

					0.47	0.34	0.47	0.15		0.77				
H09	1.54	-0.4	0.57	0.51	0.53	0.01	0.76	-0.67	-0.36	-0.72	-1.5	-0.08	0.61	1.49
H10	**-5.34***	-1.55	0.39	1.26	-0.28	-1.35	0.02	0.05	**2.06***	**2.28***	1.49	0.91	3.92	1.46
H11	0.16	-1.83	-1.21	0.04	-0.28	0.77	0.87	1.14	0.27	-0.39	0.57	-0.06	0.68	1.62
H12	0.8	1.41	0.15	0.09	0.11	-0.49	-0.68	-0.99	-0.04	0.5	-0.96	-0.08	0.46	1.70
H13	0.82	-0.79	0.85	-0.22	0.13	0.19	0.29	0.57	-1.54	0.84	1.2	**-2.14***	0.97	1.69
H14	-0.83	-0.67	0.53	-0.23	1.19	0.84	-0.4	0.2	-0.71	0.16	0.54	-0.45	0.40	1.78
H15	**2.76***	1.35	**2.9***	1.51	1.97	-0.01	-0.95	0.51	1.74	**-3.98***	**-3.9***	**-3.22***	5.80	2.43
H16	-0.75	**-2.53***	0.05	-0.33	0.01	0.42	0.25	0.83	0.86	-0.08	0.57	0.83	0.81	1.56
H17	-0.09	-0.57	-0.09	-0.15	-0.14	-0.09	0.32	0.91	0.93	-0.38	-0.63	-0.06	0.23	1.76
H18	1.72	0.36	1.22	1.18	1.19	0.37	0.72	-1.12	**-2.82***	-1.16	-0.4	-0.84	1.62	2.04
H19	-0.81	-1.32	-0.82	0.21	0.22	0.93	0.62	-0.1	-0.08	0.18	0.25	0.8	0.43	1.86
H20	0.4	0.68	0.11	0.05	-0.29	0.43	-0.81	-0.2	0.15	-0.24	-0.17	-0.23	0.15	1.81
H21	0.01	-0.16	-0.61	-0.67	-0.66	-0.29	-0.61	-0.68	0.37	0.66	1.06	1.26	0.46	2.01
H22	1.33	-0.28	1.8	-0.33	0.39	1.22	1.36	0.23	-0.98	0.21	**-2.21***	**-2.02***	1.56	3.38

Note: * |Z- score| > 2 is equivalent to $p < .05$.

Appendix

File 1: the clock- type performance for the mean
http://www.healthup.org.tw/gps/reliabilitynurse.htm

File 2: the clock- type performance for the fit statistics
http://www.healthup.org.tw/gps/reliabilitynurse2.htm

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