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The Use of Rasch Analysis as a Tool in the Construction of a Preference Based Measure: The Case of AQLQ

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SUMMARY

The majority of quality of life instruments are not preference-based measures and so cannot be used within cost utility analysis. The Asthma Quality of Life Questionnaire (AQLQ) is one such instrument. The aim of this study was to develop a health state classification that is amenable to valuation from the AQLQ.

Rasch models were applied to samples of responders to the AQLQ with the aim of i) selecting a number of items for a preference based utility measure (AQL-5D), ii) reducing the number of levels for each item to a more manageable number of levels for establishing AQL-5D. Selection of items for the evaluation survey was supported with conventional psychometric criteria for item selection (feasibility, internal consistency, floor and ceiling effects, responsiveness and regression against overall health).

The role of Rasch analysis in reducing the number of item levels to a preconceived target number of levels proved unsuccessful. However, Rasch analysis proved to be a useful tool in assisting in the initial process of selecting items from an existing HRQL instrument in the construction of AQL-5D. The method is recommended for use alongside conventional psychometric testing to aid in the development of preference-based measures.

Key words: Rasch analysis, preference-based measures, asthma, quality of life

INTRODUCTION

Rasch analysis is a mathematical modelling technique [Rasch, 1960] commonly used in education in the development and validation of assessments and examination papers [Willmott & Fowles, 1974; Bhakta *et al,* 2005]. It is increasingly being used in health related quality of life (HRQL) studies in the development of new quality of life questionnaires [See for example: Duncan *et al,* 2003; Gilworth *et al,* 2004; Pesudoves, Garamendi & Elliott, 2004] and in the validation of existing questionnaires [See for example: Raczek *et al,* 1998; White & Velozo, 2002; Valderas, Aonso & Prieto, 2004]. However, to date Rasch analysis has not been used in the development of a preference based utility index.

This paper presents an approach to the process of selecting items and reducing the number of item levels using Rasch analysis, for deriving a much smaller classification system that is amenable to valuation. The approach described here develops the methodology adopted for the short form (SF)-36, where the 36 item, eight dimension instrument was reduced to a six dimension health state classification [Brazier, Roberts & Deverill, 2002; Brazier *et al,* 1998]. The advantage of a health state classification system is that each dimension of the classification has X levels, and by selecting one level from each dimension it is possible to derive a unique health state. In this way the SF-6D, for example, derives 18,000 health states, these states constitute six statements and have been shown to be amenable to evaluation.

This paper uses a case study of the Asthma Quality of Life Questionnaire (AQLQ), which has been designed to assess health related quality of life (HRQL) in patients with asthma. It has been shown to be reliable and valid for use in this population [Juniper *et al,* 1993; Juniper, Buist *et al,* 1999]. The paper sets out to use Rasch analysis as a tool alongside conventional psychometric methods, firstly to select items for a preference based utility index and secondly to reduce the existing number of levels of the AQLQ from seven to a more manageable number. In this paper we do not argue that Rasch analysis is offering a single formulaic solution to the problem of developing a health state classification from an evaluative measure of HRQL. What we attempt to show is how Rasch analysis can help ensure this process to a solution makes the best use of the richness and sensitivity of the original instrument. A companion paper describes a study that values the resulting health state classification system [Yang *et al,* In submission].

The AQLQ

The AQLQ is a 32 item instrument that was designed to assess HRQL in patients with asthma. It asks a series of questions across four domains: symptoms (12 items), activity limitations (11 items), emotional function (5 items) and environmental stimuli (4 items). For each item the respondent is asked to choose from a series of seven levels, ranging from extreme problems (level 1) to no problems (level 7).

Level responses are converted into scores which range from 1 (level 1) to 7 (level 7) and scores are summed and averaged over items to obtain a domain score, or an overall score across all 32 items. This potentially generates too many states for valuation and states that would too large for valuation using choice-based preference elicitation techniques.

Two versions of the AQLQ exist which are virtually identical, with the exception of the first five items: the “individualised” version of the AQLQ asks respondents to choose their five “most important activities” from a list of 27 activities and then state how each of these chosen activities has been limited by asthma within the previous two weeks, whereas the "standardised" version of the questionnaire asks how asthma has limited strenuous, moderate, social, work related activities or sleeping. The aim of the Rasch analysis was to select a number of items to be used in the development of a preference based measure that were common to both the standardised and individualised versions of the AQLQ.

An Overview of Rasch Analysis

Rasch analysis is a mathematical technique that converts qualitative (categorical) responses to a continuous (unmeasured) latent scale using a logit model, and can be conceptualised as "a statistical approach to the measure of human performance, attitudes and perceptions" [Tesio, 2003]. In relation to HRQL questionnaires, Rasch analysis converts each categorical item (question) to a continuous latent scale, where the scale is conceived to be a continuous measure of HRQL.

Tennant [Tennant, 2004] describes the concept behind Rasch analysis, as applied to HRQL instruments, and explains that HRQL can be measured on a latent ("ruler") scale where:

- the underlying scale is independent of the person measuring the scale
- points on the ruler may be added together
- there is an ordering across the scale, i.e. the higher one is on the ruler scale the better ones' HRQL

In education, a person's position on the underlying latent scale is measured from the respondent's ability to answer questions and the difficulty of the items set within an examination or test. When applying Rasch analysis to HRQL responses, each respondent's position on the underlying latent (HRQL) scale accounts for a person's degree of health problems. To apply Rasch models to HRQL instruments it is assumed that: patients with more severe problems should indicate they have difficulties with more items (tasks) described in the instrument than patients with less severe problems. It is further assumed that the easier an item (task) is to achieve the more likely it will be achieved [Tennant, 2004].

An Illustration of Rasch Analysis

To illustrate the concept of Rasch analysis, let us take a hypothetical three-item questionnaire given to patients with asthma, where the response option for each item is dichotomous (as a result of my asthma I ***suffer/do not suffer*** from symptom X). The three items ask about the presence or absence of symptoms relating to: shortness of breath, wheezing and clearing the throat. Further, in terms of asthma symptoms shortness of breath is regarded as more severe than wheezing, which, in turn, is regarded as more severe than clearing the throat. Let us also assume that the questionnaire is asked of three patients with asthma:

- Patient A has severe asthma and suffers from shortness of breath, wheezing and clearing their throat
- Patient B has moderate asthma and suffers from wheezing and clearing their throat
- Patient C has minor asthma and has problems clearing their throat

Under the Rasch model it is assumed that the underlying HRQL of Patient C, the least severe patient is better than Patient B, which in turn is better than Patient A, who has the worst HRQL (Figure 1). Further, patients with asthma suffering from shortness of breath are assumed to have worse HRQL than patients suffering from wheezing, and patients suffering from wheezing are assumed to have worse HRQL than those suffering with clearing their throat.

Figure 1 about here

The Rasch Rating Scale Model

The Rasch model used in this paper is known as the Rasch rating scale model and is fitted to allow for multi level item responses to all items, as is the case with the AQLQ, where the latent (ruler) scale for item levels may overlap between items. For example, let us consider two items, one asking about shortness of breath and the other wheezing, where patients may answer always, sometimes or rarely for each item. The illustration in Figure 2 shows that, on average, the HRQL of patients with wheezing is generally better than that for patients who suffer from shortness of breath. However, patients who state they are rarely short of breath can have better HRQL than patients who are always wheezing.

Figure 2 about here

The Rasch rating scale model allows for multi level responses and assumes that item and patient responses are independent variables that may be estimated separately. The mathematical formula for the model is set out below.

$$\ln\left(\frac{p_{nij}}{1-p_{nij}}\right) = f(\theta_n, \delta_i, \tau_j)$$

where p_{nij} is the probability of patient *n* with asthma severity θ_n responding to item *i* with item difficulty δ_i and at item level *j* with level difficulty τ_j.

The next section of this paper sets out the role of Rasch analysis, alongside psychometric criteria, in the development of a health state classification for AQLQ. The section also sets out the role of Rasch analysis in the reduction of the number of item levels of the items selected for the health state classification.

METHODS

Using Rasch Analysis to Develop a Health-State Classification – the AQL-5D

From an economists perspective Rasch analysis helps to understand the relationship between items (and item levels) and HRQL, but not the appropriate weighting for a health state classification system. A Rasch model may indicate that one item response is worse than another for respondents, but it does not indicate anything about the extent to which it would be preferred, this requires additional information on preferences, and this is the subject of a companion paper [Yang *et al,* In submission].

Thus, the aim of this analysis is to create a health state classification measure by selecting one item from each of the four AQLQ domains (symptoms, activity limitations, emotional function and environmental stimuli); therefore, four Rasch models were fitted one for each AQLQ domain. In addition the AQLQ asks a series of questions about sleep (Items 5 [Standardised version only], 20, 24 and 29), so we aimed to select an additional item for a fifth domain in the health state classification asking how asthma affected sleep. A separate Rasch analysis for sleep related items was not conducted here, but instead these items were selected from the Rasch analysis from the two domains that included sleep items (symptoms and activity limitations).

Since the new measure will have five dimensions, we will refer to this as AQL-5D.

Rasch Model Assumptions: Initial Selection of Items for AQL-5D

Prior to using Rasch to aid in the selection items for a preference based measure, it was necessary to establish whether each of the four domains of the AQLQ fitted the Rasch model. In other words, the first step was to validate whether the items of the four AQLQ domains measured symptoms, activity limitations, emotional function and environmental stimuli HRQL. The first step in checking the fit of a Rasch model is to identify items where responders to the AQLQ are unable to distinguish between item response levels. This process is achieved by examining individual item threshold probability curves (a plot of the probability of being in each item level across the latent [HRQL] scale [Figure 3]). In Figure 3 the x-axis depicts the underlying latent (logit) scale and the y-axis the probability of being in a particular item level. As an illustrative example, if the latent (ruler) scale for each level of an item is ordered then respondents are able to distinguish between item levels (Figure 3a), however if the latent scale is unordered then responders have difficulty distinguishing between levels (Figure 3b). If curves are unordered, adjacent item levels should be merged and the Rasch model refitted using the merged levels. The merging step is repeated until all items are ordered.

Figure 3 about here

The selection of the appropriate item levels to merge is left to the analyst, using a summary of the frequency of responses at each item level aids this choice, and eyeballing the threshold probability curve and merging levels where curves lie close together.

Levels may be collapsed generically, across all items in a questionnaire (notwithstanding the ordering within a particular item) by questionnaire domain, or individually item by item. The choice is left to the analyst and may be dependent on the number of items being examined (if a questionnaire contained a large number of items it may be preferable to collapse generically across the whole questionnaire). In the initial stage of developing the AQL-5D items are collapsed at the individual item level.

After ordering has been achieved across all items the goodness of fit statistics for the overall Rasch model are examined. The overall goodness of fit of the Rasch model is measured in terms of item-trait (HRQL) interaction, the person separation index and the person and item fit residuals. These are described below.

The item-trait interaction measures whether data fit the Rasch model for discrete groups of responders. The groups are selected by dividing the responders into a series of subgroups based upon where each responder lies on the latent scale of the Rasch model. Thus responders who tend to have similar HRQL for an AQLQ domain will be grouped together. Observed and expected responses are compared across items and traits and the difference between these responses is summarised using the χ^2 test statistic. A good fitting Rasch model should have no deviation between the observed and expected responses and therefore the convention is that the p-value for the overall model χ^2 statistic should be greater than 0.01 for a good fitting model [Kubinger, 2005].

The ***person separation index*** (PSI) measures the level of agreement between responders and lies on a scale between 0 and 1, the higher the PSI value the better the agreement between respondents. A PSI of 0.7 or more indicates a well fitting Rasch model [Nunnally, 1978].

Fit residuals estimate the amount of divergence between the expected and observed responses for each respondent or item response; fit residuals are summed over all items (item fit residuals) or summed over all persons (person fit residuals). The residuals are standardised to approximate the Z-score and therefore the mean item or person fit residual should be approximately zero with a standard deviation approximately equal to one.

If the overall item-trait fit of the model is statistically significant ($p < 0.01$), i.e. poor Rasch model goodness of fit, the fit of each of the individual items included in the Rasch model should be examined. As with the overall model goodness of fit, items with an individual χ^2 p-value of < 0.01 are said not to fit the Rasch model, in other words these items do not contribute to the underlying latent scale, i.e. symptom, activity limitation, emotional function or environmental stimuli HRQL. The item with the lowest p-value (that is < 0.01) is removed, the model is refitted and the overall goodness of fitness statistic examined for the new model. The process is repeated until only well fitting items remain and the overall item-trait goodness of fit of the model is greater than 0.01.

Once the model fit is satisfied the analyst is left with a sub-sample of items for each of the AQLQ domains and the process of selecting items for AQL-5D can begin.

Thus, items were excluded from the initial selection stage of the development of AQL-5D if:

- Items were not common to both the individualised and standardised versions of the AQLQ (We wished to derive a preference based measure that could be used with both versions)
- At the initial Rasch model fitting stage the item levels needed collapsing due to responders being unable to distinguish between levels
- Items were eliminated as they did not fit the Rasch model (did not measure the underlying HRQL trait: symptoms, activity limitations, emotional function or environmental stimuli)

Using Psychometric Criteria in the Development of AQL-5D

Tennant and colleagues state that quality of life measures should be "unidimensional … and have good traditional psychometric properties" [Tennant, 2004]. Therefore, the performance of the AQLQ was also tested using five conventional psychometric criteria: feasibility (rate of missing data), internal consistency (correlation between item and domain scores), distribution of responses (e.g. the absence of ceiling or floor effects), and responsiveness (between baseline and follow-up visits). In addition, we examined the relationship between item responses and general health in order to establish independent criteria for describing the correlation of an item with HRQL.

The five criteria were applied across all 32 AQLQ items and were used as a further method for identifying and eliminating items from inclusion in a health state classification system. These criteria were chosen to represent conventional psychometric criteria for assessing instruments. Though the cut-off levels chosen for each criterion is arbitrary (unless stated otherwise in the text), there main purpose is to select those items that perform best against each criteria. The five methods are described below:

1. Feasibility – Prevalence of missing data

A high prevalence of missing data reduces the usefulness of an item. Overall, the AQLQ had very low levels of missing data, so the cut off was set at 1% for inclusion in a health state classification system.

2. Internal Consistency – Correlation of an item score and its domain score

We hypothesised that if the correlation between an item and its domain score was poor that the item was not representative of the domain. Spearman's correlation coefficient was calculated for each item to domain score. The cut off value for the criteria was ≤ 0.65.

3. Distribution of responses across the seven response

Since AQL-5D will be covering the spectrum of asthma with a smaller number of items, it is important that items utilise the whole range of 7 response levels rather than just a few of them. Specifically, it is important for the items not to suffer from floor or ceiling effects i.e. a large proportion of respondents indicating they are in the worst or best level, which limits the ability of an item to assess change below or above the floor or ceiling range. The distribution of respondents' answers was examined across the seven levels of response. If the proportion of responders in the extreme levels (i.e. level 1 or level 7) was over 20% the item was rejected.

4. The responsiveness at two time points – Standardised Response Mean

Responsiveness is generally defined as the ability of an instrument to detect a change when it has occurred, and thus, it is a test to be used for time series data [Beaton *et al,* 2001; De Bruin *et al,* 1997; Wright & Young, 1998]. Of the several possible ways to calculate this, the standardised response mean (SRM) was used, defined as:

$$\text{SRM} = \frac{\text{Average}(x_f - x_b)}{\text{Standard Deviation}(x_f - x_b)}$$

Where x represents the item score and subscripts f and b represent follow-up and baseline data respectively. There is no gold standard for good or acceptable levels of responsiveness, but SRM such as this conventionally use the criterion for a "small" effect size of ≤ 0.2 established by Cohen [Cohen, 1978].

5. Regression coefficients between a general health indicator and the item

Items selected for AQL-5D will on the one hand present specific domains of asthma related quality of life, and on the other hand represent a component of a more general concept of HRQL. In other words, an ideal item will be correlated with some measure of overall health. This was pursued by regression analysis between the general health question of the SF-36 (as the dependent variable) and the individual AQLQ items (as categorical explanatory variables). Technically, and strictly speaking, the use of an SF-36 item as a continuous dependent variable is problematic, but this was intended as an exploration of the importance of each item with respect to the patients' overall health. A very low R^2 would suggest that the item has little to do with the patient's perception of their health. The criterion was set at $R^2 \leq 0.15$.

Using Rasch Analysis to Select Items for AQL-5D

Any item that remained in the AQLQ after the above exclusion criteria had been applied was considered as a potential candidate for inclusion in AQL-5D. Item selection was predominantly based upon the spread of the seven item levels across the latent space, where the wider the spread the better the item. The logit (latent) scale in Rasch analysis is centred at zero (See Figure 3) and the different levels of an item should be spread evenly across the latent space, therefore, items with a greater spread of levels at logit 0, represented items where the respondent was more likely to distinguish between item levels. Item (χ^2) goodness of fit statistics and results from the five psychometric tests were also taken into consideration when selecting items.

Using Rasch Analysis to Collapse Item Levels

Once five items were selected for AQL-5D the authors attempted to collapse the number of item levels, per selected item, from seven to a smaller number. It was felt that five would be a reasonable number for respondents in the evaluation survey [Yang *et al,* In submission] to distinguish between when imagining the hypothetical health states. The choice of five levels was chosen *a priori* to all Rasch and psychometric analysis. A further requirement of the level collapsing was to generically collapse item levels for the five selected items to aid responders in the evaluation survey to distinguish between health states, given that four of the five items share a common set of response choices.

Further Rasch analysis was used in order to collapse seven levels to five levels, where threshold probability curves were examined and item levels that were closer together, in comparison with other levels were merged. Each of the selected items was examined using Rasch analysis within the domain level Rasch models (symptoms, activity limitations, emotional function, environmental stimuli).

RUMM2020© was used to fit Rasch models [RUMM2020 ©, 2004] and SPSS Version 12 was used to carry out the psychometric tests [SPSS, 2003].

AQLQ Datasets

Two data sets of asthma AQLQ responders were used in this study. The “Trial” data comes from a multinational trial, and included patients with severe persistent asthma [Humbert *et al,* 2005]. Patients filled in the individualised version of the AQLQ on several occasions throughout the trial period. For this paper, patients from the treatment and placebo arms are not distinguished, and unless otherwise stated, analyses are based on 482 “baseline” observations of this Trial data. However, there were three exceptions.

Firstly, since the responsiveness analysis (psychometric criteria 4) needs more than one observation, the baseline and follow-up information from the Trial data were used. Furthermore, in order to carry out the regression analysis the SF-36 was needed (psychometric criteria 5), so information from a second dataset, known as the “Observation” dataset was used. The Observation data set comes from a UK trial of computerised decision support (and thus observational in a therapeutic sense), with 3,000 patients covering a wide range of asthma severities [Eccles *et al,* 2000]. The Observation data set included both the AQLQ and the SF-36 questionnaire.

Lastly, three Rasch analyses were conducted for the symptoms, environmental function and environmental stimuli domains, but regarding the activity domain, given that the first five questions of the individualised version of the questionnaire depend on the responder’s choice of activities, it was felt to be inappropriate to include the responses to these questions in the item selection process. Therefore, in order to supplement for this, data from the Observation dataset was introduced. The standardised version of the AQLQ was used in the second round of observations, consisting of 2,119 cases. Rasch models were fitted to a random sample of 413 cases from the Observation data set for the activity domain of the AQLQ.

Using Rasch Analysis to Validate Item Choice

The aims of the validation were threefold: firstly to confirm the validation of item selection across different samples of responders to the AQLQ (the Trial and Observation populations). Secondly, to confirm the validity of item responses across randomly chosen samples from the same population (the Observation dataset) and thirdly to confirm the validity of the Rasch model for a larger sample of patients (N = 880).

Further samples of data were drawn from the Observation dataset to validate the Rasch model item selection for all four domains of the AQLQ. After excluding the 413 cases randomly selected for the main item selection process the remaining 1706 responders in the Observation dataset were divided into three further random samples: two samples consisted of 413 randomly selected patients and the third sample consisted of the remaining 880 responders.

RESULTS

At the initial stage of the development of AQL-5D four Rasch models were fitted to AQLQ responders, one for each of the AQLQ domains. Examination of items on the latent scale across the seven levels of item response for each of the four models (domains) of the AQLQ showed that responders were unable to distinguish between levels for the following items: 30 (symptoms), 4 (activity), 11 (activity), 25 (activity), 28 (activity), 21 (emotion), 9 (environment) and 17 (environment). The selection of levels to collapse was made after examining the item probability threshold curves for the eight unordered items. Items were collapsed individually in each Rasch model. Notwithstanding the individual item approach, ordering of levels was achieved by collapsing the two mildest levels of item response (none and very little problems) the two most severe levels (problems all or the majority of the time) and the three middle levels across all unordered items, leaving just three levels for each of these items. The eight items that needed collapsing in the initial stage of item selection were excluded from consideration in the AQL-5D.

The next step in the initial Rasch analysis was to make sure that each of the four AQLQ domains achieved overall Rasch model goodness of fit (measured from the overall model item-trait [HRQL] χ^2 statistic). To achieve this the individual item goodness of fit χ^2 statistics were examined and items that did not fit the Rasch model (Item fit p-value < 0.01) were removed one at a time until the overall Rasch model item-trait goodness of fit p-value exceeded 0.01. The following poorly fitted items were excluded from the four Rasch models and were excluded from selection in AQL-5D:

items 12, 16 and 30 from the symptoms domain

items 1, 5, 11, 19 and 28 from the activity limitations domain

item 17 from the environmental stimuli domain

It was unnecessary to exclude any item from the emotion domain.

Table 1 summarises the overall Rasch model statistics for each of the four AQLQ domains. All Rasch model goodness of fit requirements are met for all four AQLQ reduced domains.

Table 1 about here

Elimination of Items Using Psychometric Criteria

The results from the conventional psychometric tests are presented in Table 2, where items not meeting the test criteria are highlighted in bold. This resulted in a further seven items being removed from the selection process: items 3, 4, 9, 20, 21, 25 and 26. With items 1 to 5 being excluded due to lack of commonality between the two versions of the AQLQ this left a possible 15 items for inclusion in AQL-5D (eight items from the symptoms domain, two from the activity limitations domain, four from the emotional function domain and one in the environmental stimuli domain, where two of the items in the symptoms domain asked about sleep).

Table 2 and 3 about here

Table 3 summarises the statistics used in the selection process of remaining items for AQL-5D. The statistics were taken from the four Rasch analysis performed on the AQLQ domains. Given that only one item remained in the environmental stimuli domain this item was automatically selected (Item 23). Two items remained for the activity limitations domain; item 32 was selected as it had a better fitting χ^2 statistic (lower χ^2 value) and had a slightly higher spread of probabilities across levels at logit 0. Two items also remained that asked about sleep, item 29 had a better fitting χ^2 statistic and had a slightly higher spread of probabilities across levels at logit 0 and was therefore selected. Item 8 was selected from the remaining non-sleep related symptoms items due to having the greatest spread of probabilities across levels at logit 0. Finally, item 7 was chosen from the emotional functioning domain because it had the largest spread across item levels at logit 0.

Rasch models and item selection were validated on three further datasets using the item selection process described above. This validation process confirmed the selection of items 7, 8, 23, 29 and 32 for AQL-5D across different samples (Trial and Observational data), across randomly chosen samples from the same population (Observational data) and confirmed the validity of Rasch analysis on a larger sample of patients (N = 880). (Results available from the authors on request).

Collapsing Item Levels for the Five Selected Items

An attempt was made to use Rasch analysis to reduce the number of levels from seven to five by studying the Rasch threshold probability curves for each selected item (Figure 4). For each item, the item levels that corresponded to item level threshold curves that were closest together were collapsed. However, various scenarios and combinations of levels failed to produce five items that fitted within the Rasch assumptions (item levels were no longer ordered when collapsed into five levels and threshold plots suggested that levels should be collapsed further). Therefore, consensus was reached, partially based on Rasch results and through agreement amongst the authors, which levels should be collapsed: for items 7, 8, 23 and 29 which asked about how asthma effected the responders in terms of time, levels were collapsed as follows: none of the time, a little or hardly any of the time, some of the time, most of the time and all of the time. The wording for item levels for item 32 is related to limitations and the five levels were chosen as follows: not at all limited, a little limited, moderate or some limitation, extremely or very limited and totally limited. Figure 5 presents the final version of the reduced preference based measure AQL-5D used in the evaluation stage of the study [Yang *et al,* In submission].

Figure 4 and 5 about here

DISCUSSION

The first stage of deriving a preference-based single index measure from the AQLQ for use in calculating QALYs was to derive a health state classification system from the AQLQ that is amenable to valuation using a preference elicitation technique. Rasch modelling was applied alongside conventional psychometric methods to identify a number of AQLQ items, one from each AQLQ domain plus a further item on sleep, that adequately represent the AQL-5D. A valuation survey has been undertaken on a sample of AQL-5D states using a sample of the UK general population and econometric models, fitted to survey responses, in order to predict health state values. These will enable the calculation of QALYs based on AQLQ data, these results are reported elsewhere [Yang *et al,* In submission]. The approach taken here to identify items for AQL-5D, to our knowledge, has not been used previously in the derivation of a preference based measure.

After the initial stages of the Rasch and psychometric analysis, where poorly performing items were eliminated from the analysis, and items that were not common to both versions of the AQLQ excluded, a total of 15 possible items were available from which to choose items for AQL-5D. Rasch analysis was then used in the second stage to select, what were felt to be, the best performing items per AQLQ domain. Finally, the number of item levels was reduced from seven to five, although this process was based in part on author opinion and judgement rather than the Rasch analysis results.

The approach used here suggests that Rasch analysis should be used as a complementary method with psychometric criteria as neither method identified all 16 items which were initially rejected. Three of the items identified in the Rasch analysis (Items 1, 12 and 30) were not identified by conventional methods. There are no obvious reasons why conventional methods failed to identify these three items, though this could be due to the arbitrary exclusion criteria chosen. Similarly, three items identified by conventional methods were not identified in the Rasch analysis (Items 3, 20 and 26). The proportion of common items excluded by both approaches was 10/16 (= 63%: Items 4, 5, 9, 11, 16, 17, 19, 21, 25 and 28). These results could be unique to this data set, however the results were cross-validated using another data set.

To the best of our knowledge, this is the first time that Rasch analysis has been used in the selection process for a preference based measure and no guidance currently exists on the most appropriate method for selecting items. We wished to select the best performing items from each domain for inclusion in a preference based measure and, at the item selection stage, there was sometimes little to distinguish between items for a particular domain. In this analysis, items were selected based primarily upon the spread of item levels at logit 0 using results from threshold probability curves, where respondents were believed to be making full use of the range of possible responses. However, it is possible that other approaches could be equally applicable. For example, choosing the best fitting model according to the item χ^2 statistic, had this approach been used a slightly different set of items would have been chosen: 15, 18, 23, 29 and 32.

The choice of Rasch analysis performed (one per AQLQ domain) and the selection of responders to be included in the Rasch analysis could also be varied, e.g. conducting a separate Rasch analysis for sleep related items rather than selecting items from the Rasch analysis from the two domains that included sleep items. Additionally, we could have selected a mixture of baseline and follow-up data from the Trial data set. However, we did validate our results on three further samples from the Observation data set and, even with a larger samples size, one set included 880 responders, our selection of items for a preference based measure appeared justified.

In addition to its role in the selection of items for a preference based measure Rasch analysis has inadvertently been used as a validation tool for the four AQLQ HRQL domains, by checking the assumptions that the items selected for each domain are appropriate and measure the underlying latent trait (HRQL).

The role of Rasch analysis in the collapsing of the number of levels to a preconceived target of five levels proved unsuccessful. However, this might be explained by the fact that when the five items were initially selected, one of the selection criteria was the spread of item levels – where the wider the item spread the better, and the chosen items typically had evenly spread item levels. Therefore, any attempt to reduce the number of levels resulted in violation of Rasch model assumptions. However, Rasch analysis can also be used to examine the appropriateness of giving responders seven possible respondent choices per item. Analysis not presented here showed that if all items were generically collapsed ordering of levels was achieved across all items using three levels (none and very little problems, problems all or the majority of the time and combining the three middle item levels). However, it was felt that three levels may not be sensitive enough to adequately capture patients' self reported health preferences. Further, the results from the valuation survey showed that individuals were able to distinguish between five item level categories [Yang *et al,* In submission]

This work has made it possible to derive patient utilities and subsequently QALYs from AQLQ when it is administered as either the individualised and standardised versions. Other versions of the AQLQ also exist; the mini AQLQ [Juniper, Guyatt *et al,* 1999], which is a 15 item shortened version of AQLQ and a 23 item paediatric version of the AQLQ (PAQLQ) which exists both as a standardised version and an individualised version [Juniper *et al,* 1996]. Our analysis focused primarily of deriving a health state classification obtained from the full 32 item AQLQ and therefore, at present AQL-5D can not be derived from mini-AQLQ or PAQLQ due to:

- differences in wording for those items common to both AQL-5D (for example item levels are phrase in terms of bother rather than limitations in PAQLQ)
- the alternative instrument combining items (mini-AQLQ combines AQLQ item 23 with 25, AQLQ item 29 with 24 and AQLQ item 32 with items 1 to 5)
- the item not being present in the alternative instruments (item 23 not in PAQLQ)

Rasch analysis has proved to be a useful tool in assisting in the initial process of selecting items from an existing HRQL instrument in the construction of a preference based measure. The method recommended should be used alongside traditional psychometric criteria to aid in the development of health state classifications for preference-based measures. The process inevitably involves compromises and some difficult decisions, but using Rasch analysis alongside conventional psychometrics ensures the best use of the description of the original questionnaire. Whilst far from perfect, it represents an improvement on past practice [Brazier *et al,* 2007], such as that used to develop the health state classification for the SF-6D [Brazier, Roberts & Deverill, 2002; Brazier *et al,* 1998], and some earlier preference based summary measures.

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Table 1: Summary of Rasch Goodness of Fit Statistics for the Four AQLQ Domains

	Items in Rasch Model	Overall item-trait χ^2	DF for item-trait	Item-trait P-value	Mean item fit (SD)	Mean person fit (SD)	PSI
Symptoms	6, 8, 10, 14, 18, ***20***, 22, ***24, 29***	87.04	63	0.024	0.12 (1.59)	-0.53 (1.48)	0.923
Activity	2, 3, $4_{(3)}$, $25_{(3)}$, 31, 32	38.11	36	0.374	-0.55 (1.87)	-0.43 (1.09)	0.945
Emotion	7, 13, 15, $21_{(3)}$, 27	37.12	35	0.372	0.16 (1.51)	-0.48 (1.31)	0.845
Environment	$9_{(3)}$, 23, 26	28.41	21	0.129	0.60 (1.33)	-0.38 (1.11)	0.739

DF = Degrees of freedom for overall item-trait χ^2 test

PSI = Person separation index

$_{(3)}$ = Denotes items where number of levels was collapsed to three to ensure ordering of levels

Items in ***bold italics*** ask questions about sleep

Table 2: Overall Summary of Five Psychometric Criteria for each of the 32 AQLQ Items (failed items are in bold)

	Question: As a result of your asthma (During the last 2 weeks)	Domain	Percent at level 1 (≥ 20%)	Percent at level 7 (≥ 20%)	Effect size (≤0.2)	Missing data (≥ 1%)	Correlation with domain score (≤ 0.65)	Regression with general health (R^2 ≤ 0.15)
Item 1	Limited strenuous activities	Activity	6.0	3.5	0.5	0.4	0.73	0.22
Item 2	Limited moderate activities	Activity	7.3	3.6	0.5	0.8	0.74	0.20
Item 3	Limited social activities	Activity	6.9	2.5	0.5	**1.2**	0.71	0.21
Item 4	Limited work-related activities	Activity	6.7	3.6	0.5	**1.0**	0.74	0.23
Item 5	Limited sleeping	Activity	5.5	4.2	0.4	**1.9**	0.71	0.25
Item 6	How much discomfort or distress as a result of chest tightness	Symptoms	6.2	5.2	0.4	0.2	0.74	0.25
Item 7	Feel concerned about having asthma	Emotional	10.0	7.3	0.4	0.2	0.74	0.22
Item 8	Feel short of breath as a result of your asthma	Symptoms	6.0	2.3	0.5	0.2	0.77	0.28
Item 9	Experience asthma symptoms as a result of being exposed to cigarette smoke	Environment	18.6	14.6	0.3	0.6	0.70	**0.08**
Item 10	Experience a wheeze in your chest	Symptoms	6.5	5.4	0.4	0.4	0.76	0.23
Item 11	Feel you had to avoid a situation or environment because of cigarette smoke	Activity	**26.8**	12.5	0.4	0.2	**0.60**	**0.06**

	Question: As a result of your asthma (During the last 2 weeks)	Domain	Percent at level 1 (≥ 20%)	Percent at level 7 (≥ 20%)	Effect size (≤0.2)	Missing data (≥ 1%)	Correlation with domain score (≤ 0.65)	Regression with general health (R^2 ≤ 0.15)
Item 12	How much discomfort or distress have you felt as a result of coughing	Symptoms	7.1	8.1	0.3	0.2	0.70	0.21
Item 13	Feel frustrated as a result of your asthma	Emotional	11.2	10.0	0.4	0.0	0.79	0.24
Item 14	Experience a feeling of chest heaviness	Symptoms	4.0	9.2	0.4	0.4	0.77	0.23
Item 15	Feel concerned about the need to use medication for your asthma	Emotional	11.8	16.8	0.3	0.0	0.75	0.17
Item 16	Feel the need to clear your throat	Symptoms	10.6	5.0	**0.2**	0.6	**0.59**	0.17
Item 17	Experience asthma symptoms as a result of being exposed to dust	Environment	17.0	6.6	0.4	0.0	0.77	**0.09**
Item 18	Experience difficulty breathing out as a result of your asthma	Symptoms	5.4	5.8	0.4	0.2	0.74	0.22
Item 19	Feel you had to avoid a situation or environment as a result of being exposed to dust	Activity	14.3	10.6	**0.2**	0.0	0.67	**0.12**
Item 20	Wake up in the morning with asthma symptoms	Symptoms	**21.2**	9.1	0.4	0.0	0.77	0.20

	Question: As a result of your asthma (During the last 2 weeks)	Domain	Percent at level 1 (≥ 20%)	Percent at level 7 (≥ 20%)	Effect size (≤0.2)	Missing data (≥ 1%)	Correlation with domain score (≤ 0.65)	Regression with general health (R^2 ≤ 0.15)
Item 21	Feel afraid of not having your asthma medication available	Emotional	**21.8**	**21.4**	0.3	0.2	0.77	**0.13**
Item 22	Feel bothered by heavy breathing	Symptoms	7.5	9.1	0.5	0.0	0.76	0.22
Item 23	Experience asthma symptoms as a result of the weather or air pollution outside	Environment	13.7	5.4	0.5	0.2	0.69	0.18
Item 24	Were woken at night by your asthma	Symptoms	8.8	15.2	0.4	0.4	0.76	0.17
Item 25	Avoid or limit going out because of the weather or air pollution	Activity	7.7	**20.4**	0.3	0.4	0.65	0.24
Item 26	Experience asthma symptoms as a result of being exposed to strong smells or perfume	Environment	10.8	16.0	0.3	0.2	0.74	**0.15**
Item 27	Feel afraid of getting out of breath	Emotional	11.0	15.8	0.4	0.2	0.76	0.24
Item 28	Feel you had to avoid a situation or environment because of strong smells or perfume	Activity	11.7	**20.0**	**0.2**	0.4	**0.55**	0.16
Item 29	Has your asthma interfered with a good nights sleep	Symptoms	10.0	14.3	0.4	0.2	0.76	0.21
Item 30	Have a feeling of fighting for air	Symptoms	5.4	18.1	0.4	0.2	0.74	0.23

	Question: As a result of your asthma (During the last 2 weeks)	Domain	Percent at level 1 (≥ 20%)	Percent at level 7 (≥ 20%)	Effect size (≤0.2)	Missing data (≥ 1%)	Correlation with domain score (≤ 0.65)	Regression with general health (R^2 ≤ 0.15)
Item 31	How much has your range of activities you would like to have done been limited by your asthma	Activity	9.4	4.2	0.5	0.4	0.71	0.30
Item 32	Among all the activities you have done how limited have you been by your asthma	Activity	1.3	3.5	0.4	0.4	0.78	0.31

Table 3: Summary of Item Statistics for 15 Potential AQLQ Items for Inclusion in a Preference Based Measure by Domain

Item	Domain	Overall item-trait χ^2	DF	P-value	Item difficulty (logit)	Spread of levels: Average
6	Symptoms	8.18	6	0.317	0.011	0.73
8	Symptoms	17.31	6	0.016	-0.446	0.88
10	Symptoms	9.27	6	0.234	-0.016	0.78
14	Symptoms	5.94	6	0.547	0.319	0.72
18	Symptoms	5.03	6	0.657	0.082	0.78
22	Symptoms	10.47	6	0.163	0.074	0.64
24 (Sleep)	Symptoms	13.09	6	0.070	0.212	0.56
29 (Sleep)	Symptoms	9.22	6	0.237	0.127	0.57
31	Activity	7.02	6	0.319	-0.863	0.75
32	Activity	5.17	6	0.522	-0.282	0.93
7	Emotion	9.40	6	0.225	-0.155	0.68
13	Emotion	9.95	6	0.192	-0.043	0.53
15	Emotion	4.43	6	0.740	0.103	0.45
27	Emotion	5.25	6	0.630	0.124	0.46
23	Environment	3.17	6	0.869	-0.311	0.62

DF = Degrees of freedom for overall item-trait χ^2 test

Figure 1: Illustration of Patient Response Scale for Three Hypothetical Patients on a Ruler/Latent Scale (Rasch Model)

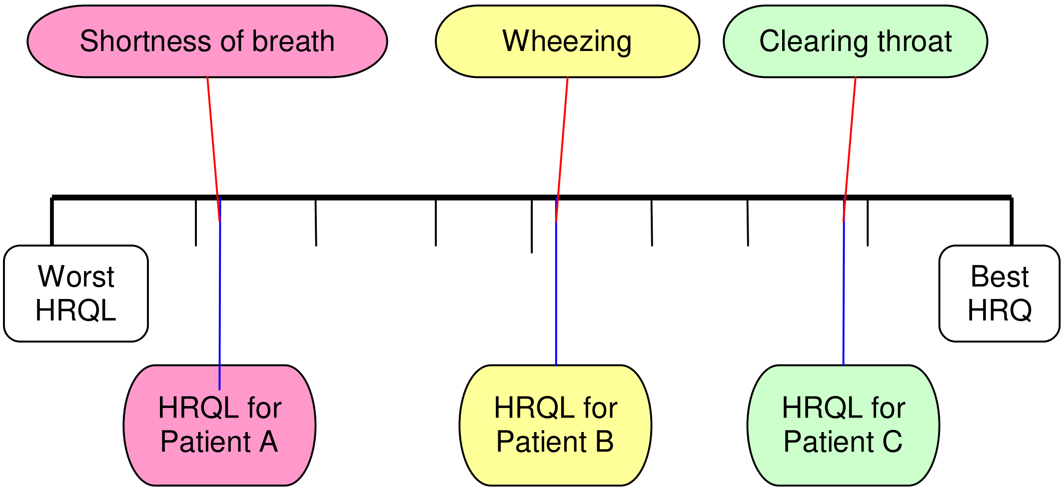


Figure 2: Illustration of Item Response Scale for Two Items for Multi-Level Item Responses (Three Levels)

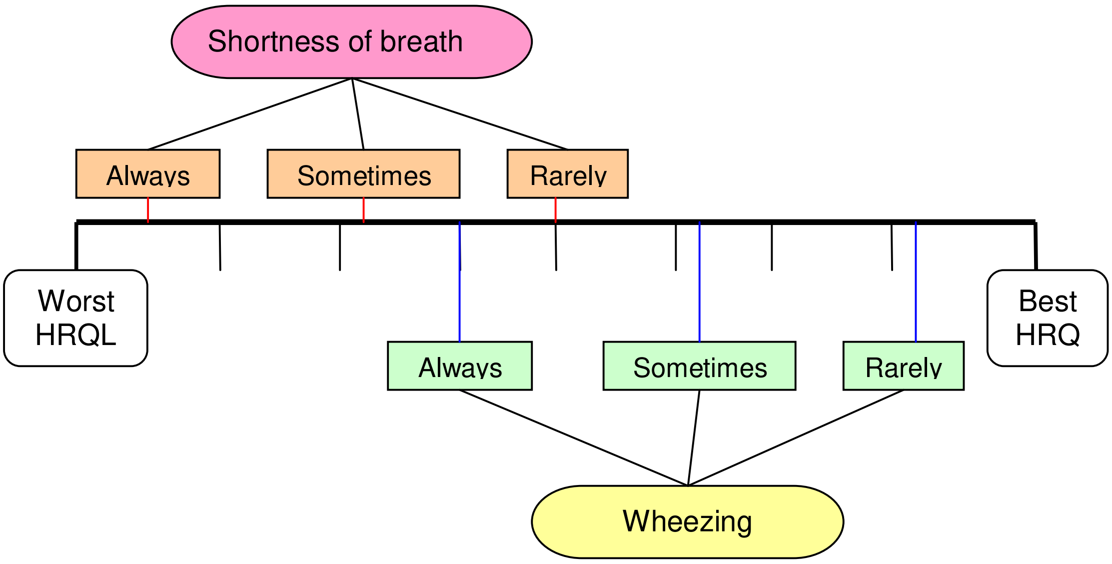
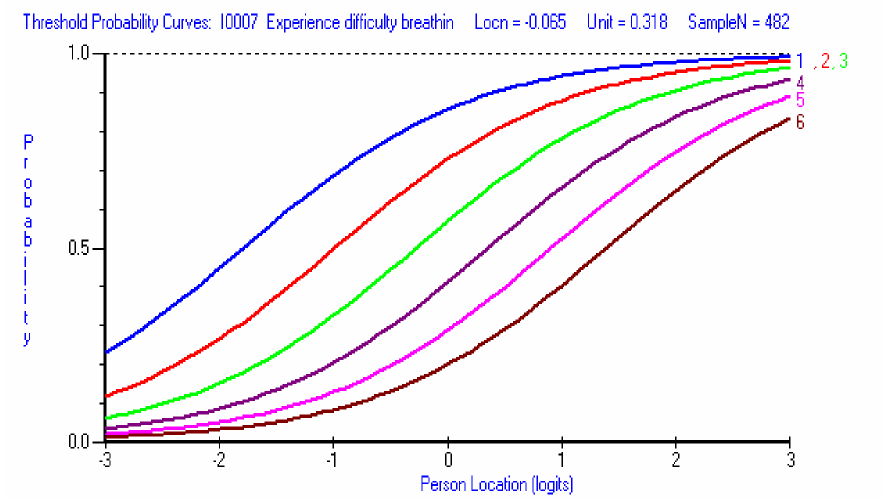
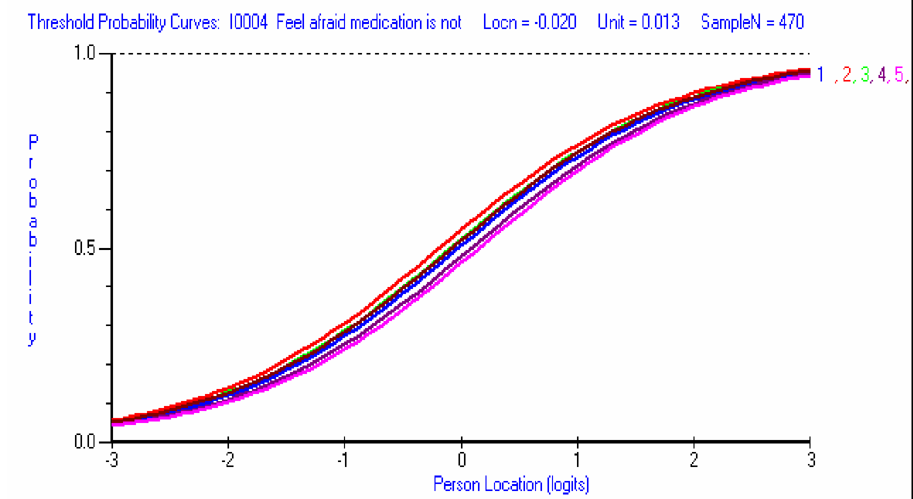


Figure 3: Illustration of the Ordering of Threshold Curves for Two AQLQ Items

3a) Item 7: Feel concerned about having asthma



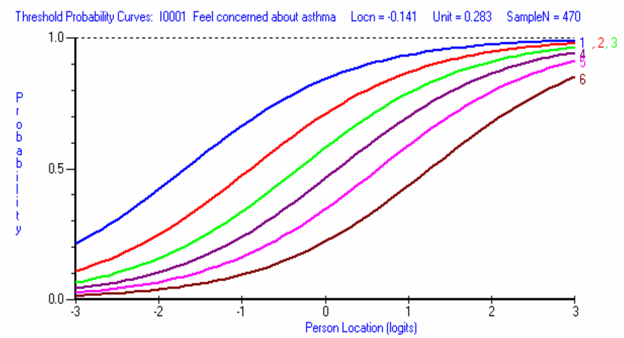
3b) Item 21: Feel afraid of not having your asthma medication available



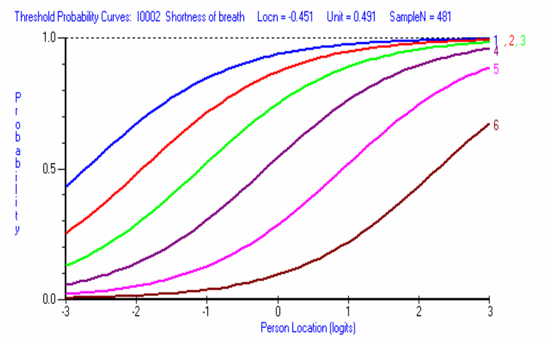
Ordered curves: colour sequence highest to lowest – blue, red, green, purple, pink, brown (levels 1, 2, 3, 4, 5, 6 for item 7)

Figure 4: Initial Probability Threshold Curves for Items 7, 8, 23, 29 and 32 of the AQLQ Prior to Item Level Collapsing

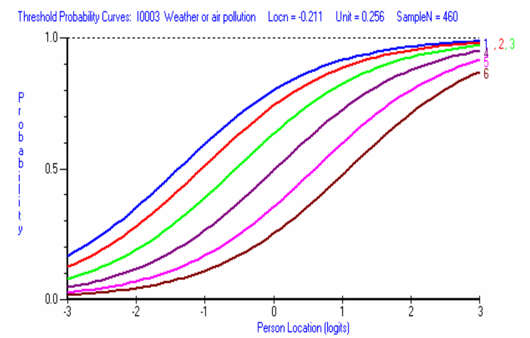
Item 7



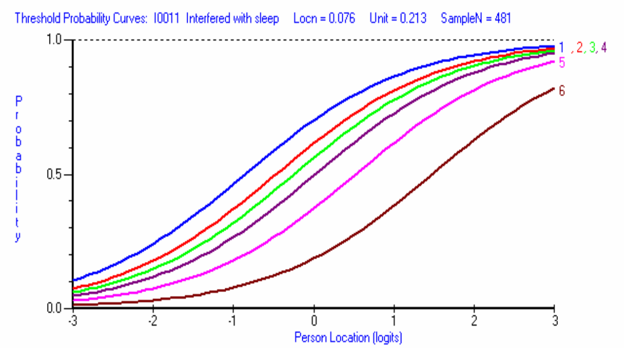
Item 8



Item 23



Item 29



Item 32

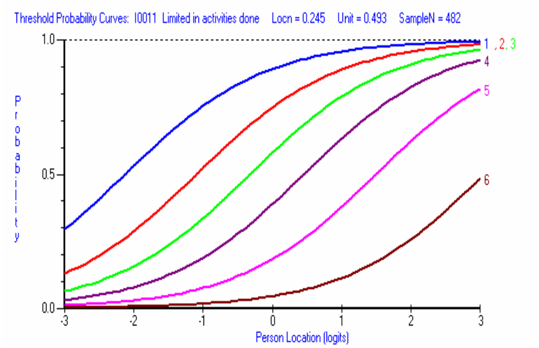


Figure 5: The Reduced Health State Classification System

CONCERN
5. Feel concerned about having asthma all of the time.
4. Feel concerned about having asthma most of the time.
3. Feel concerned about having asthma some of the time.
2. Feel concerned about having asthma a little or hardly any of the time.
1. Feel concerned about having asthma none of the time.

SHORT OF BREATH
5. Feel short of breath as a result of asthma all of the time.
4. Feel short of breath as a result of asthma most of the time.
3. Feel short of breath as a result of asthma some of the time.
2. Feel short of breath as a result of asthma a little or hardly any of the time.
1. Feel short of breath as a result of asthma none of the time.

WEATHER & POLLUTION
5. Experience asthma symptoms as a result of air pollution all of the time.
4. Experience asthma symptoms as a result of air pollution most of the time.
3. Experience asthma symptoms as a result of air pollution some of the time.
2. Experience asthma symptoms as a result of air pollution a little or hardly any of the time.
1. Experience asthma symptoms as a result of air pollution none of the time.

SLEEP
5. Asthma interferes with getting a good night's sleep all of the time.
4. Asthma interferes with getting a good night's sleep most of the time.
3. Asthma interferes with getting a good night's sleep some of the time.
2. Asthma interferes with getting a good night's sleep a little or hardly any of the time.
1. Asthma interferes with getting a good night's sleep none of the time.

ACTIVITIES
5. Overall, totally limited with all the activities done.
4. Overall, extremely or very limited with all the activities done.
3. Overall, moderate or some limitation with all the activities done.
2. Overall, a little limitation with all the activities done.
1. Overall, not at all limited with all the activities done.