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Applying the Rasch measurement to explore elderly passengers' abilities and difficulties when using buses in Taipei

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SUMMARY

This study developed an approach for measuring elderly passengers' abilities and to explore their difficulties in accomplishing the actions and motions required to patronize the bus service. A conceptual framework about the required actions and motions in bus-taking was established and a questionnaire with 18 items was designed to test their ability to use buses. A face-to-face survey was conducted to collect self-rated information from 304 elderly bus passengers in Taipei. The Rasch model was applied to estimate the difficulty of each item and the ability of each person to use a bus. Results showed the relatively difficult items primarily involved keeping balance on the moving bus, reading the posted information at the station, and recognizing the buses approaching the stations; the levels of physical ability were negatively associated with the respondent's age. Suggestions are made based on improving the facilities or services to help the elderly passengers achieve the necessary actions or motions for using the bus service.

KEY WORDS: elderly bus passenger; physical ability; latent construct; Rasch analysis

1. INTRODUCTION

Aging populations are occurring in most developed countries. In these aging societies, it has been found that senior people (over 65 years of age) increasingly participate in some outdoor activities in order to maintain their social connections and receive emotional feedback [1]. However, the demand for outdoor activities might not be fulfilled because travel options are somehow constrained. Golob [2] found that non-home activities of elderly people and the total time spent on traveling are negatively associated with their age. About 21% of Americans over 65 years of age do not drive and more than one-half of these non-drivers over 65 years of age (i.e., approximately 3.6 million Americans) stay at home all day, partially due to a lack of transportation options [3]. A decrease in physical ability might be the main reason that the travel options of elderly people are limited and they are deterred from using the road to some degree [4]. Increased age is associated with a decline in some physical abilities such as perceptual mechanisms (i.e., vision and hearing), cognitive performance (i.e., memory and attention), and physical strength (i.e., balancing and clutching). Limitations on physical abilities force the elderly to make some changes in their transportation mode choices.

Rosenbloom [5] found that as the age of the elderly traveler increased, traveling as a passenger increased significantly and making trips as a driver decreased [6]. Chang and Wu [7] also showed that as the elderly traveler became older, they tended to select more conservative ways to travel, such as taking buses or taxis, or hitching rides with their family members or friends [8]. Traveling by bus avoids negotiating traffic directly, which reduces a large proportion of the potential risk of accidents for elderly travelers [9]. However, traveling by bus is more economical than by taxi; it also enables the

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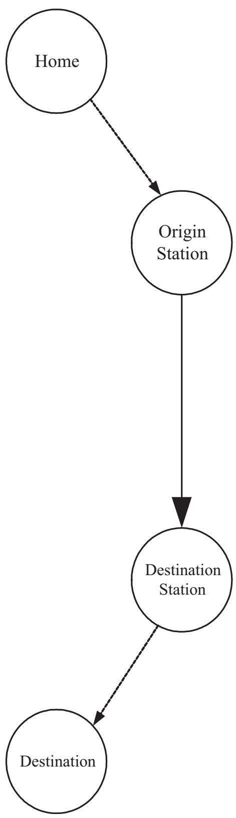
elderly to travel independently without inconveniencing others or coordinating with another person's trips. Traveling by bus is therefore quite appropriate for the elderly, especially for younger elderly people (i.e., 65–75 years of age) who might participate in outdoor activities on a frequent basis.

Elderly people, hampered by some forms of physical disability, might also encounter some difficulties in necessary actions or motions when taking buses. If elderly people's difficulties in these necessary actions or motions for bus-taking can be measured, the traffic authorities or bus service providers can then issue instructions or enhance the facilities or services to provide the elderly with a safer and user-friendlier environment according to their needs. This study aimed to develop an approach to measure the elderly passengers' ability of taking buses and explored the possible difficulties they faced along their bus-taking trips. A conceptualized framework for the actions and motions required for bus-taking was first established, and a questionnaire was then designed to collect the required data to evaluate the relative difficulties of these required actions or motions. With an empirical exploration conducted on elderly bus passengers from Taipei, the results of this study have introduced a new approach to identify elderly bus passengers' difficulties in bus-taking; it is expected that the results of this study will be shared with other transportation authorities worldwide who are making an effort to provide safer and user-friendlier travel options for the elderly.

2. ABILITY AND DIFFICULTY OF ELDERLY PASSENGERS TO USE BUSES

Even though elderly bus passengers need not deal directly with complicated traffic; they still have to maintain some physical abilities in order to travel by bus. In other words, if driving an automobile on the road is considered to be a tough test for elderly travelers to coordinate the vehicle and traffic conditions with human factors, then taking buses might be regarded as a relative easy test for them in terms of the necessary actions or motions in approaching the bus stations, traveling on the routes, and approaching the destination. Based on the required actions or motions on a bus trip, 18 items were conceptually collected and are shown in Figure 1 for the discussion to follow.



Approaching the stations:
1. walking independently to the station
2. reading the information posted at the station
3. discerning the approaching buses
4. beckoning the bus

Traveling on the route
5. stepping onto the bus
6. purchasing the ticket
7. moving to the seat on the bus when it starts to move
8. maintaining balance while seated on the moving bus
9. maintaining balance while standing on the moving bus
10. maintaining balance while standing when the bus is accelerating or decelerating
11. being aware of the location and direction along the route
12. being aware of the approaching destination station
13. informing the driver and preparing to leave the bus
14. stepping down from the bus

Approaching the destination
15. knowing the route to the destination
16. knowing the bus service information for the return trip
17. walking independently to the destination
18. finding the location of station for return trip

Figure 1. A conceptual framework for the required actions or motions when using buses.

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As shown in Figure 1, items in the course of bus-taking can be simply divided into three stages. Within the stage of approaching the station, four items need to be achieved: (1) ‘‘walking independently to the station,’’ (2) ‘‘reading the information posted at the station,’’ (3) ‘‘discerning the approaching buses,’’ and (4) ‘‘beckoning the bus.’’ Items with the stage of approaching the station would mainly demand elderly passengers’ physical strength and visual abilities. Previous studies have shown that elderly people have approximately 12–15% less muscle strength than young people [10,11]. Arthritis also commonly occurs in the elderly population [12]. Muscle strength influences the elderly people’s ability to walk independently to the station. Older people also tend to have a smaller useful field of vision than younger people [13], and the gradual degradation of ocular muscles influence their ability to focus on objects at a distance or under poor lighting conditions. As a result, poor visual ability is expected to lessen the elderly passengers’ ability to read the information at the station and discern the approaching buses; moreover, poor visual ability might deter them from signaling to the approaching bus drivers.

At the stage of traveling on the route, the elderly travelers might encounter the following 10 items: (1) ‘‘stepping onto the bus,’’ (2) ‘‘purchasing the ticket,’’ (3) ‘‘moving to the seat on the bus when it starts to move,’’ (4) ‘‘maintaining balance on the seat when the bus is moving,’’ (5) ‘‘maintaining balance while standing on the moving bus,’’ (6) ‘‘maintaining balance while standing when the bus is accelerating or decelerating,’’ (7) ‘‘realizing the location and direction along the route,’’ (8) ‘‘being aware of the approaching destination station,’’ (9) ‘‘informing the driver and preparing to leave the bus,’’ and (10) ‘‘stepping down from the bus.’’ These 10 items will require physical strength, cognitive abilities, and sense of direction [14] from the elderly passengers. It has been shown that the speed of contraction and coordination of muscles in the elderly are significantly slower than young people [10], which may influence in the ability of the elderly to step up and down from the vehicles. Joint flexibility declines by nearly 25% in older adults [15], which may decrease their ability to maintain their balance on moving buses. It has been found that the general cognitive ability of an elderly person worsens [16], reaction times become longer [17], and the ability to navigate is reduced secondary to the loss of cognitive abilities [18].

When approaching the destination, another four possible items arise: (1) ‘‘being aware of the route to the destination,’’ (2) ‘‘determining the bus service information necessary for the return trip,’’ (3) ‘‘walking independently to the destination,’’ and (4) ‘‘finding the location of the station for the return trip.’’ These four items will demand the physical abilities of the elderly to gain access to the final destination and to prepare the necessary information for the return journey. Such physical abilities are also related to visual abilities, cognitive abilities, and physical strength, as already discussed.

3. APPROACH FOR MEASURING THE RELATIVE DIFFICULTY OF ITEMS AND PERSONAL PHYSICAL ABILITY

Without support from existing techniques and standard scales for measuring such an issue, this study started by designing a self-rated questionnaire to collect the subjective opinion of the elderly regarding their performance on taking buses. Such an opinion is a latent trait of each elderly passenger’s generalized evaluation on achieving the necessary actions and motions for bus-taking. In order to ensure the validity of the material collected and the precision of the measures estimated, we first considered how to gather the necessary information and designed a measuring tool to evaluate the relative difficulty of each item and the relative physical ability of each elderly passenger in this section.

3.1. Questionnaire design for gathering the latent information

Latent traits are commonly explored by means of questionnaires that include appropriate items that the respondents can answer based on their daily experience. Since there was no available questionnaire to follow, we had to design our own questionnaire for this study. Essentially, considering the procedures of taking buses as a physical ability test for elderly passengers, the necessary actions and motions can thus be considered as the items in the test. Personal responses to these items can be used as a tool to reflect the elderly passengers’ evaluation on their own physical ability to use buses.

A well-designed questionnaire should also provide an opportunity for respondents to express the strength of their feelings or judgments about the items referred to. Therefore, it has been suggested that

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the questions designed to measure the latent trait should be answered on an ordinal scale, with several categories representing the respondent's possible levels of judgment. Such an ordinal data design helps to instruct the respondents to answer their most likely considerations. However, as it violates the property of additivity, ordinal data has limitations in statistical inference. Thus, a special technique is applied to transfer these ordinal responses into values on an interval scale so that they can be used to provide a comparative basis for further discussion.

3.2. Measuring physical ability and item difficulty considered by the elderly passengers

Presumably, every elderly passenger, n, has a unique value of his/her physical ability, θ_n, to take the bus, which is the personal parameter to be measured. Such a latent trait can be revealed by the elderly passenger's answers to the designed items. That is, elderly travelers who have higher physical abilities for using the bus will respond with high scores (i.e., relatively easy to accomplish) on a greater number of items than will those with lower physical abilities. In addition, items in the questionnaire represent the necessary actions or motions that the elderly passengers need to achieve during bus travel. Some items might be easy, but others might be difficult to achieve, thus we can consider that there is a unique item difficulty value, b_i (the item parameter), for item, i, in this study. Items with higher difficulty values are considered to be harder for elderly passengers to achieve. Such items might be potential obstacles in using buses for elderly people and need to be improved.

Like the common knowledge in an educational test, it is apparent that the difference between the person parameter, θ_n, and the item parameter, b_i, will determine the response of traveler, n, in considering his/her own performance on item, i. This observed response could then be formulated as a probability function determined by the value of $\theta_n - b_i$. Furthermore, in order to provide a basis for comparison, both the person and item parameters must be measured on a consistent interval scale.

All the elderly passengers' responses to the questionnaire were collected on an ordinal scale. To obtain a precise statistical inference, a mathematical technique to convert these ordinal raw data into the values on an interval scale was needed. Thus, we chose the Rasch measurement model [19] to meet the goals of this study. A brief introduction to the Rasch model is given below.

3.3. An introduction to the Rasch model

The Rasch model has been intensively used to estimate values on an interval scale from raw ordinal responses in psychometric studies [20,21]. To simplify our introduction of the Rasch model, we shall consider only the dichotomous responses to begin with. The questions are assumed to be the type of "Can you easily achieve the following necessary action or motion?" The response is either "yes" or "no." A score of 1 is assigned to an item to which the traveler responds "yes, I can," otherwise, a score of 0 is assigned. The probability that an elderly passenger, n, will respond with "yes, I can" for item, i, is expressed as

$$P(1|\theta_n, b_i) = \frac{e^{\theta_n - b_i}}{1 + e^{\theta_n - b_i}} \tag{1}$$

and the probability that an elderly passenger, n, will respond with "no, I can't" for item, i, is then expressed as

$$P(0|\theta_n, b_i) = 1 - P(0|\theta_n, b_i) = \frac{1}{1 + e^{\theta_n - b_i}} \tag{2}$$

Therefore, the odds ratio that an elderly passenger, n, can achieve item, i, is

$$\frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = e^{\theta_n - b_i} \tag{3}$$

and the logarithm of the odds ratio, known as the "logit," is

$$\ln \frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = \theta_n - b_i \tag{4}$$

which isolates the parameters of interest.

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The person and item parameters in the case of dichotomous responses can be estimated from the response odds ratio in the data set using the formulation of Equation (4). In addition to dichotomous responses, the Rasch model has been modified to be applicable to polytomous rating scale instruments such as the five-point Likert scale [22,23]. The modified Rasch model decomposes a polytomous response into several dichotomous responses and formulates one multinomial choice problem into several binary choice problems. That is, it assigns b_{ik} as the value of the item parameter for the rating category, k, to item, i, and assumes that Equation (1) refers to the probability of subject, n, responding with rating category, k, rather than $k-1$ to item, i. In other words, we can model the log odds of the probability that a person responds in category, k, for item, i, compared with category, $k-1$, as a linear function of the person parameter, θ_n, and the relative parameter of category, k, namely b_{ik}, for item, i

$$\ln\left(\frac{P_{nik}}{P_{ni(k-1)}}\right) = \theta_n - b_{ik} \tag{5}$$

Following Andrich's modification of the Rasch model for a polytomous response, two types of formulation are widely applied in assessing the values of item and person parameters, namely the "rating scale model" and the "partial credit model." The rating scale model is used only for instruments in which the definition of the rating scale is the same for all items, while the partial credit model is used when the definition of the rating scale differs from one item to another. Specifically, the partial credit model is similar to the rating scale model except that each item, i, has its own threshold parameters, F_{ik}, for each category, k [24]. This is achieved by a reparameterization of Equation (5)

$$b_{ik} = b_i + F_{ik} \tag{6}$$

and the partial credit model becomes

$$\ln\left(\frac{P_{nik}}{P_{ni(k-1)}}\right) = \theta_n - b_i - F_{ik} \tag{7}$$

The partial credit model, developed by Masters [23], is a unidimensional latent trait model for responses scored in two or more ordered categories. The model can be viewed as an extension of Andrich's Rating Scale model to situations in which ordered response alternatives are free to vary in number and structure from item to item. The item step parameter of this model, $b_{ik,}$, is decomposed to a location parameter, b_i, and a threshold parameter, F_{ik}.

This partial credit model is a member of the family of latent trait models which share the property of parameter separability and so permit "specifically objective" comparisons of persons and items. It is widely applied in the assessment of latent trait when (1) credits are given for partially correct answers, (2) there is a hierarchy of cognitive demand on the respondents for each item, (3) each item requires a sequence of tasks to be completed, or (4) there is a batch of ordered response items with individual thresholds for each item. In assessing the physical ability of elderly passengers, it is not necessary to assume that the rating scales of the items are the same, and thus we suggest applying the partial credit model for the proposed empirical studies.

3.4. Reliability and validity statistics in the Rasch model

In latent trait measurement, reliability indices help us to examine whether or not the model is convincing and the material is replicable, and validity indices help us to examine whether or not the properties of our material are consistent with the assumption of the measurement. In the Rasch model, indices of reliability and validity are calibrated, respectively, via person and item aspects [25] to provide the critical proof on the quality control of data. We give a brief introduction of these two indices of Rasch measurement in the following paragraphs.

Reliability in latent trait measurement is commonly defined as the consistency of the responses to a set of items or the consistency of scores from the same instrument [26]. Following such a concept, reliability index R in the Rasch model is defined as the degree to which scores are free

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from measurement errors [27]. As a result, the reliability estimate for persons (R_p) is shown [28] as follows:

$$R_{\mathrm{p}} = \frac{\mathrm{SA}_{\mathrm{p}}^2}{\mathrm{SD}_{\mathrm{p}}^2} \tag{9}$$

The total person variability ($\mathrm{SD}_{\mathrm{p}}^2$) represents how much respondents differ on the measure of interest. The adjusted person variability ($\mathrm{SA}_{\mathrm{p}}^2$) represents the reproducible part of this variability (i.e., the amount of variance that can be reproduced by the Rasch model). This reproducible variability is divided by the total person variability to obtain the person reliability estimate (R_{p}) with values ranging between 0 and 1, which is consistent with the concept of Cronbach's α [29].

On the other hand, reliability for items (R_{I}) is estimated in the same manner as for persons, with item variance being substituted for person variance:

$$R_{\mathrm{I}} = \frac{\mathrm{SA}_{\mathrm{I}}^2}{\mathrm{SD}_{\mathrm{I}}^2} \tag{10}$$

where the total item variability ($\mathrm{SD}_{\mathrm{I}}^2$) represents how much items differ on the measure of interest. The adjusted item variability ($\mathrm{SA}_{\mathrm{I}}^2$) also represents the proportion of total item variability that can be reproduced by the Rasch model.

It is important to note that the limitation in applying the Rasch model is that this model is regarded as a prescriptive rather than a descriptive approach [28]. That is, the data must fit the model, or the assumptions of the model must be rejected for a particular data set, i.e., the degree to which the previously described properties hold depends on how closely the data fit the model. With the comparison between the observed and expected patterns, two fit statistics, namely information-weighted fit (''infit'') and outlier-sensitive fit (''outfit'') [30], are generated to evaluate the validity in the Rasch model. An overview of the derivation of fit statistics is summarized in the following paragraphs.

Based on the estimated parameters, each observation for person, n, on item, i, with K categories (denoted as X_{ni}, $X_{ni} = k$ if the kth category is chosen), has its expected response value E_{ni}:

$$E_{ni} = \sum_{k=1}^{K} k(P_{nik}) \tag{11}$$

where $k(k = 1,2,\ldots, K)$ represents the category, k, of item, i, and P_{nik} is the probability of person, n, being observed in category, k, on item, i. The variance, W_{ni}, and the standardized residual, Z_{ni}, of each observation, X_{ni}, are then obtained:

$$W_{ni} = \sum_{k=1}^{K} (k - E_{ni})^2 P_{nik} \tag{12}$$

$$Z_{ni} = \frac{X_{ni} - E_{ni}}{\sqrt{W_{ni}}} \tag{13}$$

These standard residuals are squared and summed to form a chi-square statistic with a degree of freedom N (i.e., the total observation number). Being divided by the degree of freedom, the mean-square (MnSq) outfit statistic is then obtained:

$$\sum_{n=1}^{N} Z_{ni}^2 \tilde{\chi}_N^2 \tag{14}$$

$$\text{Themean} - \text{squareoutfitstatistic}\frac{\sum_{n=1}^{N} Z_{ni}^2}{N} \tag{15}$$

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In addition to the MnSq outfit statistic, the infit statistic weighs the squared standardized residual Z_{ni}^2 by their individual variance, W_{ni}. It can be calculated as

$$\text{Mean} - \text{squareinfit} = \frac{\sum_{n=1}^{N} W_{ni} \times Z_{ni}^2}{\sum_{n=1}^{N} W_{ni}} \tag{16}$$

The main difference of these two fit statistics is the outfit statistic places more emphasis on unexpected responses far from a person's or item's measure, while the infit statistic places more emphasis on unexpected responses near a person or item's measure [28]. The expected values of these two MnSq fit statistics are 1, and the guideline for determining unacceptable departures from expectation still remains under discussion. Generally, the toleration range for the MnSq is suggested from 0.75 to 1.3 [30]. To achieve a more generalized standard, both the outfit and infit statistics can be further expressed as normalized residuals (*Z*-standardized fit, Zstd) via a transformation into a *t*-statistic with an approximate unit normal distribution [31]. Such a Zstd statistic has an expected value of 0 and a variance of 1, which has previously been used to select items at the 0.05 significance level and according to the ± 2 standard deviation criteria.

4. DESIGN OF EMPIRICAL STUDY

An empirical study was conducted to explore the elderly passengers' physical ability to use the bus service. The questionnaire design, interview survey, and application of Rasch analysis are illustrated below.

4.1. Questionnaire design

A questionnaire was designed with 18 items which represent the necessary actions or motions that an elderly bus passenger has to perform (Table I). The respondent elderly passengers were asked to state

Table I. Content of the questionnaire.

Variable/question	Type
Items to explore the self-rated physical ability to use buses	
How easy can you achieve the following specific action or motion when taking the bus?	
Item 1: walking independently to the station	5-point scale
Item 2: reading the information posted at the station	5-point scale
Item 3: discerning the approaching bus	5-point scale
Item 4: beckoning the bus	5-point scale
Item 5: stepping onto the bus	5-point scale
Item 6: purchasing the ticket on the bus	5-point scale
Item 7: moving to the seat on the bus when it starts to move	5-point scale
Item 8: maintaining balance on the seat of the moving bus	5-point scale
Item 9: maintaining balance while standing on the moving bus	5-point scale
Item 10: maintaining balance while standing when the bus is accelerating/decelerating	5-point scale
Item 11: being aware of the location and direction along the route	5-point scale
Item 12: being aware of the approaching destination station	5-point scale
Item 13: informing the driver and preparing to leave the bus	5-point scale
Item 14: stepping down from the bus	5-point scale
Item 15: knowing the way to the destination	5-point scale
Item 16: being aware of the bus information for the return trip	5-point scale
Item 17: walking independently to the destination	5-point scale
Item 18: finding the location of the station for the return trip	5-point scale
Respondent's personal characteristics	
Age	Numeric response
Gender (male, 1; female, 0)	Binary response

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the level of ease with which they could achieve each item. All 18 items were answered on a five-point Likert scale, namely ''very difficult,'' ''difficult,'' ''neutral,'' ''easy,'' and ''very easy.'' The responses in these five categories, from ''very difficult'' to ''very easy'' for each item, represented the physical ability from low-to-high, respectively. In addition to these items designed to measure elderly passengers' considerations when taking buses, the age and gender of the respondents were also included in the questionnaire as the socioeconomic characteristics for statistical comparisons.

4.2. Interview survey

According to the study objective, the elderly bus passengers in our empirical study were defined as those who are over 65 years of age and have been using buses at least once per month in the past 1 year. Although such elderly bus passengers occupy but a small proportion of the elderly population in Taiwan [32], their responses, based on the real bus-taking experience, are believed to be more convincing and reliable to serve as the material of our inference. Besides, only the major cities provide convenient bus service in Taiwan. Hence, the elderly bus passengers in Taipei City were finally considered as the study population for this empirical exploration.

Taipei, the largest city in Taiwan with 3.07 million people, provides a very convenient service for taking mass rapid transit and buses [33]. According to the statistics of Taipei City [34], there were 306 000 elderly people over 65 years of age in Taipei at the end of 2006, and about one-sixth of them chose buses as their main method of travel [7]. Thus, it is estimated that there are about 51 000 elderly bus passengers in Taipei City, who are the target population for this empirical study.

A survey of face-to-face interviews with elderly bus passengers was held via the street investigation in Taipei City. That is, some well-trained investigators were sent to several main bus stations in Taipei and asked to investigate those elderly people who were waiting for or just alighting from the buses. If the elderly people were verified as the target respondents, the investigators would help them to complete the questionnaire with necessary assistance. After eliminating the incomplete responses, 304 effective questionnaires were collected to serve as the data for this empirical study, which represented about 0.6% of the target population in Taipei City. Among these respondent elderly bus passengers, from 65 to 86 years of age with a mean of 69.49 years; 139 (45.7%) were males and 165 (54.3%) were females. The respondent elderly bus passengers did not differ significantly from the study population of interest at $\alpha = 0.05$ in terms of the distribution of gender for elderly people published in the official statistics of Taipei City [34].

An inspection on the unidimensionality of the data was also conducted via factor analysis. The first factor explained 77.4% of the total variance, while the second factor only explained 11.2% of the total variance. These collected data are thus suitable to apply the Rasch model because the information of the responses mainly resulted from one single latent trait.

4.3. Application of the Rasch measurement model

The Rasch measurement model provides a means for constructing interval measures from raw ordinal category data. A value on an interval scale will be estimated for each item (i.e., the item parameter) and each respondent (i.e., the personal parameter), respectively. The responses of the 304 elderly bus passengers for the 18 items were then analyzed with WINSTEPS [35], an iterative computer program, which estimates θ_n for person n and b_i for item i in logit units. WINSTEPS helps to deal with these polytomous responses by applying the Masters–Andrich modification [23] of the Rasch model. The estimated parameters and model fit statistics could therefore be calibrated via a joint maximum-unconditional-likelihood estimating procedure [29].

The estimated parameters and fit statistics of our whole Rasch model are shown in Table II. The Rasch measurement anchored the mean value of all item parameters at zero logit in order to provide a basis for cross-comparisons between item difficulties and person abilities. The study results showed the average value for the estimated abilities of all respondent elderly bus passengers was 1.07 logit. It implies that the required actions or motions for bus-taking are perceived as easy by most of the respondent elderly bus passengers.

The WINSTEPS program also provided the reliability information for both items and persons, as shown in Table II. The item reliability index of 0.98 and person reliability index of 0.87 indicate that

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Table II. Model estimation and fit statistics obtained from the Rasch analysis.

	Number of measures	Number of observations	Mean of raw scores	Mean of measures	Standard error	Infit Zstd	Outfit Zstd	Reliability
Item	18	304	1071.1	0.0 logit	0.11	−0.1	−0.1	0.98
Person	304	18	63.4	1.07 logit	0.34	−0.2	−0.3	0.87

the data are consistent with the assumptions of the Rasch model in the item and person aspects, respectively. In addition, the infit and outfit Zstd statistics of the whole model are all near zero in both item and person aspects, indicating that the overall validity of our model is acceptable.

5. STUDY RESULTS

5.1. Item analysis

Estimates of the item parameters are displayed in Table III. The first column contains a description of each item; the second shows the estimated parameter for each item; the following columns are the infit and outfit statistics, which are represented by the forms of both MnSq and Zstd. All the Zstd statistics for these 18 items are in the acceptable range of ± 2, which implies the responses do not significantly deviate from the assumptions of the Rasch model. The items in Table III have been ordered by their estimated values for comparison purposes.

All the estimates from a Rasch model are relative, thus it is generally suggested to anchor the mean value of all item estimates at zero logit, and then the estimates for each item and person can be calibrated with this reference point. Items with higher estimates on difficulty are those actions or motions which are generally considered to be more difficult to achieve for these elderly passengers; items with lower estimates on difficulty are those actions or motions which are generally considered to be easier to achieve. From Table III, the results show that item 10 had the highest value among all the item estimates, which indicates that keeping a standing balance when the bus is accelerating or decelerating is the most difficult action for the elderly bus passengers. Next to that is item 9, which represents keeping a standing balance on the moving buses. Results from these two item estimates indicate one important cue that standing on a moving bus is the most severe challenge for elderly bus

Table III. Estimates of item measures and fit statistics from the Rasch analysis.

Item	b_i	Infit		Outfit	
		MnSq	Zstd	MnSq	Zstd
10. Maintaining balance while standing when the bus is accelerating/decelerating	1.69	1.16	0.7	1.17	0.8
9. Maintaining balance while standing on the running bus	1.12	1.13	0.6	1.11	0.4
2. Reading the information at the station	1.08	1.20	0.8	1.24	1.2
8. Maintaining balance on the seat of the running bus	0.74	1.10	0.5	1.19	0.9
3. Recognizing the coming bus	0.33	1.27	1.4	1.15	0.7
7. Moving to the seat on the bus when it starts to move	0.25	0.98	−0.1	0.96	−0.3
11. Knowing the location and direction along the route	0.16	0.94	−0.3	0.91	−0.7
4. Beckoning the approaching bus	−0.14	0.80	−1.5	0.76	−1.9
12. Being aware of the approaching destination station	−0.19	0.86	−0.9	0.81	−1.4
16. Knowing the bus information for the way home	−0.25	1.08	0.4	1.06	0.3
5. Stepping up onto the bus	−0.26	0.83	−1.1	0.82	−1.1
14. Stepping down from the bus	−0.29	0.86	−0.9	0.84	−1.1
1. Walking independently to the station	−0.41	0.87	−0.9	0.79	−1.6
17. Walking independently to the destination station	−0.47	0.87	−0.9	0.82	−1.4
18. Finding the location of the station for the return trip	−0.48	0.91	−0.6	0.85	−1.0
15. Knowing the walking path to the destination station	−0.49	0.93	−0.4	0.91	−0.6
13. Informing the driver and preparing to get off the bus	−0.84	0.97	−0.2	0.90	−0.7
6. Purchasing the ticket on the bus	−1.57	0.81	−1.1	0.79	−1.7

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passengers. Combined with the 4th highest ranking item estimate of keeping balance on the seat of the moving bus (item 8) and the 6th highest ranking item estimate of moving to the seat on the bus when it starts to move (item 7), these results all reflect the elderly passengers' fear of losing their balance and falling on the moving bus, and they need more protection in order to retain their stability when the bus is in motion.

Besides the four items related to the elderly passengers' physical abilities to maintain their balance on the moving buses, reading the information posted at the station (item 2) and recognizing the approaching buses (item 3) were two additional items with relatively high estimates. These two items are both related to elderly passengers' visual abilities, which indicate that they need more help or guidance at the bus station. According to the values of difficulty for these two items, it is noteworthy that elderly passengers might find it more troublesome to read the announced information (static text) than to discern the approaching bus (moving objects), which indicates that the current size of words or graphs at the bus station might be too small and unclear for them to read.

Items 11, 12, 15, 16, and 18 are the five items related to elderly bus passengers' cognitive ability and mental capacity. Except for item 11 with a smaller positive parameter than the average item measure (zero logit), the other estimates were all negative. Being aware of the location and direction of the bus, and finding their way home are relatively easy for the elderly passengers. Items 1, 4, 5, 14, and 17 are the five items which were designed to test the elderly passengers' physical strength and muscle coordination. However, the negative parameters for these item estimates seemed to indicate that the elderly bus passengers did not feel that it was very difficult to walk along the streets, wave hands to signal the approaching buses, and step up or down the bus steps. Stepping up onto the bus and stepping down from the bus were not considered as difficult tasks by the respondent elderly passengers, as expected. It might be the case that some ground levels and platforms of bus stops have been raised in Taipei City in recent years and further investigation is needed to verify this. In all, compared with those items related to maintaining balance, it can be seen that the elderly bus passengers generally feel able to act or move well on the stationary buses, but are quite poor on the shaking or moving buses.

The items with the two lowest difficulty estimates were "informing the driver and preparing to leave the bus (item 13)" and "purchasing the ticket on the bus (item 6)." These results might indicate that the current facilities for informing the bus driver of an intent to leave the bus and for purchasing a ticket are quite suitably designed for elderly passengers in Taipei. The notice bell buttons are commonly installed near the passengers' seats, so that the passengers can push the button and pass the message to the bus driver easily. Purchasing a ticket on the bus is not difficult at all because the bus fare in Taipei is commonly made by throwing coins into the fare box or with the electronic payment of an EasyCard. Elderly passengers over 70 years of age are allowed to travel free in Taipei if they show their senior citizen identification cards. That is why this item was generally regarded as the easiest action by the elderly passengers in Taipei.

5.2. Item–person analysis

The self-rated physical abilities of these 304 elderly bus passengers were estimated from −2.46 to 3.26 logit by the Rasch model. The item and person parameters were both measured on the same interval-scaled unit of "logit," in which the difference between the item and person estimates had a consistent meaning. The item–person map, as shown in Figure 2, which plots the values of all item and person parameters together, provides a straightforward and graphical illustration to disclose the worthy information behind the cross-comparison between person and item parameters.

The left field of the item–person map indicates the distribution of the self-rated bus-taking ability of the responding elderly bus passengers. The levels of ability are in order from top-to-bottom. The number of respondents located in each level is represented by the combinations of the "#" and ".", and the respondents located in the higher positions indicate that their abilities were relatively high. The right field of the map shows the difficulty of each necessary action or motion in taking buses. When an item is located at a higher position along the vertical axis, it is thought to be a tougher action or motion for elderly bus passengers to achieve. Because the values of both person ability and item difficulty are relative, it is common to anchor the average value of all item parameters at zero, which provides the basis for cross-comparison. When an elderly bus passenger and an item are located at the same level on

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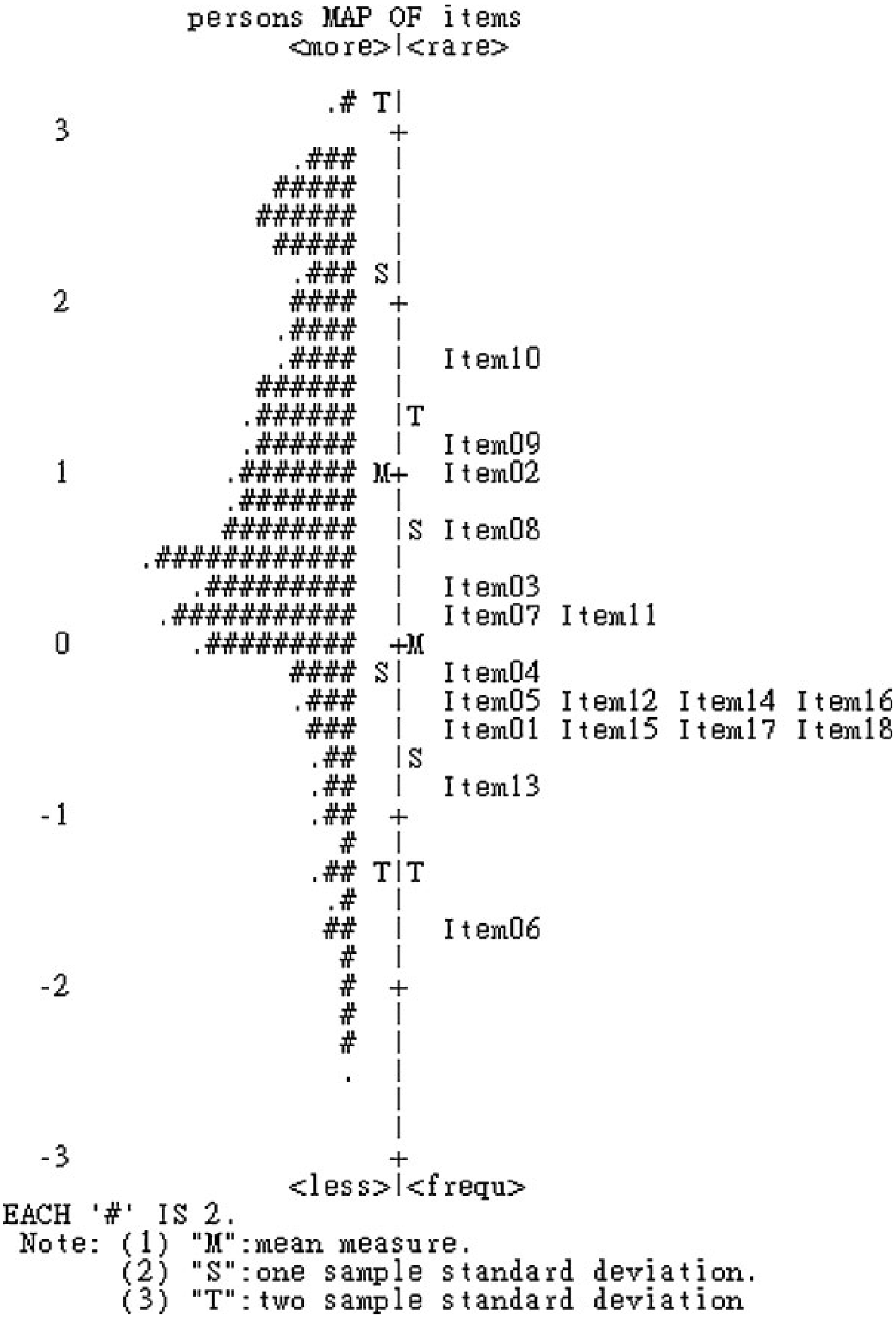

Figure 2. Item–person map for the responding elderly bus passengers.

the item–person map, he/she will have a probability of 0.5 to achieve this item. If most of the respondents' abilities are located at the positions higher than the difficulty measure of a specific item, it implies this item is considered as relatively easy to achieve by these respondents.

According to the estimates shown on the item–person map (Figure 2), it appears that item 10 was the most difficult item among all 18 items and only one-fourth of the respondent elderly bus passengers could achieve it with ease. Items 9 and 2 were the next two most difficult items, and only about one-third of the elderly bus passengers could pass them easily. Furthermore, we also found that more than

80% of the respondent elderly bus passengers could easily achieve those 11 items with negative values of item difficulty, and even more than 90% of elderly passengers could achieve items 13 and 6 without any difficulty. Thus, the proportion of elderly passengers that could not achieve a given item with ease was easily identified by the item–person map. It provided a clear illustration about what services or facilities should be improved with priority in order to provide a safer and friendlier travel service for the elderly bus passengers.

5.3. Further analysis of person ability

The interval-scale property of the Rasch measurement also enabled us to extend the results for further examination. By relating each respondent's ability measure to his/her age, some useful information is easily observed in Figure 3. Each respondent's age and physical ability measure are diagrammed by the horizontal and vertical axes, respectively, in Figure 3. On the horizontal axis, the elderly respondents are divided into three subgroups by their ages, namely the younger elderly (65–70 years), the middle elderly (71–79 years), and the older elderly (80 years and older).

On the vertical axis, we used four thresholds (1.69, 0.74, −0.49, and −1.57 logit), according to the clusters of the difficulty levels of items, to categorize the perceived physical ability into five groups, denoted A–E. The threshold between A and B was 1.69 logit, which is equal to the difficulty level of the most difficult item (item 10). Respondents in group A were those elderly passengers with ability measures higher than the highest difficulty measure of all items. These elderly respondents were thought to be able to achieve all the necessary actions or motions when using buses with ease. The threshold between B and C was 0.74 logit, which is equal to the difficulty level of item 8. Elderly respondents with ability measures from 0.74 to 1.69 logit were categorized into the B group. These elderly respondents' ability measures were around the levels of difficulty measure for the top four difficult items. It indicated that these respondents could achieve the necessary actions or motions with ease, except for the top four difficult items. The threshold between C and D was −0.49 logit, which is equal to the difficulty level of the item 15. It indicated that the C group included those elderly respondents with ability measures from −0.49 to 0.74; this range covered the difficulty measures of 12 items which were regarded as the necessary actions or motions with moderate difficulty to achieve when using buses. The threshold between D and E was −1.57 logit, which is equal to the difficulty level of the least difficult item (item 6). That is, except for the easiest two items, respondents whose ability measures were lower than the difficulty measures of the remaining 16 items were categorized into group D. Such elderly bus passengers will face a number of threats when trying to achieve the necessary actions or motions on bus trips. Elderly passengers whose ability measures were lower than the difficulty measures of all items were categorized into group E. Every necessary action or motion in using the bus would threaten this group of elderly bus passengers. Their bus usage might be inappropriate but would be the only available means of travel. These elderly passengers would need the most care for their outdoor travels.

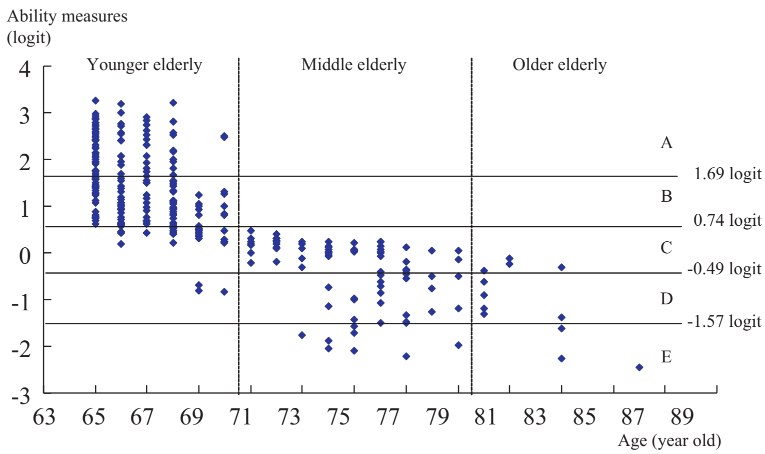

Figure 3. Distribution of the ages and ability measures of the responding elderly bus passengers.

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The numbers of the responding elderly bus passengers in the groups of younger, middle, and older elderly were 211, 81, and 12, respectively, and the number of these responding elderly bus passengers in the groups of ability level from A to E were 73, 83, 110, 28, and 10, respectively. Among the 211 younger elderly passengers, 73, 83, and 52 respondents were categorized into the groups of ability levels from A to C, respectively; only 3 of them were categorized into group D and no one was categorized to group E. Among the 81 middle elderly, no one was categorized in the ability groups A and B; there were 54, 20, and 7 respondents categorized into C–E groups, respectively. In the remaining 12 older elderly respondents, their ability measures were also distributed from groups C–E as well (4 in C, 5 in D, and 3 in E). Findings from these two groups of elderly respondents over 70 years of age pointed out a critical problem behind the existing subsidy policy involving elderly passengers. Elderly people over 70 years of age are allowed to take the bus free of charge; however, there were no elderly people in our samples who could achieve the top four difficult items with ease. The necessities for achieving these four actions or motions could be the major obstacle to encourage the elderly people over 70 years of age to patronize the bus service. Thus improving the bus facilities and service to enhance the elderly people's willingness to use the bus service would be a critical requisite.

The gender difference on the bus-using ability of elderly passengers cannot be proved in this empirical study. The average physical ability measures of male and female respondents are 0.96 and 1.16 logit, respectively. The *p*-value of the independent sample mean test is 0.26, which indicates that the mean difference between male and female is not significant. On the other hand, an obvious negative correlation between the ages and ability measures of the elderly bus passengers is disclosed in Figure 3. Such an observed relation can be easily verified, owing to the property of interval-scaled measures offered by the Rasch measurement. The Pearson correlation coefficient between the age and ability measures was -0.779 and significant at $\alpha = 0.01$, which supported our hypothesis that the perceived physical ability will decrease as the elderly are aging. The significant difference ($\alpha = 0.01$) between the perceived physical ability measures of the elderly under 70 years of age and those of the elderly over 70 years of age could be also verified by applying the "independent samples *t*-test" directly. With the reasonable experimental designs, such interval-scaled measures from the Rasch model can be extended to some meaningful studies.

6. DISCUSSIONS

6.1. Implications for research

This study has conducted a demonstration on introducing a new approach to measure perceived physical abilities and difficulties of elderly bus passengers in their bus patronage, and shows its capability to provide interval-scaled measures for further investigations and comparisons. By considering the procedures of taking buses as a physical ability test for elderly bus passengers, this study has developed an exploring instrument via an 18-items questionnaire to test their ability to use buses. Personal responses to these items can be used as a tool to reflect the elderly passengers' evaluation of their own physical ability to use buses.

The Rasch measurement, which can convert raw ordinal responses into values on an interval scale, was reviewed and employed as the instrument for assessing the relative level of ability of each person and difficulty of each item. By relating the measures of person ability and item difficulty, the item–person map provides a straightforward and graphical illustration on the corresponding proportion of elderly bus passengers who can achieve each given item with ease. By extending the measures with indicative variables, such as age, some worthy information is clearly disclosed, which provides valuable information to enhance the hardware and software of existing bus systems for elderly passengers' patronage.

The Rasch model applied in this study is the conventional form which is limited to explore one single latent construct at a time because of the assumption of the unidimensionality. Recently, some psychometric researchers have relaxed this assumption. By increasing the influential factors (i.e., the facets) in the Rasch measurement, the Multi-facet Rasch Model has been widely applied in purifying the effects of person ability, item difficulty, and other facets. Furthermore, if the bus-taking ability is considered to be composed of several component latent constructs (e.g., vision ability, motion ability,

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and hearing ability), the multidimensional Rasch model has been developed to explore and evaluate the correlations among these component latent constructs. It might help to light on some worthy viewpoints by exploring more travelers' latent considerations.

6.2. *Implications for practice*

This study also raises some practical suggestions on the critical items found from the empirical study results. Not only providing an academic example for related research, it is also hoped that our efforts can make practical contributions to building a safer and friendlier bus service for the elderly people. From the findings of this empirical study, the bus-taking actions/motions with higher difficulty were found to be related to elderly passengers' balance-keeping ability. To reduce the possible harm upon the elderly passengers, more effort should be made to decrease the risk of falling and its consequences when using buses. Instant warnings about the bus operations or moving status (e.g., starting, acceleration, deceleration, and right/left turn) might be helpful to warn elderly passengers to take the necessary actions [36]. Providing more priority seats for elderly passengers could avoid the risks associated with standing on the moving buses. Moreover, providing seatbelts for all priority seats would offer further protection for elderly passengers to keep them balanced on the seats. Aids made of flexible materials, such as armrests or guardrails, are also suggested in order to reduce the impact of bumping [37]. The inner-bus monitoring and broadcasting system is also suggested to be equipped near the seat of the driver. Once the bus driver detects some tottering elderly people standing on the moving bus, she/he can immediately announce the seat-yielding request via such a broadcasting system without any delay. Besides, the bus company could also provide some compulsory training courses for bus drivers to correct their sharply accelerating/decelerating behaviors.

Items related to vision ability are also found to be the difficult tasks for the elderly bus passengers when using buses. That is, decline in vision disturbs their ability to read the information and recognize an approaching bus. Improvements via simple corrections or technical innovations are expected to help the elderly with these tasks. For instance, enlarging the size of characters for the necessary information on the station or bus, setting the press-to-start vocal instruction buttons on the station, and establishing the bus approaching light or voice warning are believed to help the elderly overcome the obstacles due to their visual disabilities. Besides, some short-range wireless communication system between bus stations and bus drivers might also help the elderly to recognize the coming bus. It is suggested that specific "boarding request" buttons be placed in the bus stations for each bus service route. When the button is pressed, such a boarding request would be transmitted wirelessly and be received by the on-board equipment of the corresponding buses. Thus, the bus drivers can decelerate the bus smoothly in advance, which avoids bypassing the bus station or making a sudden deceleration of the bus.

Another positive parameter on the difficulty of these possible actions or motions was found on "realizing the location and direction along the route." In fact, degrees of memory loss and senile dementia were also important issues when the outdoor mobility of the elderly is discussed. Since the "helping-hand," a prototype of integrated aid to the elderly for mobility assistance and monitoring, was disclosed by the PAMM project [38], several portable personal GPS guidance aids have been invented to provide directions for the elderly users and enable their rescue in case of an emergency. It is hoped in the near future that the communication conventions of such personal facilities can be standardized and integrated with the bus GPS system.

Discussions and suggestions on the improvements of bus facilities can better ensure the elderly bus passengers' safety on their bus travels; it is also expected to increase the elderly people's willingness for taking buses. We do hope our efforts attract those elderly people who are able, but refuse to take the bus due to safety or physical ability considerations, to patronize the bus service through word-of-mouth.

7. LIST OF SYMBOLS AND ABBREVIATIONS

n	serial number of each respondent
θ_n	physical ability value of the n^{th} respondent
i	coding number of each item

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b_i difficulty value of the i^{th} item
k ordinal number for each category in an item
b_{ik} respective difficulty value for the k^{th} category of the i^{th} item
F_{ik} threshold parameter for the k^{th} category of the i^{th} item
R_p person reliability estimate
SD_p^2 total person variability
SA_p^2 adjusted person variability
R_I item reliability estimate
SD_I^2 total item variability
SA_I^2 adjusted item variability
MnSq mean-square fit statistic
Zstd Z-standardized fit statistic

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